NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO TECHNICAL REPORT **TR-HFM-080**

Optimizing Operational Physical Fitness

(Optimisation de l'aptitude physique opérationnelle)

Final Report of Task Group 019.

Published January 2009

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Foreword

This document represents the deliberations and final product of Research Technical Group – 019: Optimizing Operational Physical Fitness. As explained more fully in the Executive Summary, this group was conceived to address the issues of mission-related testing and training. This report summarizes our efforts toward meeting this objective.

The successful completion of a Research Technical Group is typically attributed to the significant contribution of a number of personnel, and this final compilation is no exception. Without the efforts, commitment, and resourcefulness of all members of RTG-019, the preparation of this final report would not have been possible. We are truly indebted to all members of RTG-019 for their participation over a period of three years, and for their contribution to this final product. A special thank you is also extended to the Nations who graciously offered to host our meetings.

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Optimizing Operational Physical Fitness

(RTO-TR-HFM-080)

Executive Summary

The revised spectrum of NATO missions requires a new approach to operational physical fitness. Specifically, a new necessity to define, assess, evaluate and optimize physical capability by setting appropriate criteria and methodologies was identified by an exploratory team that met in Spain in 2002. As a result of the exploratory meeting, HFM-080/Research Task Group 019 on “Optimizing Operational Physical Fitness” was established “to determine the requirement for physical fitness for military personnel in order to prepare military personnel for physical task requirements, to prevent physical overburdening, and to reduce injuries.” (Annex VIII AC/323 (HFM)A/9).

In order to optimize the physical capacity of soldiers by setting appropriate criteria and evaluation methodologies, members of HFM-080 reviewed mission essential task lists (METL) and types of missions undertaken by NATO forces in the past and present. The physical demanding tasks of digging, marching and manual materials handling were identified by members as being the key common tasks performed in recent and current NATO missions (humanitarian, peace-keeping, conflict resolution, counter-terrorism, etc.). As well, the identification of these common tasks was derived from a review of other pertinent military documents. HFM-080 members agreed that the common physically demanding military tasks of marching, digging, and manual materials handling would each be described in individual chapters, and in terms of intensity and duration, physiological requirements, testing to predict performance, and training to improve performance. A chapter of this report is dedicated to summarizing the research being conducted on an evidence based job analysis and methodology to determine the physical requirements of special military occupations (Special Operation Forces – Austrian Army). In addition, factors outside the training realm that influence performance on these military tasks are summarized. These factors are either individual (intrinsic) or environmental (extrinsic) characteristics. The intrinsic factors considered are age, gender, body dimensions, and genetics. The extrinsic factors that considered are effects of nutrition (including hydration), heat, cold, altitude, clothing, and extended operations. An Appendix on pre-employment screening tests and active duty testing of Common Military Task (CMT) performance used by various NATO countries was compiled and included in this Report, which will provide information for Staff Officers and serve as a reference.

Optimisation de l'aptitude physique opérationnelle

(RTO-TR-HFM-080)

Synthèse

La révision du spectre des missions de l'OTAN requiert une nouvelle approche de l'aptitude physique opérationnelle. Cette nécessité nouvelle de définir, d'estimer, d'évaluer et d'optimiser la capacité physique en fixant des critères et des méthodologies appropriés a été identifiée par une équipe exploratoire qui s'est réunie en Espagne en 2002. A la suite de cette réunion exploratoire, le Groupe de recherche 019 HFM-080 consacré à l' « Optimisation de l'aptitude physique opérationnelle » a été créé « en vue de déterminer les exigences d'aptitude physique pour le personnel militaire aux fins de préparer ledit personnel militaire aux exigences des tâches physiques, de prévenir le surmenage physique et de limiter les blessures. » (Annexe VIII AC/323 (HFM) A/9).

Dans le but d'optimiser l'aptitude physique des soldats par l'établissement de critères et de méthodologies d'évaluation appropriés, les membres du HFM-080 ont passé en revue les listes des tâches essentielles à la mission (METL) et les types de missions entrepris par les forces de l'OTAN aujourd'hui et par le passé. Les tâches physiquement exigeantes consistant à creuser, marcher et manipuler du matériel manuel ont été identifiées par les membres comme les principales tâches communes accomplies lors des missions récentes et actuelles de l'OTAN (humanitaire, maintien de la paix, résolution de conflits, anti-terrorisme, etc.). L'identification de ces tâches communes s'est également fondée sur l'examen d'autres documents militaires pertinents. Les membres du HFM-080 ont convenu que les tâches militaires communes physiquement exigeantes consistant à marcher, creuser et manipuler du matériel manuel devraient chacune être décrites dans des chapitres individuels, en termes d'intensité et de durée, d'exigences physiologiques, de tests en vue de prédire les performances et d'entraînement pour améliorer les performances. Un chapitre du présent rapport est consacré au résumé des recherches menées sur l'analyse factuelle des tâches et la méthodologie visant à déterminer les exigences physiques de spécialités militaires particulières (Forces d'opérations spéciales – Armée autrichienne). Par ailleurs, les facteurs extérieurs à l'entraînement qui influencent les performances lors de ces tâches militaires sont résumés. Ces facteurs sont des caractéristiques individuelles (intrinsèques) ou environnementales (extrinsèques). Les facteurs intrinsèques considérés sont l'âge, le sexe, les dimensions corporelles et la génétique. Les facteurs extrinsèques considérés sont les effets de la nutrition (y compris l'hydratation), la chaleur, le froid, l'altitude, l'habillement et les opérations prolongées. Une annexe consacrée aux tests utilisés par diverses nations de l'OTAN pour l'accomplissement des Tâches militaires communes (CMT) – tests de sélection lors du recrutement et tests destinés au personnel en activité – a été compilée et incluse dans le présent rapport, dans le but de fournir des informations aux officiers d'état-major et de servir de référence.

Chapter 1 – INTRODUCTION

by

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ABSTRACT

With the conclusion of the RSGs 4, 8, and 17, as well as the Workshop on Optimizing the Performance of Women in the Armed Forces of NATO, there remained open questions concerning mission-related testing and training. The Research and Technical Organization (RTO) recognizes the need to address these issues in light of the wide range of missions (coordinating humanitarian relief, coordinating emergency and relief operations in the event of a disaster, both nature and man-made, civil emergency measures, addressing instability caused by regional and ethnic conflicts, defence against terrorism and countering other threats to modern society) and increased deployment of NATO personnel on operations since 1997 (NATO in the 21st Century @ http:www.nato.int/docu/21-cent/html). The revised spectrum of NATO missions requires a new approach to operational physical fitness. Specifically, a new necessity to define, assess, evaluate and optimize physical capability by setting appropriate criteria and methodology was identified by an exploratory team that met in Spain in 2002. As a result of the exploratory meeting, Task Group 019 on Optimizing Operational Physical Fitness was established to determine the requirement for physical fitness for military personnel in order to prepare military personnel for physical task requirements, to prevent physical overburdening, and to reduce injuries. The efforts of RTG-019 Optimizing Operational Physical Fitness will represent the international agreement for evidence-based findings which may provide the basis for policy decision.

1.1 BACKGROUND

The Defence Research Group (DRG) of the North Atlantic Treaty Organisation (NATO) is a body that stimulates and coordinates research, and consists of a number of Panels, each covering separate areas of research. In 1969, the Anglo-Netherlands-Norwegian Cooperation Program (ANNCP) set up a Project on Physical Fitness. There was a 1970 meeting in the United Kingdom (UK) and a 1973 Symposium in Oslo, Norway. In 1974, ANNCP closed and Panel 8, which coordinates Human and Biomedical Research in NATO was persuaded to establish a Research Study Group (RSG) on Physical Fitness. Since the disbandment of the ANNCP, three Research Study Groups (RSGs) (RSG 4, 8, and 17) and one workshop pertaining to physical fitness have been sponsored and completed under Panel 8.

1.2 RSG 4

RSG 4 on Physical Fitness with Special reference to Military Forces was established in 1975, and focused on identifying the military requirement for physical fitness, the measurement and training of peak anaerobic (alactic) power/strength, anaerobic and aerobic power, the importance of physical fitness as it pertains to sustain military operations (sleep deprivation, time zone change, environmental influences, ergogenic aids, and sustained cognitive performance), medical aspects of physical training (age, gender, overuse and traumatic injuries, coronary heart disease, risk factors and screening, heat and cold injuries, fitness and G tolerance, exercise and health), and test of physical fitness and body composition. The final report summarizing the work of RSG 4 was published in August of 1986 (AC/243 (Panel VIII) D/125).

1.3 RSG 8

RSG 8 on Nutritional Aspects of Military Feeding (Military Nutrition) was established and focused on nutrition and optimum physical performance (muscle glycogen, glycogen strategies, micronutrients and performance, caloric restriction, environmental factors), nutrition and coronary heart disease (CHD) risk factors in the military population (lipid metabolism, and CHD, influences of diet), body composition and its relation to health and physical performance of military personnel, rations of selection NATO countries (composition of survival, emergency, and combat rations and their influence on performance), nutrition education and weight control programmes, and nutritional strategies to enhance military performance. The final report summarizing the work of RSG 8 was published in December of 1989 (AC/243 (Panel 8/RSG 8) D/9).

1.4 RSG 17

RSG 17 was formed to study critical biomedical issues relevant to physical fitness training in NATO military forces. RSG on the Biomedical Aspects of Military Training elaborated on the training issues left over from the RSG 4 work. Specifically, RSG 17 focused on the physiology of physical training (responses to training, description of training programs for aerobic fitness, muscular strength, muscular endurance, and other fitness related factors like flexibility and body composition), principles of physical training (overload, specificity and reversibility principles, training variables of intensity, frequency and duration, training guidelines and training evaluation), trainability of military populations (adaptations to training, influencing factors, military application, training effects, and response of women), practical guidelines for development military physical training programs, injuries related to physical training (incident rates, risk factors, costs of injuries, prevention strategies, policy and management considerations), and models of physical training responses. The groups report (AC/243 (Panel 8)TR/16, 0875-94) summarized the knowledge that had been consolidated through the NATO membership and which concerned physical fitness for the military role.

1.5 WORKSHOP ON OPTIMIZING THE PERFORMANCE OF WOMEN IN THE ARMED FORCES OF NATO

During the period of 13-16 October 1995, a NATO DRG Panel 8 Workshop on Optimizing the Performance of Women in the Armed Forces of NATO was held in London, U.K. The pre-stated aim of the meeting was to establish contacts between military policy planners and the scientific programmes of different nations, which would promote collaboration and avoid duplication in research work. Topics covered in the Workshop included many of the issues relating to the integration and performance of women in Sea, Land and Air Forces, with emphasis being placed on practical experiences (attitudes towards integration, plans for future integration), anthropometry and physical fitness (differences between genders and some of the effects that these difference have on clothing, personal military equipment and workstation design), gender and physical selection standards (Nations progress reports pertaining to the introduction of fair, scientifically based and legally defensible job-related standards), gender differences in the heat and cold, cognitive differences, women in teams (mixed gender teams or all female teams in comparison to the traditional all male teams), and policy and social issues (health care, pregnancy, sexual harassment). One of the major outcomes of this Workshop was the production of draft position statements and recommendations for future research (AC/243 (Panel 8) TP/13).

"The agreed draft position statements were the following:

a) Gender differences in physical performance do not preclude any roles in the Armed Forces of NATO from being satisfactorily performed by some women.

b) A complex of strategies should be pursued in order to overcome any limitations in the operational performance of females that are due to their lower physical strength compared to males. These strategies should include:

   i) The study of physically demanding roles with a view to ergonomic redesign of tasks and equipment in order to decrease the physical demands wherever it is possible without detriment to operational effectiveness;

   ii) The optimization of physical training to maximize women's strength potential; and

   iii) The implementation of true role-related physical selection tests with flexibility regarding team size and composition in order to increase the number of roles that are not limited by excessive physical demands.

c) Quantification of team performance is required to determine how mixed teams can be fully effective in military roles including combat." (AC/243 (Panel 8) TR/13).

1.6 OBJECTIVES AND SCOPE OF RTG-019: OPTIMIZING OPERATIONAL PHYSICAL FITNESS

With the conclusion of RSGs 4, 8, and 17, as well as the Workshop on Optimizing the Performance of Women in the Armed Forces of NATO, there remained open questions concerning mission-related testing and training. The revised spectrum of NATO missions requires a new approach to operational physical fitness. Specifically, a new necessity to define, assess, evaluate and optimize physical capability by setting appropriate criteria and methodologies was identified by an exploratory team that met in Spain in 2002. As a result of the exploratory meeting, HFM-080/Research Task Group 019 on Optimizing Operational Physical Fitness was established "to determine the requirement for physical fitness for military personnel in order to prepare military personnel for physical task requirements, to prevent physical overburdening, and to reduce injuries." (Annex VIII AC/323 (HFM)A/9). The stated specific goal of this RTG is "to improve the readiness of military personnel to carry out their primary mission by the establishment of mission/job-related physical fitness standards (Annex VIII AC/323(HFM)A/9).

The Terms of Reference (TOR) for RTG-019 was based on operational fitness vice general fitness issues. Specifically, RTG-019 was established to focus on the following topics:

a) Physical fitness elements and assessment;

b) Mission/job oriented physical requirements;

c) Determination of physical fitness standards for military tasks;

d) Mission oriented physical fitness training programs;

e) Gender considerations for standards and training; and

f) Pregnancy and military performance.

(Annex VIII AC/323(HFM)A/9).

The first meeting of RTG-019 was held in Warendorf, Germany during the period of 23-25 June 2003. At this meeting the TOR established during the exploratory meeting held in Spain were reviewed and ratified. Specifically, it was the consensus of the participating members of RTG-019 that the topic of "physical fitness elements and assessment" was adequately covered during RSGs 4 and 17, and would therefore be excluded from the work of this group.

The group members also decided to exclude "gender considerations for standards and training" as a specific objective. This decision was based primarily on two key points. First, this topic was covered during the Workshop on Optimizing the Performance of Women in the Armed Forces of NATO. Second, one of the recommendations resulting from that workshop was for the establishment of a new RTG on the topic due to the number of unanswered questions remaining at the end of the workshop. For these reasons, it was felt that this topic could not be adequately addressed within this RSG as a separate objective, but could best be addressed as it pertains to the performance of common military tasks.

The major outcome of the 1st meeting held in Warendorf, Germany was the identification of common physically demanding tasks (marching, digging, materials handling (manual), assault, military operations in urban terrain, climbing and close quarter battle) representative of recent and current NATO missions (humanitarian, peace-keeping, conflict resolution, and counter-terrorism).

The 2nd meeting of RTG-019 was held in Vienna, Austria during the period of 20-23 June 2004. At this meeting there was a slight realignment of chapters. Specifically, it was the consensus of the group that the topic of "pregnancy and military performance" be excluded from the work of RTG-019 due to a myriad of difficulties in conducting research with pregnant subjects, and due to the limited data available in this area. Difficulties in studying pregnant women include the potential for complications (to mother and baby) and research design limitations. As well, pregnant soldiers are quite often excluded from physically demanding tasks for the duration of their pregnancy, and are non-deployable in theatres of operation. Therefore, it was felt that the topic of "pregnancy and military performance" did not fit within the context of Optimizing Operational Physical Fitness. It was also the consensus of the group to exclude the common military task of Assault due to the wide range of Assaults (Sea, Land and Air) and difficulties in defining the task.

It was also discussed that current NATO missions are becoming increasingly complex in nature requiring soldiers to perform many military activities. While military tasks such as MOUT and FIBUA are of relevance to current NATO operations, it was decided to exclude this proposed chapter due to the lack of both published information and research being conducted in this area. However, it was agreed upon that NATO Special Operation Forces (SOF) are being used in many specialized missions (which include tasks such as MOUT, FIBUA, Close Quarter Battle, etc.) and that these complex mission demands cannot be described exclusively by a single common military task (i.e. marching, digging, lifting and carrying). Based upon the fact that the Austrian Federal Army was conducting research to establish a model of optimal weighted sports motor components as a basis for the development of task specific individual and group training recommendations for Special Forces soldiers, and the relevance and applicability of this research to current NATO missions, it was agreed to dedicate a chapter of the final report to the summary of this research.

The third meeting of RTG-019 was held in Lahti, Finland, 23-25 May 2005, whereas, the fourth and final meetings were held in Vienna, Austria (26-28 June 2006 and 18-20 December 2006 respectively).

1.7 STRUCTURE OF THE TECHNICAL REPORT

RTG-019 members agreed that the common physically demanding military tasks of marching, digging, and manual materials handling would each be described in individual chapters and in terms of:

a) Intensity and duration;

b) The physiological requirements;

c) Testing to predict performance; and

d) Training to improve performance.

It was agreed upon that a chapter of the final report would be dedicated to summarizing the research being conducted on an evidence-based job analysis and methodology to determine the physical requirements of special military occupations (Special Operation Forces – Austrian Army).

In addition, RTG-019 members agreed that the following factors influencing performance would be briefly summarized (factor description and effects on performance) and contained in one chapter:

a) Sustained operations;

b) Temperature (cold);

c) Temperature (heat);

d) Nutrition;

e) Altitude;

f) Clothing;

g) Age;

h) Gender;

i) Hydration;

j) Genetics; and

k) Anthropometry.

It was also agreed upon that an Annex on pre-employment screening tests and active duty testing of Common Military Task (CMT) performance used by various NATO countries would be compiled and included in this Technical Report, which will provide information for Staff Officers and references.

1.8 INTENDED CUSTOMER

The efforts of RTG-019 Optimizing Operational Physical Fitness will represent the international agreement for evidence-based findings which may provide the basis for policy decisions. To this end, the intended customers of this Technical Report are NATO Panel 8, National representatives, and exercise scientists.

1.9 REFERENCES

[1] NATO in the 21st Century @ http:www.nato.int/docu/21-cent/html.

[2] Optimizing the Performance of Women in the Armed Forces of NATO. AC/243 (Panel 8) TP/13.

[3] RSG 4 on Physical Fitness with Special Reference to Military Forces. AC/243 (Panel CIII) D/125).

[4] RSG 8 on Nutritional Aspects of Military Feeding (Military Nutrition). AC/243 (Panel 8 RSG8) D/9).

[5] RSG 17 on Biomedical Aspects of Military Training. AC/243 (Panel 8/TR16) 0875-94).

Chapter 2 – IDENTIFICATION OF COMMON MILITARY TASKS

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2.1 BACKGROUND

In order to optimize the physical capacity of soldiers by setting appropriate criteria and evaluation methodologies, members of RTG-019 reviewed mission essential task lists (METL) and types of missions undertaken by NATO forces in the past and present. The physical demanding tasks of digging, marching and manual materials handling were identified by members as being the key common tasks performed in recent and current NATO missions (humanitarian, peace-keeping, conflict resolution, counter-terrorism, etc.). As well, the identification of these common tasks was derived from a review of other pertinent military documents as summarized below.

2.2 CANADIAN FORCES

The mission of the Department of National Defence and the Canadian Forces (CF) is to defend Canada, its interests and its values, while contributing to international peace and security. The CF has long recognized the important of physical fitness in achieving its roles and objectives. In 1983, the Ergonomics Research Group (ERG) of Queen's University was contracted by the CF to develop minimum physical fitness standards (MPFS) for all military elements (Air, Sea, Land). In 1985, key stakeholders in the project to develop MPFS for CF personnel identified entrenchment digging, land evacuation, low/high crawl, sandbag carry, and sea evacuation as the common military tasks which all CF personnel might be required to perform in any emergency situation.

These five common military tasks (MPFS '88) were identified during the Cold War period hence their relevance and applicability to current military demands required confirmation. To this end, in 1996 the ERG of Queen's University was contracted to develop and validate the MPFS for CF personnel. The project commenced with a verification that the five common military tasks identified and utilized in MPFS '88 remain reflective of current military duties and operations in both times of peace and war. This was accomplished through the review of contemporary literature and media reports related to military exercises during peace-keeping and emergency duties. Table 2-1 depicts the common emergency tasks by operation (Deakin, Pelot, Smith and Weber, 2000). Results of this review confirmed that the original five common military tasks used in MPFS 1988 were in fact representative of the common military tasks performed during the period of the late 1990's and 2000. During this review process, evidence emerged that lifting is a major task in military work. As a result, a sixth common military task (Jerry Can Lift) was added to the list of common military tasks performed by CF soldiers.

Table 2-1: Common CF Emergency Tasks by Operation

Operation	Sea Evacuation	Land Evacuation	Low/High Crawl	Entrenchment Dig	Sandbag Carry	Lifting
Manitoba Flood: Domestic Operation		X		X	X	X
Saguenay Flood: Domestic Operation		X			X	X
Eastern Ontario Ice-Storm: Domestic Operation		X			X	X
Peacekeeping: International Operations		X	X	X		X
Humanitarian Operations: International				X		X
Gulf War			X			X

Adapted from: Deakin, Pelot, Smith and Weber, (2000). *Development and Validation of Canadian Forces Minimum Physical Fitness Standard (MPFS 2000).* Ergonomics Research Group, Queen's University, Kingston, Ontario, page 23.

While it is recognized that the CF MPFS represents the minimal level of physical fitness required by CF members to permit them to meet the physical demands of the common military tasks, it is also recognized that there may be other groups in the CF, such as the Army, that require a higher level of physical fitness. In a study to develop physical fitness standards for the Canadian Army, a series of representative common tasks were selected and ratified by a committee of Army experts as being representative of the physical requirements of the Canadian (Army) soldier. The representative tasks were identified as a casualty evacuation, ammunition box lift, maximal effort digging (trench), and a 13 km weight-loaded march (Singh, M., Lee, S.W., Wheeler, G.D., Chahal, P., Oseen, M. and Couture, R., 1991).

2.3 DUTCH ARMY

The modern Dutch military soldier must be physically fit in order to confront physically demanding situations, changing environments, and different information sources (Valk and Pasman, 2005). In 2004, a study to develop a list and descriptions of tasks performed by small units based on 6 missions conducted in the past (UNPROFOR, IFOR, SFOR, KFOR, ISAF and UK Gulf), was conducted by Smeenk, Barbier, Wilschut, Fiamingo, and Knijnenburg. Results of this study demonstrated that the tasks of "observation posts", "checkpoints" and "patrols" were the most frequently conducted tasks by small units. Of importance is that this study mainly dealt with peace support operations, and tasks performed in other military scenarios may be comprised of different physically demanding tasks.

In a study by Koerhuis, van Montfoort, Pronk and Delleman (2004), the most physically demanding tasks performed during different scenarios were described for five different types of combat soldiers of the Dutch Army (airmobile brigade, commandos, armoured infantry, marines and Object Ground Defence Soldiers (OGRV)). The results of this study showed that the offensive and defensive scenarios are the most physically demanding scenarios, and it was concluded that loaded walking is one of the most physical demanding tasks performed by combat soldiers during these scenarios. In addition, "fire and manoeuvre" activities, alternate kneeling and standing up, digging, lifting and carrying were identified as other physically demanding tasks performed by combat soldiers.

2.4 UNITED KINGDOM

In a study to research and develop task-related occupational tests and standards for Royal Naval (RN) personnel, traditional physical test criteria were reviewed and a number of task analyses of critical job components were conducted. The critical and generic components of the job were identified as shipboard fire-fighting, casualty carrying, and escaping through various hatches and safety doors on board a typical RN vessel (Bilzon, Scarpello, Bilzon, and Allsopp, 2002). Further, the tasks "Boundary Cooling", "Drum Carry", "Extinguisher Carry", "Hose Run" and "Ladder Climb" were identified by subject matter experts, and endorsed by the Royal Navy as being representative of shipboard fire-fighting tasks performed by RN personnel.

With respect to developing physical fitness standards representative of the physical demands of performing generic RAF Combined Incident Team tasks, initial work conducted by Nevola, Puxley, Messer, Roberts, and Collins (2003) identified 14 Core Operational Tasks (COTs). Three of the 14 COTs that were defined as a Bona Fide Occupational Requirement (BFOR) for RAF combined incident teams involved digging or shovelling. Other COTs included, but was not limited to lifting, and lifting and carrying tasks (Nevola, Coyles, Puxley, and Collins, 2003). To ensure that all Royal Air Force (RAF) personnel have a minimal level of fitness commensurate with performing some of the Core Operation Tasks required when on operations, a project was conducted to develop an operational fitness assessment (Rayson, Wilkinson, Carter, Richmond and Blacker, 2005). Four Representative Service Tasks (RSTs) (single lift of a weighted ammunition box, a sandbag carry, a Fire and Manoeuvre sequence, and a trench dig) were designed to represent the physical demands of performing the 14 Core Operational tasks.

A detailed job analysis of all entry level Army occupations resulted in the identification of four Representative Military Tasks (RMTs) that were common to most military occupations and critical to soldier performance. These four RMTs were defined as a single life of an ammunition box, a continuous carry of 2 – 20 kg water jugs (jerry cans), a repetitive lift and 10 metre carry of an ammunition box, and a road march of 12.8 km (Rayson, 1988).

2.5 UNITED STATES

During a study to develop criterion performance tasks for the purpose of establishing "physical abilities" standards for entry to the Unites States (US) Army, Myers, Gebhardt, Crump and Fleishman (1984) analyzed 1,999 critical tasks across all job categories. Table 2-2 depicts the reported rank order of the most frequent physical tasks in the U.S. Army as reported by Myers et al., 1984.

Table 2-2: Rank Order of the Most Frequent Physical Tasks in the U.S. Army

Physical Tasks	Total	Very Heavy MOS	Heavy MOS	Moderately Heavy MOS
Lift/lower	41%	40%	40%	43%
Carry/load bear	30%	31%	30%	28%
Pull/torque	6%	8%	6%	7%
Push	5%	5%	5%	7%
Climb/descend	4%	4%	5%	3%
Reach	2%	2%	2%	1%
Stoop	2%	2%	2%	2%
Dig	1%	1%	1%	2%
Crawl	1%	1%	1%	<1%
Kneel	1%	1%	1%	1%
Crouch	1%	1%	1%	1%
Hammer/pound	1%	1%	1%	1%
Stand	<1%	0%	0%	<1%
Recline	<1%	<1%	<1%	<1%
Handle/finger	<1%	<1%	1%	<1%
Throw	<1%	<1%	0%	0%
Walk/March	<1%	0%	<1%	<1%
Rush/run	<1%	<1%	0%	0%
Swim/dive	<1%	<1%	0%	<1%
Sit	0%	0%	0%	0%

As part of a Training and Doctrine Command (TRADOC) directed initiative to develop physical performance standards for all U.S. Army Military Occupational Specialties (MOSs), the physical task requirements for all of the Army MOSs were identified (Sharp, Patton and Vogel, 1998). The identified physical task demands were based on a description of the physical requirements for all MOSs as contained in Army Regulation 611-201 (Headquarters, Department of the Army, 1995). A series of databases of the physically demanding tasks performed by U.S. Army soldiers was developed, and of interest is that the six task categories developed in the databases were:

i) Lifting and carrying;

ii) Lifting and lowering;

iii) Climbing;

iv) Digging;

v) Walking, marching, and running; and

(vi) Pushing and pulling.

Lifting and carrying was identified as the most common physically demanding task, representing 232 tasks performed by 172 different MOSs. The next most physically demanding task identified was lifting and lowering, representing 92 tasks performed by 75 different MOSs. Digging represented 18 tasks performed by 18 different MOSs, whereas walking, marching and running represented 22 tasks performed by 18 different MOSs. It was noted that although there were few entries in the walking, marching, running database, long distance road marching with a loaded backpack was considered an important physical task, specifically for infantry soldiers (Sharp et al., 1998).

2.6 SUMMARY OF THE IDENTIFICATION OF COMMON MILITARY TASKS

Table 2-3 below summarizes the common military tasks by Nation, as derived from the review of relevant documents pertaining to the research and development of physical fitness standards and/or training regimes.

Table 2-3: Summary of Common Military Tasks by Nation

Nation	Common Military Tasks			Authors
	Manual Materials Handling	Marching	Digging	
Canada – Army	Ammunition box lift, jerry can lift and carry	Weight loaded march	Entrenchment dig	Singh et al., 1991
Canada – Air Force/Navy	Sandbag Carry, Jerry Can lift and carry		Entrenchment Dig	Deakin et al., 2000
Netherlands	Lifting and carrying	Loaded walking		Koerhuis et al., 2004
United Kingdom – Navy	Casualty carrying, drum carry, and extinguisher carry			Bilzon et al., 2002
United Kingdom – Royal Air Force	Ammunition box lift, and sandbag carry			Rayson et al., 2005
United Kingdom – Army	Ammunition box lift (single repetition), jerry can carry, and ammunition box lift (repetitive) and carry	Road march	Trench Dig	Rayson, 1988
United States	Lifting and carrying, lifting and lowering, and pushing and pulling	Walking, marching, and running	Digging	Sharp et al., 1998

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Chapter 3 – COMMON MILITARY TASK: MARCHING

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3.1 INTRODUCTION

"On the field of battle man is not only a thinking animal, he is a beast of burden. He is given great weights to carry. But unlike the mule, the jeep, or any other carrier, his chief function in war does not begin until the time he delivers that burden to the appointed ground." (Marshall, 1950)

Foot marches can be defined as the movement of troops and equipment mainly by foot with limited support by vehicles. They are characterized by combat readiness, ease of control, adaptability to terrain, slow rate of movement, and increased personnel fatigue. A successful foot march is when troops arrive at their destination at the prescribed time and are physically able to execute their mission (Department of the Army, 1990).

Many NATO nations have soldier modernization programs that aim to equip soldiers with fully-integrated state-of-the-art technologies that will enhance the five NATO soldier capability areas: lethality, protection, mobility, sustainability, and command and control. Military carriage capacity can have an impact on a number of these capabilities areas. In particular, it is critical to soldiers mobility and sustainability, and ultimately, to soldier performance and survival on the battlefield (Leeuw, 1998).

Mobility is defined as the capability of the dismounted soldier to traverse through any kind of terrain irrespective of weather conditions. The objective is to extend the geographic sphere of influence of the soldier. The main functions in this capability area are to orient, navigate, receive and provide information on the terrain, to traverse on foot, and to carry his/her load while on the move. Sustainability is the capability of the dismounted soldier to continue his/her job for an extended period of time.

The British Defense Organization developed four generic criterion tasks to represent the key activities identified in a job analysis. Marching under load was identified as a requirement for a number of occupations and is a fundamental and common task required of all personnel (Rayson, 1997).

In the Canadian Army a series of common tasks were selected by a committee of army experts, at headquarters and in the field, as being representative of the physical requirements of the Canadian Soldier. The basic idea was that all soldiers, irrespectively of their trade, could be called upon to carry out the duties of the infantryman at some point in the battle scenario. One of the common tasks identified was a weightload march cross country in full fighting order in all weather and light conditions (Lee, 1992).

The Netherlands Army selected four common military tasks including road marching as being representative of the physically most demanding activities for the soldier in the field. Task-related physical selection standards were implemented for these tasks. Most of these tasks are also included in the physical readiness test of the Dutch Army, the so-called FIT-test. The yearly FIT-test consists of a short transfer, obstacle course, repetitive lifting/load bearing, loaded marching and loaded speed marching. The requirements on the march test are related to the specific function profile (Dijk et al., 1996, Koerhuis et al., 2004).

The scope of this chapter is to provide a review of the literature with respect to the common military task of road marching. The aim is to give evidence-based information on performance issues related to the military task of road marching. The chapter starts with a historical overview of loads carried by units in military operations (3.2) and definitions of different categories of combat loads (3.3). The energy cost (3.4) and also the physiological determinants (3.5) of loaded marching are discussed to get a better picture of limiting factors of performance on this task. Tests to monitor performance and evaluate changes in road marching performance are discussed in section 3.7. Training is one approach to increase road marching performance. Guidelines (3.8) are deduced from several training studies with military populations. Injury factors can adversely affect soldier's mobility and reduce the effectiveness of an entire unit. These factors are therefore reviewed (3.9). To support field commanders in planning and training, reference values of loaded march performance are given and the impact of loads carried on performance during the traverse and when arriving at the place of action are discussed (3.10). The chapter concludes with the finding that in modern wars the soldiers are still or even more overburdened than in past wars. Management of the soldier's load is essential to find a proper balance of firepower and mobility of the unit.

3.2 LOADS CARRIED BY UNITS IN MILITARY OPERATIONS

Lothian (1922) examined available sources to determine loads carried by the soldiers of various armies up to World War I. Until about the 18th century, troops carried loads that seldom exceeded 15 kg while they marched. Extra equipment and subsistence items where often moved by auxiliary transport including assistants, horses, carts, and camp followers. After the 18th century, auxiliary transport was de-emphasized, and more disciplined armies required troops to carry their own loads. Modern soldiers often carry a considerable amount of equipment and supplies while on the march, some of which they remove if they come into contact with hostile forces (Lothian 1922, Porter 1992).

During the Crimean War (1854 – 1856) British and French infantry loads were estimated to be about 29 and 33 kg respectively. British loads were reduced to 25 kg in 1907 but increased to 32 – 36 kg in WW1. Loading of the soldier did not stop after WW1. Holmes (1985) cited the loads shown in Table 3-1 for a variety of operations from WW1 to the Falklands Campaign.

Table 3-1: Loads Carried by Various Units and/or Carried at Various Times (from Holmes 1985)

Unit	Weight (kg)
French Poilu (WW I)	39
British Infantry on the Somme (WW I)	30
French Foreign Legion (WW I)	45
Wingate's Chindits (WW II)	31 – 41
U.S. Forces in North Africa (WW II)	60
U.S. Marines in Korea	38
U.S. in Vietnam	34
Falklands Campaign	54

Throughout history, soldiers have been expected to successfully complete missions under the most arduous of circumstances. Though technology and tactics have varied, the physical demands placed on soldiers have remained constant. Numerous historical examples support this. In 1805 during the battle of Austerlitz (Holland), Napoleon moved a corps 125 km in 50 hours and had them enter battle directly off the march. During Civil War, Major General U.S. Grant marched union troops 65 km in 27 hours to position them for the final siege of Vicksburg. In 1943 the 3rd Infantry Division marched 160 km to Palermo in 5 days.

McCaigh and Gooderson (1986) reported on the load carried by troops from the United Kingdom who were engaged in a military conflict in the South Atlantic in May and June 1982. Climate and terrain imposed heavy demands on the physical capabilities of the troops deployed. The lack of metalled roads and wheel transport dictated that almost all movement of personnel was on foot. The load carried by the individual soldier varies with their task. The lightest load, referred to as the Assault Order, is comprised of the equipment required to live and fight for a period of up to 12 hours. The addition of rations and clothing to sustain a soldier for a period of 24 hours produced the next heaviest load, referred to as the Combat Order. Finally when all personal clothing and equipment and additional rations are carried, the resulting load is known as the Marching Order. Typical weights of these loads are given in Table 3-2.

Table 3-2: Weights of Clothing and Personal Equipment Carried by a British Infantryman (kg) (Adapted from Haisman, 1988)

			Weight	Total Weight
A)	Dress	Clothing, boots and helmet	7.0	7.0
B)	Assault dress	Clothing, etc., as in A, weapon, ammunition, digging tool and equipment	19.4	26.4
C)	Combat dress	Dress and equipment as in A and B, food and warm clothing	3.7	30.0
D)	Marching order	Clothing and equipment as in A, B and C, spare clothing, rations, rucksack and sleeping bag	10.2	40.2
E)	Additional equipment	There are a number of additional items which could have to be carried ranging in weight up to 16 kg		

It can be calculated that the marching order weight of 40 kg represents 51% of the nude-weight of the 50th percentile infantryman (Gooderson and Beebee, 1976), and that the 5th percentile infantryman would have been carrying 63% of this nude body-weight. Thus for an ‘average’ load weight of 50 kg the 50th percentile infantryman would have been carrying 70% of his nude body-weight and it is certain that many men were more heavily laden. Up to 20%, probably a conservative estimate, of the soldiers listed fatigue due to the weight carried or due to the lengths of the marches as a significant problem.

In addition to the basic infantry load a number of heavy and bulky items were also carried by some soldiers (Table 3-3). With the addition of support weapons, radios and extra equipment the total load carried can rise to the very high figures quoted for military operations, e.g. up to 68 kg in the Falklands operation (McCaig and Gooderson, 1986) over distances of 60 km.

Table 3-3: Examples of Weights of Additional Equipment (kg)

Additional Equipment	Weight (kg)
Machine gun	10.9
Machine gun tripod	13.6
Belt of machine gun ammunition	2.95
Anti-tank rocket launcher	16.0
2 x Anti-tank rounds	3.4
Mortar barrel	12.3
2 x Mortar bombs	8.9
Radios	1.5 – 10.8

Dublik (1987) reviewed information gathered by the Walter Reed Army Institute of Research. The members of seven infantry battalions who participated in Operation Urgent Fury in Grenada were interviewed. The general conclusion was that many soldiers were overloaded. Too few commanders enforced load discipline. A soldier stated in the interview:

> "We attacked to secure the airhead. We were like slow-moving turtles. My rucksack weighed 54 kg. I would get up and rush for 10 meter, throw myself down and couldn't get up. I'd rest for 10 or 15 minutes, struggle to get up, go 10 more meters, and collapse. After a few rushes, I was physically unable to move, and I am in great shape. Finally, after I got to the assembly area, I shucked my rucksack and was able to fight, but I was totally drained."

Not all soldiers who fought in Grenada were overloaded. Some unit commanders cut their soldiers' load to the minimum, limited contingency equipment and eliminated all non-essential items. These commanders took some risks, but they knew overloaded soldiers would reduce the unit's ability to fight and win.

Perkins (1986) reported that when elements of the 2nd and 3rd Battalions of the 325th Airborne Infantry Regiment conducted a combat air assault onto Point Salines airfield on the island of Granada in October 1983, the soldiers in these units were carrying approximately 36 kg each. This weight led to a marked decrease in their combat effectiveness.

In a 1990 article from Infantry Magazine, entitled "Load carrying ability through physical fitness training", the authors discussed recommended doctrinal carrying weights versus data collected at the Joint Readiness Training Center (JRTC). Though the Infantry school recommends a maximum of 33 kg for approach marches and 22 kg for combat actions, the authors determined that weights actually carried during simulated battle at JRTC were far greater. They found that occasionally units carried an average of 45 kg per individual and the most extreme loads were as high as 76 kg. They concluded by saying that heavy loads are the reality of the modern day battlefield and that despite the availability of transport, the need to carry loads will remain (Bahrke, 1990).

In 2003 a Soldier Load Study was conducted in Afghanistan (Dean, 2004). The study focused on the modern warrior's combat load as experienced by a U.S. Army light Infantry brigade task force fighting a low intensity conflict in the desert and mountainous regions of Afghanistan. Data was collected over a two month period in the Afghan spring of 2003 as the task force conducted continuous, hard hitting combat operations to not only deny maneuver and safe haven to enemy, but to capture or destroy Anti-Coalition Militants composed of hostile Taliban and Al Qaeda elements. A team of experienced infantrymen collected the data and conducted observations while accompanying and soldiering with the units during numerous combat operations. This study provides a rare insight into what Soldiers carry into battle.

According to the findings of the Task Force Assessment Team the dismounted infantryman was heavily loaded while conducting modern combat operations (Dean, 2004). While carrying one of the lighter combat loads in a Rifle Company, the average light Infantry Rifleman was still transporting over 43 kg of critical combat equipment in his Approach March Load when he conducted short duration dismounted operations in Afghanistan in mild to hot weather. The weights of his Approach March Load increased even further during cold weather operations and his Emergency March loads were averaging over 58 kg.

The modern dismounted infantryman continues to be over-burdened while conducting combat operations. The excessive weights on the backs of the soldiers, coupled with the harsh environments in which they operate prove detrimental to maximize Soldier performance. Despite units going to great lengths to minimize the loads that their Soldiers are carrying, the weight of the Infantry's combat load is far too great and considerably exceeds the upper envelopes established by US Army Doctrines (Dean, 2004).

Table 3-4: Average Fighting Load, Approach March Load and Emergency Approach March Load (in pounds) by Duty Position within a Light Infantry Rifle Company, while Being Active in Combat Operations in Afghanistan (Taken from Dean, 2004)

Position in Unit	Average Fighting Load	Average FL% Body Weight	Average Approach March Load	Average AML % Body Weight	Avg Emergency Approach March Load*	Average EAML % Body Weight
Rifleman	63.00	35.90%	95.67	54.72%	127.34	71.41%
M203 Grenadier	71.44	40.95%	104.88	60.25%	136.64	77.25%
Automatic Rifleman	**79.08**	44.74%	110.75	62.71%	**140.36**	79.56%
Antitank Specialist	67.66	37.57%	99.04	55.02%	130.20	79.65%
Rifle Team Leader	63.32	35.61%	93.78	52.43%	130.27	80.65%
Rifle Squad Leader	62.43	34.90%	94.98	52.59%	128.35	73.62%
Forward Observer	57.94	33.00%	91.40	52.12%	128.56	76.59%
Forward Observer RTO	60.13	35.37%	87.07	51.42%	119.13	74.94%
Weapons Squad Leader	62.66	34.02%	99.58	54.37%	132.15	69.19%
M240B Gunner	**81.38**	44.46%	113.36	62.21%	132.96	68.92%
M240B Asst Gunner	69.94	38.21%	**120.96**	66.11%	**147.82**	80.08%
M240B Ammo Bearer	68.76	36.59%	**117.06**	62.19%	**144.03**	78.46%
Rifle Platoon Sergeant	60.66	31.53%	89.96	46.35%	119.16	62.67%
Rifle Platoon Leader	62.36	34.02%	93.04	50.33%	117.62	65.44%
Platoon Medic	54.53	31.08%	91.72	51.58%	117.95	69.88%
Radio/Telephone Operator	64.98	35.60%	98.38	54.08%	no data avail	no data avail
Mortar Section Leader	58.31	30.59%	109.99	57.34%	**149.30**	90.49%
Mortar Squad Leader	60.98	37.89%	**127.24**	78.26%	**142.30**	**96.80%**
60mm Mortar Gunner	63.79	38.06%	108.76	64.22%	**143.20**	88.14%
60mm Mortar Assistant Gunner	55.34	31.93%	**122.16**	70.28%	no data avail	no data avail
60mm Mortar Ammo Bearer	53.13	30.14%	101.13	60.59%	no data avail	no data avail
Rifle Company Commo Chief	68.13	38.16%	109.69	61.67%	no data avail	no data avail
Fire Support Officer	54.11	27.32%	93.08	46.81%	no data avail	no data avail
Fire Support NCO	52.10	31.92%	90.08	55.22%	**143.30**	**98.83%**
Sapper Engineer	59.02	33.05%	95.70	53.50%	132.08	77.92%
Company Executive Officer	60.50	34.03%	93.65	52.81%	no data avail	no data avail
Company First Sergeant	62.88	33.69%	90.42	48.11%	126.00	86.30%
Company RTO	64.70	35.65%	98.09	54.27%	130.00	72.13%
RifleCompany Commander	66.10	37.08%	96.41	53.77%	111.20	70.83%
TOTAL AVERAGE	**63.08**	**35.27%**	**101.31**	**56.74%**	**131.74**	**77.82%**

3.3 COMBAT LOAD DEFINITIONS

Field Manual 21-18 (Department of the Army, 1990) provides guidance about how to conduct foot marches, including recommended maximum loads and prescribed rates of march in different conditions. Overall, the information is based on a combination of available target audience, operational need, available technology, and military judgement. It provides a published reference for determining acceptable military performance.

Combat load recommendations in the manual are based on military experience (Knapik, 1989) and on energy cost studies (from Harper et al., 1997). The combat load is the minimum mission-essential equipment required for Soldiers to fight and survive immediate combat operations, and is determined by the commander responsible for carrying out the mission. The combat load is the essential load carried by Soldiers in forward subunits or the load that accompanies Soldiers other than fighting load. Combat loads consist of three categories: Fighting Load, Approach March Load, and Emergency Approach March Load (FM 21-18).

3.3.1 Fighting Load

The fighting load includes bayonet, weapon, clothing, helmet, load bearing equipment and a reduced amount of ammunition. For hand-to-hand combat and operations requiring stealth, carrying any load is a disadvantage. Soldiers designated for any mission should carry no more than the weapons and ammunition required to achieve their tasks; loads carried by assaulting troops should be the minimum.

Unless some form of combat load handling equipment is available, cross-loading machine gun ammunition, mortar rounds, antitank weapons, and radio operators equipment causes assault loads to be more than the **limit of 21.7 kg**. This weight restricts an individual's ability to move in dynamic operations. Extremely heavy Fighting Loads must be rearranged so that the excess weight can be redistributed to supporting weapons or can be shed by assaulting troops before contact with the enemy (FM 21-18).

3.3.2 Approach March Load

The approach march load includes clothing, weapon, basic load of ammunition, Load Bearing Equipment, small assault pack, or lightly a loaded rucksack or poncho roll. On prolonged dynamic operations, the Soldier must carry enough equipment and munitions for fighting and existing until re-supply. In offensive operations, Soldiers designated as assault troops need equipment to survive during the consolidating phase, in addition to carrying munitions for the assault. A **limit of 32.7 kg** for a Soldier should be enforced (FM 21-18).

3.3.3 Emergency Approach March Loads

Circumstances could require Soldiers to carry loads **heavier than 32.7 kg** such as approach marches through terrain impassable to vehicles or where ground/air transportation resources are not available. Therefore, larger rucksacks must be carried. The Emergency Approach March Loads can be carried easily by well-conditioned Soldiers. When the mission demands that Soldiers be employed as porters, loads of up to 54.5 kg can be carried for several days over distances of 20 km a day. Although loads of up to 68 kg are feasible, the Soldier could become fatigued or even injured. If possible, contact with the enemy should be avoided since march speeds will be slow (FM 21-18).

The Infantry school added to this guidance that a soldier's weight must be taken into account. The optimal load for a soldier has been determined to be 30 percent of his body weight, and the maximum load should not exceed 45 percent of his body weight (Burba, 1986).

Based on observations during the war in Afghanistan Dean and his colleagues of the Devil Assessment Team (2004) made the recommendation that FM 21-18 be rewritten to reflect the realities of modern operations and the loads and equipment that today's Soldiers are carrying.

3.4 ENERGY COST OF MARCHING

Studies of load bearing have focused primarily on energy cost (Bobbert, 1960; Goldman and Iamprieto, 1962; Hughes and Goldman, 1970; Pandolf et al., 1976; Epstain et al., 1988; and Legg et al., 1992). Mathematical models have been developed to estimate energy expenditure during load carriage (Givoni and Goldman, 1971; Pandolf et al., 1977; and Epstein et al., 1987).

In principle, an optimum method of load carriage should induce stability, bring the centre of gravity of the load as close as possible to that of the body and make use of the larger muscle mass muscles (Legg, 1985). Locating the load as close as possible to the center of mass of the body appears to result in the lowest energy cost when loads are carried on the upper body (Soule and Goldman, 1969; and Winsmann and Goldman, 1976). Legg and Mahanty (1985) investigated five different methods of carrying a load close to the trunk. They reported that the least metabolic strain was imposed by a front/backpack method, with slightly higher oxygen costs associated with load carriage in a trunk jacket and three varieties of backpacks. Although the use of a front/backpack is physiologically associated with the lowest oxygen uptake, the method is impractical to use in many military situations. Objects on the chest may impair vision, thereby limiting manoeuvrability and restricting breathing. Consequently the backpack method of load carriage is generally favoured. Legg et al., (1992) showed that backpack load carriage is associated with lower heart rate and relative oxygen uptake (5%) than shoulder load carriage.

Studies conducted on treadmills for short periods of time show that the energy cost of backpack load carriage increases in a systematic manner with increases in:

Body Mass (Falls and Humphrey, 1976; Goldman and Iampietro, 1962; and Passmore and Durnin, 1955);

Load Mass (Borghols 1978; Goldman and Iamprieto, 1962; and Soule et al., 1978);

Velocity (Goldman and Iamprieto, 1962; Soule et al., 1978; and Workman and Armstrong, 1963);

Grade (Borghols, 1978; Goldman and Iamprieto, 1962; Pandolf et al., 1977); and

Type of Terrain (Haisman and Goldman, 1974; Pandolf et al., 1976; Soule and Goldman, 1972; and Patton et al., 1991).

Givoni and Goldman (1971) used these relationships to develop an equation for predicting energy costs of locomotion with backpacks. Pandolf et al., (1977) revised this equation and included a factor for energy cost of standing with loads. This formula was developed to include standing and walking at all speeds up to running 8.6 km/h, at grades from 0 to 25% with loads from 0 to 70 kg and a variety of terrains. Since the Pandolf equation only considers speeds up to 8.6 km/hour, Epstein et al., (1987) expanded the equation to include a term for running (up to 11.5 km/hour). The Pandolf equation has been independently validated using a range of loads and body masses (Duggan and Haisman, 1992).

Table 3-5: The Equations to Predict the Short Term Energy Cost of Locomotion with Backpack Loads

Equation Givoni and Goldman 1971 $M_w = T \bullet (W + L) \bullet [\, 2.3 + 0.32 \bullet (V - 2.5)^{1.65} + G \bullet (0.2 + 0.07 \bullet (V - 2.5))]$
Equation Pandolf et al., 1977 $M_w = 1.5 \bullet W + 2.0 \bullet (W + L) \bullet (L / W)^2 + T \bullet (W + L) \bullet (1.5 \bullet V^2 + 0.35 \bullet V \bullet G)$
Equation Epstein et al., 1987 $M_r = M_w - 0.5 \bullet (1\text{-}001 \bullet L) \bullet (M_w = -15 \bullet L - 850)$

Symbols: M_w = metabolic cost of walking (watts); M_r = metabolic cost of running (watts); W = body mass (kg); L = load mass (kg); T = terrain factor; V = velocity or walk rate (m/s); G = slope or grade (%)

Terrain factors: 1.0 = black topping road; 1.1 = dirt road; 1.2 = light brush; 1.5 = heavy brush; 1.8 = swampy bog; 2.1 = loose sand; 2.5 = soft snow 15 cm; 3.3 = soft snow 25 cm; 4.1 = soft snow 35 cm

Energy expenditure is an important variable in military field situations. It provides commanders with valuable information about the physical strain of a certain loaded traverse. Choosing the right combination of load carried and speed, given certain characteristics of terrain and distance, dictates soldier's mobility and the capacity of the soldier to continue their job for an extended period of time. As an example, energy expenditure for certain combinations of speed, load carried and terrain factors are shown in Figure 3-1. Speed of traverse, more than load carried, is a very important factor determining the actual energy expenditure.

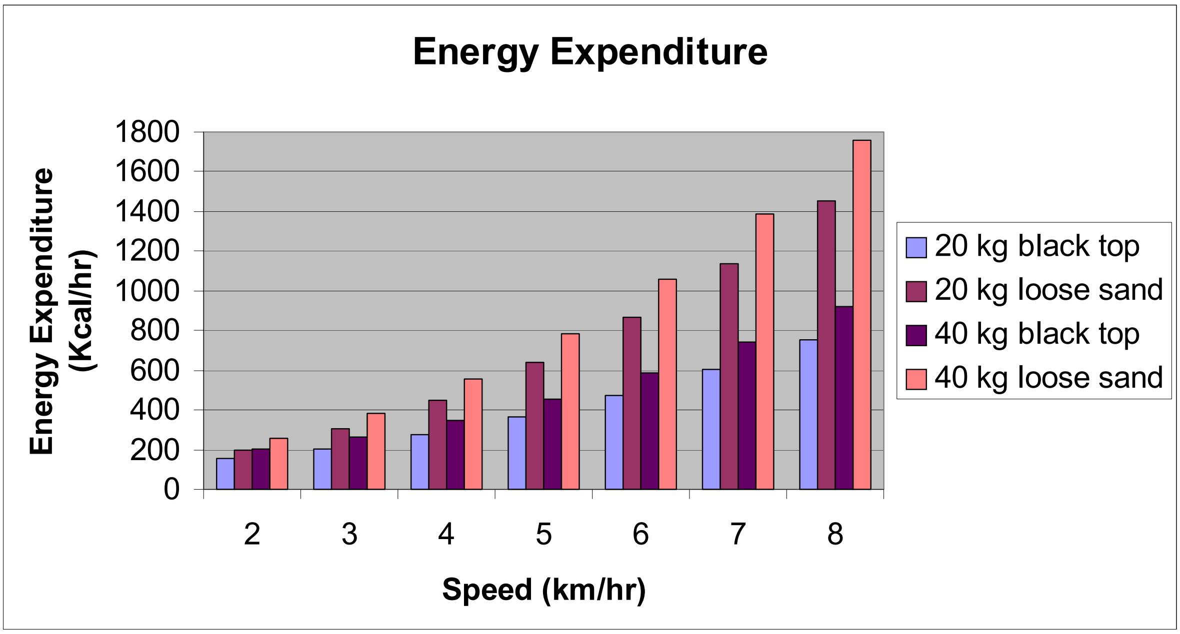

Figure 3-1: Effect of Speed, Terrain and Load Carried on Energy Expenditure. (Pandolf 1977)

A limitation of the Pandolf equation may be the fact that it does not account for possible changes in energy cost over time. In studies used to develop the equation, energy costs was examined for short periods, usually less than 30 minutes. Research gives conflicting results about the effect of duration of work on energy expenditure. Epstein et. (1988) and Patton et al., (1991) showed that the energy cost of prolonged (>2 hours) load carriage at a constant speed increased over time at higher loads and/or speeds. Epstein et al., (1988) found an 8.8% increase in VO_2 over 2 hours while carrying 40 kg at a speed of 4.5 km/hour and a 5% grade. They concluded that an exercise intensity greater than 50% of VO_2max was required before an increase in VO_2 was found. Patton et al., (1991) noticed an increased VO_2 even at initial intensities of about 30% of VO_2max. They concluded that applying the prediction model which estimates energy expenditure from short-term load carriage efforts to prolonged load carriage can result in significant (10 – 16%) underestimation of the actual energy cost. A factor which may be of particular importance is the reduction in mechanical efficiency due to altered locomotion biomechanics as the subjects adjusts to the weight of the pack (Rowell, 1971; and Martin and Nelson, 1986). However these results were not confirmed in a more recent study of Sagiv et al., (1994). Differences in aerobic fitness of subjects and the system used to carry the load may explain the differences found in these studies. Whether or not energy cost increases over time is an important issue because increased energy cost is related to earlier fatigue and possible decrements in military performance of the individual soldier.

Studies have illustrated that subjects adjust their kinematics in response to a heavy backpack load. The adjustments include a shortened stride length (Martin and Nelson, 1985), greater knee flexion at heel-strike, and a straighter knee at mid stance (Han at al., 1993). Givoni and Goldman (1971) suggested that as the product of speed (km/h) and load (kg) exceeds the numerical value of 100, there is an inefficiency, which increases energy cost. Martin and Nelson (1986) in studying the walking patterns of men and women during load carriage, found a decrease in stride length and swing rate while stride rate increased with increasing load. In addition, there was an increased forward inclination of the trunk at their heaviest load (36 kg). Stride length is one factor known to affect VO_2 during running where variations from an optimum length result in increasing greater energy demands (Daniels, 1985). Quesada et al., (2000) studied the biomechanical and metabolic effects of varying backpack loading on marching. Each 15% body weight load increment resulted in a proportional metabolic cost increase of approximately 5 to 6%.

The energy expenditure equations can provide valuable information as to the physical severity of load carriage tasks and the potential for ensuing fatigue. For field studies it is possible to estimate absolute energy rate, total energy expenditure and relative exercise intensity during loaded marching. To estimate energy expenditure rate the standard equation of Pandolf et al., (1977) can be used. Total energy expenditure can be estimated by multiplying the estimated energy expenditure rate by march time. Estimating relative exercise intensity requires several steps (Knapik et al., 1993):

1) Estimated energy expenditure rate (Pandolf et al., 1977) is converted to liters O_2/min under the assumption that about 5 kilocalories is the energy equivalent of 1 liter O_2;

2) VO_2max (l/min) of each soldier is estimated or measured using lab test or field tests (ACSM, 2000); and

3) Energy expenditure rate (liters O_2/min) is divided by the VO_2max (liters O_2/min) and multiplied by 100% to obtain the estimated relative exercise intensity.

Rayson et al., (1995) argued that it is essential to measure the maximum or peak oxygen uptake during the actual task loaded marching and not maximum oxygen uptake derived from treadmill running tests in the laboratory or predicted maximum oxygen uptake from field running tests. The VO_2max measured during loaded marching is significantly less than that measured during running (Rayson et al., 1995). This is in accordance with other studies that have shown VO_2max to vary with the kind of exercise performed and the muscle used (Asmussen and Hemmingsen, 1958; Hermansen et al., 1970; Petrofsky and Lind, 1978;

and Smith et al., 1996). An important aspect of this finding relates to the description of intensity of submaximal efforts. During an analysis of the physical demand of a task, the intensity of submaximal efforts should be expressed as a function of the maximal power (VO_2max) of the task being examined and not as a function of another kind of work, i.e. VO_2max of running. For example if the VO_2 of a loaded march is expressed as being 50% VO_2max for running, one should assume the individual is marching at a sustainable rate. In reality, however, the individual is working at 63% VO_2peak for loaded marching, a value which may exceed the maximum sustainable work rate (Rayson et al., 1995). Using the VO_2max for running thus significantly underestimates the work effort.

The same idea of underestimating the intensity of work may be applied to using heart rate to estimate the work effort. Knapik et al., (1993) showed that when soldiers were asked to perform a 20-km march with a load of 15 kg as quickly as possible, the mean peak heart rate was 155, which is well below the predicted maximal heart rate of 191 for this group of soldiers. Nevertheless, the soldiers were working at or near maximal levels of loaded marching. A comparison of heart rate for loaded marching and running greatly underestimates the actual intensity of the work in loaded marching.

3.5 PHYSIOLOGICAL DETERMINANTS OF MARCH PERFORMANCE

There are many factors that influence the ability of a soldier to carry load and road march. These include mass of load, speed of march, type of terrain, distribution of the load (Datta and Ramanathan, 1971; and Kinoshita 1985), volume of the load (Holewijn and Lotens, 1992) and the medical condition of the soldier (Knapik et al., 1992). Some of these factors have been studied, but usually in relation to the energy cost of the task and not in relation to the physiological profile of soldiers that determines load-carriage performance.

A typical research approach to relate task performance to the physiological profile is to administer subjects a series of physiological tests that measure muscle strength, anaerobic capacity, aerobic capacity and body composition. The subjects are also administered to a load carriage test. Task performance on the load carriage test is then correlated with the various physiological measures.

Several authors have shown a negative relationship between fatness and march performance (Dziados, 1987; and Rayson et. al., 1995), though there is little consensus to the extent of impact of body fat. Excess body fat is dead weight in the performance of work and degrades the performance of physical tasks involving movement of the body and an external load. An interesting question is whether carrying weights has the same effect on energy expenditure as passive body weight (fat). Goldman and Iamprietro (1962) studied subjects walking on a treadmill at speeds of 2.4 – 6.4 km/hour, grades of 3 – 9% and carrying loads of 0 – 30 kg. They concluded that for fairly fit individuals walking at a given speed and grade the energy cost/kg is independent of the extra weight carried. Up to limits of 30% of body weight the energy cost/kg is found to be the same for weight load and live weight (Datta and Ramanathan, 1971). Borghols et al., (1978) also reached the conclusion from their experiments (speed 5 km/hr, carrying loads 0 – 30 kg), that there is no difference in energy cost/kg whether the weight is carried as an external weight or as live weight. They suggest that a decrease in body fat mass may permit subjects to increase their work load or to do the same work with less exertion. Within the range of 0 – 30 kg each kilogram carried load accounts for an average increase in oxygen uptake of 0.335 $ml \cdot kg^{-1} \cdot min^{-1}$ and a heart rate of 1.1 beats per minute.

Higher lean body mass is associated with faster load carriage. Lean body mass is strongly related to strength and this helps to support and move the load carried. The correlations are stronger for lean body mass than for percent body fat. Table 3-6 shows correlations of load carriage performance with lean body mass and percent body fat.

Table 3-6: Correlations of Load Carriage Performance with Lean Body Mass and Percent Body Fat (Male Subjects)

	Distance	Load	Lean Body Mass	Percent Body Fat
Dziados et al., (1987)	16 km	18 kg	– 0.30	0.15
Mello et al., (1988)	2 km	46 kg	– 0.54	0.00
	4 km	46 kg	– 0.39	0.38
	8 km	46 kg	– 0.45	0.48
	12 km	46 kg	– 0.55	0.29
Knapik et al., (1990)	20 km	46 kg	– 0.26	0.05

Studies by Rayson et. al. (1993 and 1995) on female soldiers and by Frykman and Harman (1995) on male soldiers, identified height as a fair predictor of the ability to march with a load. In a study by van Dijk et al., (1996) a positive correlation of 0.46 was found between height and the performance on a marching test with load carried up to 62.5 kg and a speed of 6 – 7 km/hr.

Load carriage ability is not well predicted by unloaded running. Knapik (1990) found a correlation of 0.16 between 3.2-km run times and 20-km loaded march times. The reason is that a slight body build is well-adapted to unloaded running, but it is not adapted to load carriage, particularly as loads become heavy. Larger people tend to have a greater lean body mass which helps to support and move the load carried (Teves et al., 1985; Harman et al., 1988; and Myers et al., 1983). Bilzon et al., (2001) tested the hypothesis that simple field tests of aerobic fitness are not predictors of load-carrying performance and personnel with greater body mass are more able to perform occupational relevant load-carrying tasks. Their data showed that there is no relationship (r = 0.12) between relative VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$), determined with an unloaded running test, and exercise tolerance time (load 18 kg speed 9.5 km/h) during load-carrying tasks. Exercise tolerance time was moderately strong related to body mass (r = 0.69, $p<0.05$) and lean body mass (r = 0.71, $p<0.05$).

Several studies have investigated the relationships between performance on loaded march tasks and various physical tests. The test batteries were reasonable comprehensive in these studies, encompassing all the aspects of physical capability. Measurements of anthropometry and body composition, strength, endurance and aerobic power provided the best predictors of marching performance (see Table 3-7).

Table 3-7: Summary of Studies Reporting Relationships between Performance on Loaded March and Physical Tests

March Task	Author/Subjects	Physical Tests – Best Predictors
Time for 16 km, 18-kg load	Dziados et al., 1988 49 males	Fat, muscle mass, isok knee flex end, isok knee ext end, isok knee flex strength, isok knee ext strength, VO_2max
Time for 12 km, 46-kg load	Mello et al., 1988 28 males	Fat, muscle mass, ILM183, isok knee flex end, isok knee ext end, isok knee flex strength, isok knee ext strength, VO_2max
Time for 20 km, 46-kg load	Knapik et al., 1990 96 males	Height, mass, fat, ffm, isom knee ext, isom hand grip, isom upper torso, isom trunk flex, isom knee flex, isom ankle plantar flex, isok knee ext, isok knee flex, arm Wingate, leg Wingate, VO_2max
Max load at 6.4 km/hr on treadmill	Rayson et al., 1993 and 1995 18 females	Height, mass, fat, ffm, age, isom trunk flex, isok knee ext, isok hip ext, isok plantar flex, isok shoulder ext, isok shoulder adductors, knee flex.ext endurance, VO_2max
Time for 3 km, 34-kg load	Frykman and Harman, 1995 13 males	Height, mass, fat, ffm, shoulder diameter, squat endurance, VO_2max
Incremental march protocol load 25 – 62.5 kg, speed 6 – 7 km/hr	Dijk, 1996 160 males	Height, ffm, shoulder height, skelet weight, isom lifting force 140 cm and 90 cm, isok shoulder press, isok squat, isom leg press, VO_2max cycling, VO_2max arm cranking, Cooperscore
Incremental march protocol load 25 – 62.5 kg, speed 6 – 7 km/hr	Dijk 1996 80 females	Ffm, mass, isok flex trunk, isok squat, isok bench press, isok shoulder press, isom lifting force 90 cm, isom leg press, isom arm ext, isom trunk ext, VO_2max cycling, VO_2max arm cranking,
Incremental march protocol 7.5 kg / 4 min above body weight 3 km/hr 5% grade	Koerhuis et al., 2005	Height, body weight, ffm, isom leg extension, isom trunk flex, isom trunk ext, dyn squat, dyn shoulder press

Legend:

ext = extension

ffm = fat free mass

flex = flexion

ILM = incremental lift machine

isok = isokinetic

isom = isometric

UP = upright pull

Amongst the strength tests, several isometric and isokinetic variables were among the best predictors. Isometric upper torso and trunk flexion strength (Knapik et al., 1990; and van Dijk, 1996), isokinetic upper torso strength (van Dijk, 1996), isokinetic knee flexion (Dziados et al., 1987; and Mello et al., 1988), knee extension strength (Mello et al., 1988) and plantar flexion (Rayson et al., 1993 and 1995) are correlated to load march performance. Core stability, strength in the core region of the body, and strength in the extension chain seems to be important for loaded marching.

Measurements or estimates of aerobic fitness were amongst the best predictors in a number of studies. The highest correlation values were recorded between marching performance and absolute VO_2max

(Frykman and Harman 1995) with a value of 0.84 ($p<0.05$). However the distance of this march task was only 3 km. In other studies, moderate correlation values of between 0.4 and 0.6 were observed between march time and aerobic fitness.

Several studies attempted to produce multiple regression models to predict marching performance. The model of Rayson et al., (1995) for maximum tolerable load included VO_2max, ankle plantar flexion, age and body fat, producing an r^2 value of 0.71. Dijk et al., (1996) used a progressive loaded march test. For men, body height, isometric trunk extension strength, 12-min run score, and isokinetic squat strength were included in their multiple regression model, with an explained variance of 56%. In women, static lift force at 40 cm, number of press-ups in two minutes, lean body mass, number of sit-ups, and bench press isokinetic strength are predictive variables in the multiple regression equation with an explained variance of 66%.

3.6 TESTING OF MARCH PERFORMANCE

Testing the physical fitness and readiness of soldiers and units is essential for military practice and training. The most important reasons are shortly discussed in the following list (Gore, 2000).

1) **Identify Weakness**. The main purpose of testing is to establish where a soldier's strengths and weaknesses lie. This involves identifying the major underlying fitness components required for performance of the task and then conducting tests that measure these components. A training program that is geared towards the development of the individual soldier and/or unit can then be prescribed.
2) **Monitor Progress**. By repeating appropriate tests at regular intervals, the unit commander can obtain a guide to the effectiveness of the prescribed training program. A "one-shot" testing experience provides very little benefit either for the soldier or the commander and is strongly discouraged.
3) **Provide Feedback**. The feedback of a specific test score often provides incentive for a soldier and unit to improve in a particular area, as he or she knows that the test will be repeated at a later date.
4) **Educate Commanders and Soldiers**. A testing program can provide commanders and soldiers with a better understanding of the task and the attributes that are required to be effective. This facilitates systematic planning of soldier development programs.

O'Connor et al., (1994) argued that one of the most difficult aspects of physical fitness training at unit level is the planning of the program. He recommended a 6-step method for use in developing and planning unit physical fitness programs. It is oriented towards full-time operational battalion and company level units.

Step one is to define the training objectives based on mission requirements. A realistic goal for road marching with loads in light infantry units is, in their opinion, to work up to carrying 45 percent of body weight for a distance of 16 km in four hours. At the end of the march, the soldiers should be able to perform critical soldier skills (O'Connor et al., 1990). Step 2 and 5 is to analyse and evaluate unit and individual fitness and task performance. Before training can be effectively planned, the current level of fitness for the unit as a whole and for individual soldiers must be known. This will identify the areas where training is needed. Evaluation and observation of soldier performance of mission-related tasks will provide information about unit and individual fitness. It is appropriate to conduct mission-specific events, such as a road march for a set distance with a prescribed load to obtain a complete picture of unit physical conditioning as it relates to military task performance. Reassessment of unit and individual fitness should be performed for determining the effectiveness of the physical training program. Testing of physically demanding mission task performance is important to evaluate the effectiveness of the physical training program.

NATO RSG-4 (1986) defined physical fitness as the capacity to perform physical activities. It consists of three components or types of fitness based on the nature of the task and the predominant source of energy for that activity. These three fitness components are muscular strength, muscular endurance, and aerobic fitness.

The military uses two approaches to monitor and evaluate the performance and physical fitness of soldiers and units. One approach is to test on a regular basis the physical capability of certain fitness components, such as sit-ups, push-ups for the muscular endurance component, or the 12-min run and 2-mile run for the aerobic fitness component. For a complete overview of military tests used by various NATO nations, the reader is referred to the review in the final report and resource manual on military physical training (von Restorff, 1994).

The second approach is to develop tests, which actually simulate the task event. Several NATO nations have developed task tests to monitor task performance and evaluate training programs. Knapik et al., (2004) recommended a number of criteria in selecting appropriate tests for use by the Defence organisation. The tests should be valid, reliable, non-discriminatory in nature, associated with occupational indicators like job performance, injury risks and attrition/job failure risks and administratively practical.

Several road marching tests are currently in use by NATO-countries. Basically three types of tests are used:

1) Loaded marching time trials with loads varying between 5 to 68 kg over distances of 5 to 20 km. The loads are chosen to approximate the different types of combat loads – Fighting Load, Approach March Load and Emergency Approach March Load. Table 3-8 outlines field tests for loaded marching and performance data.
2) Incremental loaded road marching test. A good example is the test developed in the Netherlands in which the intensity was increased by manipulation of the load and speed. Loads of 25 kg, 38 kg, and 50 kg were carried in sequence at a speed of 6 km/h; a 63 kg load was carried at 6, 6.5 and 7 km/h. The performance measure was distance covered until the soldier was unable to maintain the pace (Dijk, 1996).
3) A submaximal test in which a pass/failure scores based on operational task or job specialities are imposed (Rayson, 1997; Lee, 1992; and Koerhuis et al., 2004).

The important factors for road marching are speed of traverse, load carried, body mass and terrain. In military training and operational settings the loaded-march tasks vary greatly. Depending on the task variables a different mix in fitness components – muscular strength, muscular endurance and aerobic fitness – is stressed. This is related to the involvement of the different energy producing systems. In this area no systematic research has been conducted. One could expect that patrolling and ruck-sack marching over longer distances or at higher speeds will predominantly stresses the aerobic component of fitness. Carrying heavier loads during road marching will also stress the muscular endurance component. In testing soldiers the specific demands of the mission – in regards to load carried, distances, terrain, speed of movement – should be kept in mind. The physical requirements of the tests have to be valid for the physical task in the field. In addition a loaded road marching test needs to be realistic, reliable, challenging and standardised.

Table 3-8: Field Tests for Loaded Marching and Performance Data

Study	Loaded March Test Time-trial	Performance	Subjects	Characteristics
Rasch et al., 1964	4.8 km – 14.5 kg track sand and clay, rolling terrain	35.1 ± 2.6	Male N = 14	4.8 km run 29.6 min ± 1.5
Dziados et al., 1987	16 km – 18 kg asphalt road, one steep hill, rolling hills 3 km	145 min ± 19	Male N = 49	Height 176 cm ± 6.7 Weight 73.5 kg ± 9.8 BF 15.5 kg ± 6.3
Knapik et al., 1996	5 km – 19 kg paved roads no grade	44.7 min ± 2.8	Female N = 21	Height 167 cm ± 7.9 Weight 67.0 kg ± 8.9 BF 27.6 kg ± 7.3 3.2 km run 20.3 min ± 1.7
Harper et al., 1997	10 km – 18 kg 10 km – 27 kg 10 km – 36 kg road not specified	89.5 min ± 10.6 92.2 min ± 10.2 108.3 min ± 13.8	Male N = 19	Height 172 cm ± 6.8 Weight 71.9 kg ± 12.3 BF 13.5 kg ± 4.4 3.2 km run 15.6 min ± 1.9
Harper et al., 1997	0 km – 18 kg 10 km – 27 kg 10 km – 36 kg	111.3 min ± 11.4 116.5 min ± 16.5 138.3 min ± 20.4	Female N = 15	Height 163 cm ± 4.8 Weight 62.2 kg ± 5.4 BF 25.9 kg ± 6.5 3.2 km run 19.2 min ± 1.7
Knapik et al., 1993	20 km – 34 kg 20 km – 48 kg 20 km – 61 kg dirt (8 km) and paved roads (12 km, no grade	171 min ± 31 216 min ± 34 253 min ± 26	Male N = 15	Height 176 cm ± 5.5 Weight 87.8 kg ± 10.3 BF 21.0 kg ± 3.6 3.2 km run 13.7 min ± 1.2
Rayson, 1997	12.8 km – 15 kg 12.8 km – 20 kg 12.8 km – 25 kg flat bitumen	98 min ± 12.4 102 min ± 11.1 103 min ± 10.6	Male N = 304	Height 176 cm ± 6.3 Weight 87.8 kg ± 10.3 VO_2max 3.6 l/min ± 0.46
Rayson, 1997	12.8 km – 15 kg 12.8 km – 20 kg flat bitumen	120 min ± 15.6 126 min ± 11.0	Female N = 75	Height 164 cm ± 6.7 Weight 62.6 kg ± 7.9 VO_2max 2.4 l/min ± 0.33
Pandorf et al., 2001	3.2 km – 14 kg 3.2 km – 27 kg 3.2 km – 41 kg paved, four small hills	25.7 min ± 2.6 30.7 min ± 3.7 36.9 min ± 4.8	Female N = 12	Height 166 cm ± 6.5 Weight 61.3 kg ± 6.5 BF 25.7 kg ± 3.2 VO_2max 3.0 l/min ± 0.5 3.2 km run 17.0 ± 1.1

3.7 TRAINING FOR MARCHING

Loaded marching is an essential task in military operations. Nevertheless, only a limited number of studies have been executed to investigate the improvement in load carriage attributable to physical training (Table 3-10).

Kraemer et al., (1987) evaluated the effect of resistance training and aerobic fitness training on a maximal effort 3.2 km load bearing task with a load of 45 kg. Soldiers were randomly assigned to one of four training groups: group 1 upper and lower body resistance training and high intensity endurance training; group 2 upper body resistance training and high intensity endurance training; group 3 upper and lower body resistance training only; group 4 high intensity endurance training only. Training took place 4 times per week for 12 weeks.

It was found that when either upper- or lower-body resistance training was combined with high intensity endurance training, load carriage performance time significantly improved. However, no improvements were evident when subjects participated in either resistance training alone or high intensity endurance training alone (Table 3-9). These results demonstrate that a combination of resistance training and aerobic fitness training is necessary to improve performance on a load bearing task of a short duration and high intensity in nature. Programs that only focus on aerobic fitness or muscular strength were not effective.

Table 3-9: Changes in Load Carriage Performance as a Function of Type of Training

Training Group	Pre-training	Post-training	Change (%)
Group 1 Total body resistance + aerobic	25:18	21:45	16
Group 2 Upper body resistance + aerobic	28:37	25:32	12
Group 3 Total body resistance only	29:27	28:12	4
Group 4 Aerobic only	30:32	30:31	0

Table 3-10: Improvements in Loaded March Performance by Training

Author	Population	Testing	Training Program	% Improvements
Kraemer 1987	Male soldiers N = 35	Time trial 3.2 km, 44.7-kg load	12 weeks 1) Aerobic 2) Aerobic – Strength 3) Strength	 0 14 4
Knapik et al., 1996	Female soldiers N = 21	Time trial 5 km, 19-kg load	14 weeks Resistance + Running	4
Harman et al., 1997	Female soldiers	Time trial 3.2 km, 34.1-kg load	24 weeks Resistance, running, backpack hiking	33
Kraemer et al., 2001	Female soldiers N = 93	Time trial 3.2 km, 34.1-kg load	6 months 1) Total body resistance 2) Upper body resistance 3) Field 4) Aerobic	 8 10 8 NS
Visser et al., 2005	Male soldiers N = 76	Incremental march test load 25 to 65 kg speed 6 – 7 km/h	8 weeks Strength and Aerobic 1) Load 20 – 32% BW, 8 – 19 km per session, weekly 2) Load 20 – 32% BW, 8 – 19 km per session, bi-weekly 3) Load 45 – 67% BW, 4 – 6 km per session, weekly 4) Load 45 – 67% BW, 4 – 6 km per session, biweekly	 7 6 18 9

Kraemer et al., (2001) examined the effects of 6 months resistance training on strength, power, and military occupational task performance in women. Untrained women, mean age 23 years, were placed in total- or upper-body resistance training, field, or aerobic training groups. Two periodized resistance training programs (with supplemental aerobic training) emphasised explosive exercise movements (3 – 8 RM training loads), whereas the other two emphasised slower exercise movements using 8 – 12 RM loads. The field group performed plyometrics and partner exercises.

Women who participated in the total body and upper body resistance training program, as well as field training, showed significant improvement in 3.2-km run times with a 34.1-kg load. On average the improvements were 17%, or 350 seconds. Aerobic training alone did not improve 3.2-km loaded-run performance times, indicating that a combination of strength/power and aerobic endurance was vital for improvement in this type of task. It is possible that enhanced load carriage may be due to improved postural support from stronger upper-body musculature, which improves the mechanics of loaded locomotion. Their data show that performance can also be enhanced in young untrained women without such direct practice. This may help in potentially reducing the incidence of overuse injuries related to task specific training.

Knapik et al., (1990) studied the effectiveness of different training programs to improve performance on a 20-km road march while carrying a total load of 46 kg. The training programs were similar, consisting of endurance training, resistance training, interval training and callisthenic exercises, except for the amount of loaded road march training. Four groups were formed: no road marching, road marching once, twice, and four times a month. Road marching was progressive with respect to the load (0 – 34 kg), and distance (8 – 16 km). There was no change from pre- to post-training in load carriage performance for any of the groups. This finding was attributed by the authors to longer rest breaks and warmer ambient temperature during post-training test period. However groups that performed either 2 or 4 loaded road marches per month during the training period covered the 20-km course significantly faster (43 min or 12%), than groups that trained either none or 1 loaded road march per month.

The criterion road march task was extremely strenuous, according to the NCOs. They commented that it was the most strenuous road march they had ever performed. On average the heart rate during the road march was 135 beats/min or 68% heart rate max which correspondents to 53% of maximal oxygen uptake (Londeree, 1976). The results indicate that road marching twice a month with progressively increasing loads is as beneficial as marching 4 times a month. Soldiers in the 4 marches a month group complained of the frequency of the marches as it interfered with other training requirements. The authors suggest that when planning training schedules units should regard 2 times per month as a minimum frequency for road march training. The results also support the specificity of training. Despite the fact that all groups performed a physical training program designed to improve the major components of physical fitness, only groups training at least twice a month were faster on the post-training march.

Knapik and Gerber (1996) examined the effect of a combined resistance and aerobic training program on manual material handling tasks and on a 5 km, 19 kg, load carriage march of female soldiers. They trained for 14 weeks, performing progressive resistance training 3 days per week and running with interval training 2 days per week. They improved their maximal effort road march time over 5-km distance, carrying a 19-kg load mass by 4%.

Harman et al., (1997) studied the effect of a 24-week physical training program that included weightlifting, running, backpack hiking and special drills on a 3.2-km run/walk performance among women carrying a 34.1-kg load, and found a 33% improvement in speed.

Loaded marching performance is an important task activity of military personnel. The optimum training to improve marching performance appears to be a combination of resistance training, endurance training and task repetition (Kraemer, 1987; and Kraemer, 2001). However, for each soldier, the specific area of relative deficiency may be in either muscle strength or aerobic endurance. Perhaps a more effective approach to improve loaded march performance would be to prescribe training programs focused on either resistance or endurance training, based on each individual's pre training performance.

Williams et al. (2004) explored the possibility of training diagnosis for a 3.2-km loaded march with a 25-kg load. Fifty men trained for 10 weeks using either:

i) Running, marching, and endurance-based circuit training; or

ii) Running, marching, and resistance training.

The march was performed before and after training, and other measurements related to loaded marching were conducted before training only. Each group was ranked by improvement in the loaded march, and divided into significantly different subgroups of 'good' and 'poor' responders (improvements approximately 20% vs. 10%). For the circuit-training group, stronger subjects with lower endurance responded better to the program. The resistance-training group tended to show the opposite effect. Recruits with a better endurance and lower strength capacity tended to respond better to the resistance-training program.

Traditionally, training for loaded marching was mainly comprised of long and extensive walks. This "tradition" is time-consuming and prone to injuries (Koplan et al., 1982; and Marti et al., 1988). However, if strength appears to be the limiting factor, short and intensive road march training might be beneficial and worth looking at.

Visser et al., (2005) examined training effects of a traditional method of loaded march training (long distance and moderate load) compared to a method based on short multiple bouts of marching (short distance and heavy load). In addition, the effect of training frequency (twice or four times a month) was studied. Fifty male and female officers of the Royal Military Academy participated in an eight-week training study. Before and after training they measured: anthropometry (body weight, height, percentage body fat), strength, aerobic endurance (shuttle-run test), a 3.2-kilometres speed march, and an incremental loaded march test. The speed march protocol was based on a 2 minutes of running and 1 minute of walking interval, carrying an external load of 17.5 kilogram. The loaded march test started at a load of 25 kg for men and 15 kg for females and was increased every 1000 meters (10 minutes) by 12.5 kg up to a total weight of 62.5 kg. Marching speed commenced at 6 km/hr, and was consecutively increased by 0.5 km/h every 1000 meters until exhaustion. All participants followed a general training program that included two training sessions per week consisting of both aerobic endurance and resistance training. In addition four marching groups were formed.

For groups 1 and 2 (duration program) march training load increased from 20 to 32% of the individual bodyweight for women and 25 to 40% for men. The training march distance increased from 8.3 km (90 min) to 16.5 km (180 min) at a speed of 5.5 km/h. For groups 3 and 4 (intensity program) training load increased from 35 to 55% of the individual bodyweight for women and 45 to 67.5% for men. The march distance increased from 4.1 km (3 bouts of 15 min) to 5.5 km (4 bouts of 15 min). Training groups 1 and 3 marched every week and groups 2 and 4 marched once every two weeks. The general physical training was effective. Overall strength and aerobic endurance increased significantly (20% and 7% respectively) for the total population. Time to complete a 3.2 km speed march with a total load of about 17.5 kg, decreased (5%) significantly. Increments in performance on the incremental loaded march test were related to the training program. The intensity programs were twice as effective as the duration programs (13.5 vs. 6.5%). March training once a week was more effective than bi-weekly march training (12.6% vs. 7.4%). Total time needed for the march training was very different between the training programs. Group 1 (intensity program weekly) trained 7 hours, group 2 (intensity program bi-weekly) 3.5 hours, group 3 (duration program weekly) 18 hours and group 4 (duration program bi-weekly) 9 hours.

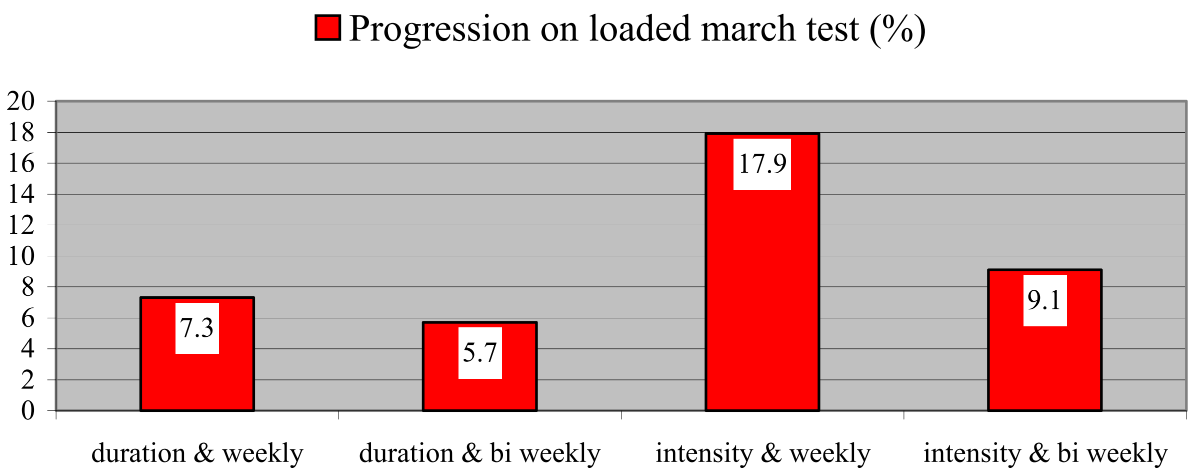

Figure 3-2: Improvements in Loaded March Performance as a Function of Type of Physical Training. (Visser et al., 2005)

It was concluded that an eight-week training program increased strength, aerobic endurance, speed march performance and loaded march performance of a moderate to well-trained group of officers at the Royal Military Academy. Based on effectiveness and training time, a 10-day training cycle for march training was advised.

Loaded march performance (load carriage) is an important duty of military personnel, and the optimal training to improve performance appears to be a combination of resistance training and lower body endurance training (Kraemer, 1987 and 2001). Both aerobic endurance and resistance training are forms of general training. Some task specific training by loaded road marching is probably needed to meet specificity requirements (McCafferty, 1977), but excessive marching may be costly in terms of training time and increased risk of injuries (Koplan et al., 1982; and Marti et al., 1988). The study of Visser et al., (2005) indicates that depending on the operational requirements, short but intensive training is a very cost effective training approach and the benefits in terms of progress in road marching performance with heavy weights are substantial. In the Netherlands a 10-day cycle for road march training has been implemented.

3.8 INJURIES RELATED TO MARCHING

Medical problems and injuries associated with load carriage can adversely affect an individual's mobility, and in military operations, reduce the effectiveness of an entire unit. Overuse injuries associated with strenuous marching are primary medical problems for recruits during basic training and for soldiers in infantry units. Ross (1993) review overuse injuries during basic military training and found that, among recruits participating in 8 weeks of basic training, the reported incidence of marching-related injuries is as high as 60 – 70%.

Knapik et al., (1992) found that 24% of infantry soldiers who participated in one road march while carrying heavy external loads suffered an overuse injury. Marching overuse injuries can impair function and subsequently impede performance in strenuous activities.

From epidemiological reports, common types of injuries include: blisters, plantar fasciitis, achilles tendonitis, shin splints, stress fractures (most commonly in the tibia and metatarsals), anterior compartment syndrome, chondromalacia patellae and low-back strain. Factors commonly implicated in marching injuries include load, excessive fatigue, terrain, footwear and amount of hiking (Volpin et al., 1989; Knapik et al., 1992; and Ross, 1993).

Vogel et al., (1994) reviewed injuries related to military physical training. Military physical training, including road marching, incurs a risk for musculoskeletal injuries. Factors or conditions, which place military personnel at risk for musculoskeletal injuries during physical training can be divided into two categories: extrinsic and intrinsic, i.e. those outside the individual and those within the individual. Jones (1983) produced a list of most common identified classes of risk factors. Most of these factors are also related to the incidence and severity of loaded march related injuries.

Extrinsic

- Training program parameters;
- Footwear; and
- Training surface.

Intrinsic

- Initial low level of fitness/inactivity;
- Anatomical anomalies;
- Inappropriate flexibility;
- Excess body fat;
- Gender and age;
- Health factors; and
- Prior injury history.

Knapik et al., (1996) reviewed the literature on prolonged load carriage and medical aspects. They noticed some common patterns of injuries with the majority of the injuries involving either the lower extremities or the back. The major load carriage related injuries are foot blisters, metatarsalgia, stress fractures, knee pain, low-back injuries, rucksack palsy, local discomfort and fatigue during load carriage. Table 3-11 gives an overview of the injuries and potential preventive measures.

Table 3-11: Common Injuries Associated with Load Carriage, Risk Factors and Preventive Measure (Adapted from Knapik et al., 1996 and 2004)

Injury	Risk Factor	Preventive Measure	Authors
Foot blisters	Carrying heavy loads	Lower carried loads Load distribution more evenly around body centre of mass	Knapik et al., 1993; and Reynolds et al., 1990
	Moist skin	Acrylic, nylon or polyester inner sock; thick, snug, dense weave outer sock Wear polyester sock inside a very thick wool/polypropylene sock Antiperspirants	Akers and Sulzberger, 1972; and Knapik et al., 1995
	Frictional forces	Spenco shoe insoles	Smith et al., 1985; and Spence and Shields, 1968
	Skin vulnerability	Precondition feet through physical training and road march practice	Knapik et al., 1995

Injury	Risk Factor	Preventive Measure	Authors
Metatarsalgia	Walking with heavy loads	Precondition feet through physical training and road march practice Reduce load mass and volume of training	Kinoshita, 1985
Stress fractures	Female gender	Precondition feet through physical training and road march practice	Brudvig et al., 1983; and Jones et al., 1989
	White ethnicity	–	Brudvig et al., 1983
	Older age	–	Brudvig et al., 1983
	Taller body stature	–	Gilbert and Johnson, 1966
	Prior physical inactivity	Precondition feet through physical training and road march practice	Gardner et al., 1988; and Gilbert and Johnson, 1966
	Load carry distance	Gradual onset in the intensity and volume of weight bearing exercise	Jones et al. 1989; and Vogel et al., 1994
Knee pain	Load carriage	Lower extremity strengthening and stretching	Dalen et al., 1978; and Knapik et al., 1992
Low-back injuries	Heavy loads	Load distribution more evenly around body centre of mass Reduce load mass Trunk and abdominal strengthening	Reynolds et al., 1990
Rucksack palsy	Heavy loads, load distribution causing compression by shoulder straps	Framed rucksack Use of hip belt on rucksack Load shifting using strap adjustments	Bessen et al., 1987; and Wilson, 1987
	Longer carriage distances	Lower training distances, aim at intensity in stead of volume	Bessen et al., 1987; and Reynolds et al., 1990
Local discomfort and fatigue	Heavy loads and long distances	Change training road marches; take the load off the soldiers back	Dalen et al., 1978; and Knapik et al., 1991
	Design of the pack system	Wear pack with hip belts	Holewijn, 1990, and Holewijn et al., 1992

Measures to prevent injuries related to loaded carriage do not stand by themselves. They form part of what is called a sequence of prevention (Dijk, 1994). First the problem must be identified and described in terms of incidence and severity injuries. Then the factors and mechanism that play a part in the occurrence of the specific injuries have to be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of injuries. This measure should be based on the etiological factors and the mechanisms as identified in the second step. Finally the effect of the measures must be evaluated.

Vogel et al., (1994) mentioned a number of preventive strategies related to march injuries that have gained acceptance in the military:

- Gradual progressive increases in frequency, duration and intensity of aerobic training activities, including loaded marching;
- Adequate rest given between training sessions;
- Use of adequate shoes;

- Warming-up and stretching prior to exercise sessions;
- Run or speed march on soft, even surface; and
- Avoid excessive overtraining.

3.9 MARCH PERFORMANCE, GUIDELINES TO FIELD COMMANDERS

"*The fighting value of a soldier is in inverse proportion to the load he carries*" Cathcart et al., (1922).

Load carriage ability is a mission essential task for many soldiers. A common mission for Special Operations Forces is surveillance-reconnaissance. In this type of operations soldiers execute an airborne or sea insertion into a hostile area, conduct a road march to an objective site and perform observations or other information gathering activities. On completion of the mission the soldier walk to a pick-up site. The road march is a critical aspect of this type of operation and because of the equipment needed, soldiers typically carry very heavy loads. This equipment may include communication gear, weapon systems, site preparation material, subsistence items, and protective equipment (Kanapik et al., 1993).

Soldiers on manoeuvres or in combat operations are often required to traverse a variety of terrain, including thick brush, at self paced (rather than fixed-paced) velocities while carrying basic fighting and subsistence loads. Therefore, the capability of assessing and predicting troop mobility over a variety of terrains while carrying loads is an important military concern for combat operations (Evans et al., 1980).

Performance in the context of load carriage means:

- The ability to complete the road march as rapidly as possible; and
- The ability to complete essential soldiering tasks during and/or at the end of the march.

3.9.1 Ability to Complete the Road March as Rapidly as Possible

Shoenfeld et al., (1978) studied 20 trained young men (VO_2max 57 $ml \cdot kg^{-1} \cdot min^{-1}$) during road marches of 6 and 12 km with a back-pack load of 30 or 35 kg. The aim was to search for an optimum backpack load for short distances, which would enable a person to perform strenuous physical tasks later. The study suggests that the optimal back-pack load for healthy young men, marching at 6 km/h on a paved level road to be 30 kg for 12 km and 35 kg for 6 km. As criteria for acceptable carried load, they used heart rate during marching (<160 beats/min), serum glucose concentration maintained at its initial value, no change in post march aerobic power performance, no change in serum muscle enzyme concentration, and subjective rating of persons about the difficulties in performing the tasks.

Harper et al., (1997) examined the relative performance of men and women on a maximal effort load carriage task. Men were significantly faster, about 20%, than women in completing maximal effort marches of 10 km with loads of 18 kg, 27 kg and 36 kg. For both males and females, the march with the 36-kg load took longer to complete than with either the 18-kg or 27-kg load.

Female soldiers had difficulty maintaining a pace while carrying 36-kg load. They completed the first part of the march significantly faster than either the third or forth segment. Hughes and Goldman (1970) postulated that a weight of 40 – 50% of the body weight was tolerable during walking with an average speed of 5 km/hour. The 36-kg load was within this range for men, but it was higher for the female subjects (59% of female body weight). The females began the march at a pace of 5 km/hr, they were unable to maintain the pace.

Knapik et al., (1993) studied the road marching performance of soldiers carrying various loads. Subjects were 21 Special Forces Soldiers who performed individual road marches carrying three loads (34, 48 and

61 kg) in the large ALICE back pack (All-purpose Lightweight Individual Carrying Equipment). Loads were the total mass of equipment and clothing on the soldier's body. All marches were 20 km in length and soldiers were asked to complete the distance as rapidly as possible. Cumulative road-march times at each checkpoint are shown in Table 3-12. These road-march times are the total time, which includes rest times of 0, 3 and 5 minutes for 34-, 48- and 61-kg loads respectively.

Table 3-12: Descriptive Statistics on Cumulative Road-March Times on 20-km Marches with Different Loads

Load		4 km	8 km	12 km	16 km	20 km
34 kg	M	33	65	99	135	171
	SD	5	10	16	23	31
48 kg	M	40	80	124	171	216
	SD	7	11	18	28	34
61 kg	M	44	91	148	199	253
	SD	4	10	32	19	26

A planner can estimate the range of times in which a unit or 95% of the unit should be able to complete the foot march by manipulating the mean and standard deviation for a given distance and load. To get the extreme range for the fastest soldiers the planner multiplies the SD (standard deviation) by two and adds this value to the mean. To get the extreme range of the slowest soldiers the planner multiplies the SD by two and subtracts this value from the mean. The resulting values represent the range in which 95% of the soldiers should be able to complete the march. Knapik et al., (1993) illustrated this with the following example. Assume a soldier is wearing a 34 kg and needs to travel on foot 8 km as quickly as possible. The best estimate of his time is 65 minutes. The SD is 10 min and two times this value is 20 min. Adding and subtracting this value from 65 min shows that 95% of soldiers should be able to complete the march between 85 and 45 min.

They also developed a table to estimate how additional loads may affect maximum effort march times. Slopes of regressions of loads on march times are shown in Table 3-13. These slopes represents the changes in march times (min) for a given change in load (kg). Thus, if a soldier is travelling 16 km, 5 additional kg of load will increase the time to complete the march with 12 minutes.

Table 3-13: Slopes of the Regression of Load on March Time (Slopes Represent the Change in March Time for a Given Change in Load) (Knapik et al., 1993)

Distance (km)	Slope (min/kg)
0 – 4	0.4
0 – 8	1.0
0 – 12	1.8
0 – 16	2.4
0 – 20	3.0

These tables are of practical use for field commanders who want to make an estimation of total march times of their soldiers. However, cautions are appropriate with regard to the use of the tables (Knapik et al., 1993). The data was collected on Special Forces soldiers travelling in daylight on mixed paved and dirt roads and carrying loads between 34 and 61 kg. Therefore the tables are most appropriately used with this type of soldiers under comparable conditions. Mean physical characteristics and physical fitness of the soldiers in this study were: age 30 years, height 176 cm, body weight 88 kg, body fat 21%, 3.6 km run 13.7 min, estimated VO_2max 54 ml•kg^{-1}•min^{-1}. The loads in this study refer to total load. It is assumed that rucksack weights are 15, 28 and 42 kg, with the remainder of the loads being clothing and equipment carried outside the rucksack. The soldiers paced themselves to complete the 20-km distance. Thus the march times at distances shorter than 20 km may be slightly faster than what soldiers actually performed.

In their report (Knapik et al., 1993) produced a table to estimate maximal effort march times in different terrain (Table 3-14). The calculations are based on the equation of Pandolf et al., (1977).

Table 3-14: Estimates of Maximal Effort March Times in Different Terrain for Male Soldiers (Taken from Knapik et al.,1993)

		Distance (km)				
Terrain	**Load (kg)**	**4**	**8**	**12**	**16**	**20**
Dirt	34	35	68	104	141	179
	48	42	84	130	179	226
	61	46	96	156	209	266
Light Brush	34	36	71	108	148	187
	48	44	88	136	187	237
	61	48	100	162	218	276
Hard Pack Snow	34	38	74	113	154	195
	48	46	91	142	195	246
	61	50	104	168	226	188
Heavy Brush	34	40	80	121	165	210
	48	49	98	152	210	265
	61	54	112	182	244	310
Bog	34	44	87	133	181	229
	48	54	108	166	229	290
	61	59	122	198	267	339
Sand	34	48	94	143	195	248
	48	58	116	180	248	313
	61	64	132	214	288	366
Soft Snow (25 cm)	34	60	118	180	245	310
	48	72	145	225	311	392
	61	80	166	270	363	461

As loads increased, march times increased. This is in line with findings in both laboratory studies (Hughes and Goldman, 1970; Myles et al., 1979; and Patton, 1991) and field studies (Mello et al., 1988; and Knapik et al., 1993), showing that subjects self pace at slower velocities with heavier loads.

During military backpack activities endurance time is determined by several factors, such as VO_2max, strength, body temperature, musculo-skeletal strain, and muscle glycogen stores (Aunola et al., 1990; Edwards et al., 1972; Ekblom et al., 1968; Bergstrom et al., 1967; Holewijn, 1990; Hurley et al., 1986; and MacDougall et al., 1974). However the first two factors are believed to be the most important ones.

When requested to work hard for 1 – 2 hours at self-paced rates while conducting simulated military operations including carrying loads in the field, physically fit soldiers will select a relative oxygen uptake of 40 – 50% VO_2max (Hughes and Goldman, 1970; Soule and Levy, 1972; Evans et al., 1980; and Levine et al., 1982). Evans et al., (1980) reported that the rate of voluntary hard work depends upon aerobic capacity. The best predictor of speed on each terrain for this work of 1 to 2 hours duration is 45% VO_2max. Men and women worked at nearly the same percentage of their maximum aerobic power. The absolute energy costs for the males and females during the self-pacing marching activities were 549 W (472 kcal/h) and 365 W (314 kcal/h), respectively. For men, this is in agreement with the finding of Hughes and Goldman (1970) and Soule and Levy (1972) who reported that men self-paced at an energy expenditure of approximately 495 W (425 kcal/h) regardless of the specific terrain and external load.

Jorgensen (1985) reviewed the literature and, based on this, he suggested that the upper general acceptable tolerance limit for dynamic work over an 8-hour working day is to be 50% VO_2max in trained subjects. In this context, acceptable indicates that the work can be continued at a constant work pace throughout the day, without any change in homeostasis, e.g. no increase in arterial lactate concentration and heart rate.

Myles et al., (1979) evaluated self-pacing walking (Exercise Fastball, 204 km in 6 days) of French infantry males for more prolonged periods (6.5 hours per day for 6 days), which is reflective of the situation for the military in continuous operations. The soldiers maintained an average energy expenditure equal to 32% of VO_2max, or 384 kcal/h during the march. This energy expenditure is close to the 425 kcal/h suggested as the maximum hard work adopted voluntarily by physically fit young men (Hughes and Goldman, 1970; and Nag et al., 1978). Myles et al., (1979) concluded that fit young soldiers will self-pace at 30 – 40% VO_2max and will continue to do so for at least 6 days. Also, Saha et al., (1979) reported that 35% VO_2max could be considered as a reasonable relative workload for sustained physical activity of 8 hours in duration.

Therefore, it would seem reasonable to conclude that relative percent VO_2max selected for self-paced physical work may be closely related to the work duration. Levine et al., (1982) conclude from their literature survey that as the duration of exercises increases from 1 to 2.5 to 6.5 hours, individuals appear to select decreasing relative energy expenditure from 46 to 40 to 36% of VO_2max.

Table 3-15: Relative Intensity During Prolonged Self-Paced Hard Physical Exercise (Loaded Marching)

Duration of March (Hours)	Relative Intensity Self Paced % VO_2max	Energy Expenditure Male Soldier (kcal/hr)	Energy Expenditure Female Soldier (kcal/hr)
1	46	549	364
2.5	40	477	317
6.5	36	429	285

In military populations “normal” VO_2max ranges between 3.5 and 4.2 l/min with an average relative oxygen uptake of 53 ml•kg^{-1}•min^{-1} for male soldiers. For female soldiers VO_2max varies between 2.0 and 2.8 l/min with an average relative oxygen uptake of 44 ml•kg^{-1}•min^{-1} (Dijk, 1994). Using the 75 kg man as a model and 36% VO_2max as the energy expenditure rate over several days, the average male soldier could perform continuously (with some rest pauses) at an average energy expenditure rate of 429 kcal/h. The average female soldier with a body weight of 60 kg, could perform at an average energy expenditure rate of 285 kcal/h (1 l oxygen is 5 kcal).

If the march duration is about 2.5 hours the suggested energy expenditures are 477 and 317 kcal/h respectively for male and female soldiers. Based on the formula of Pandolf et al., (1977) possible combinations of speed and load for male and female soldiers are shown in Tables 3-16a and 3-16b.

Table 3-16a: Combinations of March Speed and Loads for March Duration of 2.5 Hours, Based on an Energy Expenditure of 477 and 317 kcal/hr for Respectively Male and Female Soldiers (Pandolf et al., 1977, blacktop road). Soldiers are supposed not to be exhausted at area of destination

Male Soldier Body Weight 75 kg	Female Soldier Body Weight 60 kg
5.5 km/h load 36 kg	5.5 km/h load 17 kg
5.0 km/h load 46 kg	5.0 km/h load 26 kg
4.5 km/h load 55 kg	4.5 km/h load 34 kg
4.0 km/h load 63 kg	4.0 km/h load 41 kg

Table 3-16b: Combinations of March Speed and Loads for March Duration of 6.5 Hours, Based on an Energy Expenditure of 429 and 285 kcal/hr for Respectively Male and Female Soldiers (Pandolf et al., 1977, blacktop road). Soldiers are supposed not to be exhausted at area of destination

Male Soldier Body Weight 75 kg	Female Soldier Body Weight 60 kg
5.5 km/h load 27 kg	5.5 km/h load 8 kg
5.0 km/h load 38 kg	5.0 km/h load 18 kg
4.5 km/h load 47 kg	4.5 km/h load 27 kg
4.0 km/h load 55 kg	4.0 km/h load 35 kg

Speed of movement, in combination with the weight of the load carried, are important factors in causing exhaustion. Figure 3-3 shows the length of the time that work rates can be sustained before soldiers become exhausted. A burst of energy expenditure of 900 to 1000 kcal per hour can only be sustained for 6 to 10 minutes. A level of 300 kcal/min energy expenditure appears to be a critical value for prolonged work over 8 – 9 hours for a soldier of about 60 kg with a maximal oxygen uptake of about 2.6 litres • min^{-1} (see also Table 3-15).

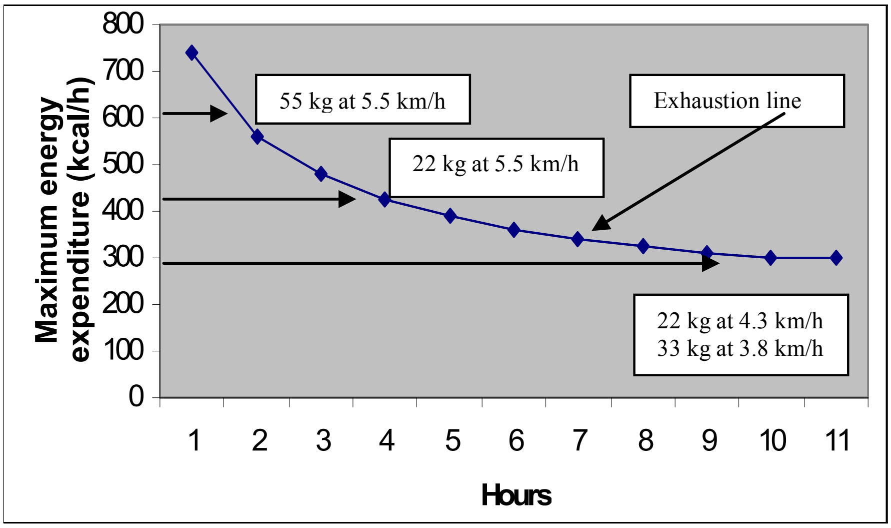

Figure 3-3: Endurance Time vs. Work Rates (Based on FM 21 – 18 Department of the Army, 1993).

When carrying loads during approach marches a soldier's speed can cause a rate-of-energy expenditure of over 300 kcal per hour. March speeds must be reduced when loads are heavier to stay within reasonable energy expenditure rates. Fighting loads must be light so that the bursts of energy available to a soldier are used to move and to fight, rather than to carry more than the minimum fighting equipment (Department of the Army US, 1993).

Based on a sustainable energy expenditure level of 429 or 300 kcal/hour for prolonged work (about 36% of VO_2max), combinations of load carried and velocity can be calculated using the equation of Pandolf et al., (1977). Figures 3-4a and 3-4b show speeds that are sustainable with given loads, which results in an energy expenditure of 429 and 300 kcal per hour. These energy expenditure rates are representative of average male and female soldiers who have to traverse to the area of destination in about 6 to 8 hours, and who are still physically able to do their assigned tasks.

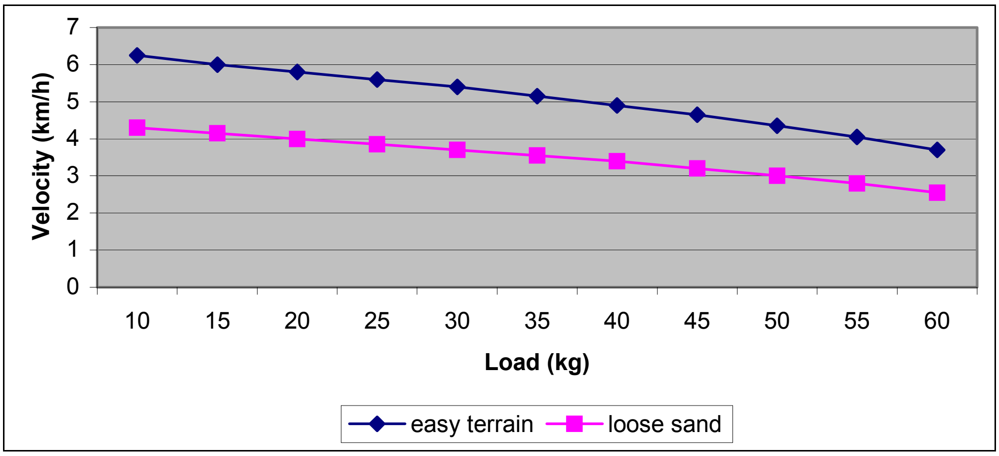

Figure 3-4a: March Speeds and Loads at an Energy Expenditure of 429 kcal Per Hour, Soldier Body Weight 75 kg, Terrain Factor 1 (black top) vs. 2.1 (loose sand) (Pandolf et al., 1977).

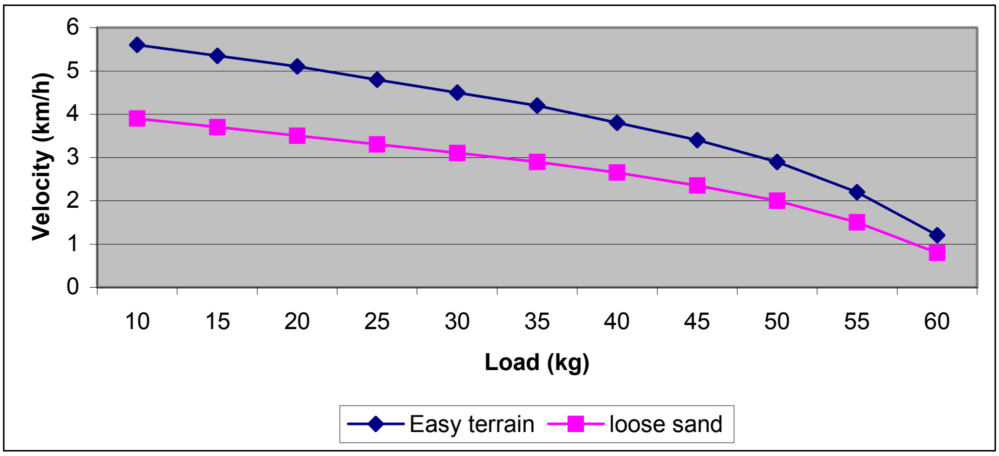

Figure 3-4b: March Speeds and Loads at an Energy Expenditure of 300 kcal Per Hour, Soldier Body Weight 60 kg, Terrain Factor 1 (black top) vs. 2.1 (loose sand) (Pandolf et al., 1977).

As velocity increases, the efficiency of walking becomes lower than running. Above a speed of about 8 km per hour unloaded running is more efficient than unloaded walking (Margaria et al., 1963; and Keren et al., 1981). With a load of 20 kg, the average load in practice during marches, the breaking point is

7.8 km per hour (Keren et al., 1981). Smaller subjects had a breaking point between walking and running (with 20-kg load) at a lower speed (6.5 km/h) than more robust subjects (8.3 km/h). It is of practical importance that without load and at speeds less than 8.2 km/h, it does not matter whether the individual runs or walks. At higher speeds the difference is critical, and soldiers are liable to be exhausted rapidly if they do not run but continue to walk. This effect is more pronounced while carrying a load, especially if the load constitutes a high percentage of body weight.

The study of Koerhuis et al., 2005 studied the relationships between endurance time and load carriage with very heavy loads. The soldiers carried loads relative to individual determined maximal load carrying capacities (MLCC). In addition the best predictors of endurance time were determined.

To determine MLCC the load carried was increased by 7.5 kg every 4 minutes until exhaustion, starting with a load that equals body mass. The marching velocity and gradient were kept constant at 3 km/h and 5%, respectively. Endurance time was determined carrying 70, 80 or 90% of MLCC. Twenty-three male combat soldiers participated. Mean anthropometric data of their subjects were: height 179.8 cm (SD 6.1), body weight 80.8 kg (SD 7.9), fat percentage 16.6 % (SD 4.5).

Maximal load carriage capacity was on average a 102.6 kg (SD 11.6). A significant difference was found in endurance times between the different load conditions at 70, 80 and 90% of MLCC (Table 3-17). Endurance time decreased with increased load.

Table 3-17: March Endurance Times with Different Load Conditions

% of MLCC	Load Carried ± SD	Endurance Time ± SD
70% MLCC	72.5 kg ± 7.5	40.9 min ± 17.2
80% MLCC	81.0 kg ± 8.8	24.5 min ± 7.4
90% MLCC	93.3 kg ± 10.1	17.7 min ± 5.8

This study indicated that during marching with heavy loads, soldiers need to be individually loaded, relative to their own MLCC. This loading strategy resulted in a more homogeneous march performance, endurance time, for a group of soldiers, compared with carrying the same absolute load by each soldier. The march performance with each soldier carrying the same absolute load (80 kg) load varied between 11.3 and 65 min (mean 30.2 minutes SD 16.1). Redistributing the load according to MLCC resulted in endurance times, varying between 13.4 and 45 min (mean 28.3 SD 8.8). In military operations the weakest person determines the group performance. Although the average endurance time remained the same, the standard deviation was twice as low, implying that the group performance improved markedly by redistributing the load according to MLCC. Redistributing the load according to body weight, which is a more practical criterion in the field, is also a better option than loading soldiers with the same absolute load. The average endurance time was 26.8 min with a standard deviation of 11.3 min, range 13.4 and 50 minutes.

3.9.2 The Ability to Perform on Essential Soldiering Tasks During and/or After the March

How well soldiers are able to perform military tasks during load carriage or after completion of a load carriage traverse is an issue vital to military operations. Performance appears to be influenced by load, volume and load distribution.

Knapik et al., (1990) studied soldier performance and mood states following an extremely strenuous road march of 20 km, carrying a total load of 46 kg. Mean physical characteristics of the soldiers participating were: age 21 years, height 178 cm, body weight 76 kg and body fat 15.7%. Following the march, fatigue was elevated 82% and vigor decreased 38% as measured by the POMS (Profile of Mood States).

Compared to pre-march values, post-march marksmanship accuracy decreased 26% for number of target hits and 33% for distance from the centroid of the target (distance of 25 m). The decrements in marksmanship are presumably due to small movements of the rifle resulting from fatigue of the upper body muscle groups, an increase in body tremors due to fatigue or elevated post-exercise heart rate or respiration.

The grenade throw and vertical jump tests were used to evaluate explosive strength and power. Maximal grenade throw distance decreased 9%, and there was no change in maximal vertical jump height. Activities like road marching do not appear to affect leg power.

It was concluded that when soldiers perform a strenuous road march with a heavy load, leaders could expect mood changes and decrements in essential soldier skills, which may significantly impact on military effectiveness.

Amos et al., (2000) reported on the physiological and cognitive performance of soldiers undertaking routine patrol and reconnaissance activities. Data were obtained during a patrol and a reconnaissance exercise followed by a short assault. During the patrol of 1.30 hrs, soldiers carried a total weight of about 30 kg. During the reconnaissance phase of 1.15 hrs, soldiers only carried webbing with water bottles and personal weapon. Oxygen consumption during the patrol was in the range of 2.5 to 3.2 litres – min^{-1}. Peak VO_2 levels greater than 3.0 litres • min^{-1} during patrol indicate that the soldiers were working hard. The VO_2 levels during the reconnaissance phase were 1.5 to 2.0 litres • min^{-1} and were generally lower than those during patrol. The soldiers displayed no evidence of deterioration in cognitive performance measured by a speed and accuracy test and State-Trait Anxiety Inventory (STAI).

Knapik et al., (1990) studied male infantry soldiers during a 5-day simulated combat operation requiring both offensive and defensive manoeuvres on foot. Soldiers carried all necessary equipment and supplies for 5 days. Total weight carried was about 25 – 29 kg, including a rucksack of 9 – 13 kg. They noticed a decline in upper-body exercise capacity and lower-body strength (8 – 10%). The decrements were attributed to the loads carried by the soldiers. Harper et al., (1997) reported a decrement in grenade throw distance as a result of a maximal effort march of 10 km with a load of 18 – 36 kg. This may be due to a nerve entrapment syndrome (Bessen et al., 1987; and Wilson, 1987) or pain in the shoulder area resulting from pressure of the rucksack straps.

Martin and Nelson (1985) examined the effect of carrying typical military loads of varying magnitude on the combative movement performance of male and female subjects. The subjects performed a series of tests that included a 22.9-meter sprint, standing long jump, agility run, reaction movement test and a ladder climb. The tests were performed under different load conditions ranging from a baseline condition (no load) to one of 37 kg. The results demonstrated a fairly consistent load effect on the performance of the men and women. In general, the decrease in performance was approximately linearly related to the increase in load.

Table 3-18: Decrements in Performance Related to Increase in Load Carried (Martin and Nelson, 1985)

Test	Load Condition 18 kg		Load Condition 37 kg		Female/Male Ratio Performance Load Condition 37 kg
	Female	Male	Female	Male	
22.9-m sprint	23%	17%	40%	29%	0.76
Standing long jump	– 17%	– 13%	– 33%	– 24%	0.82
Agility run	24%	14%	50%	36%	0.72
Reaction movement test	9%	6%	19%	15%	0.86
Ladder climb	6%	3%	126%	39%	0.41

The ladder climb was the only test of the five, which required a considerable involvement of the arms in the performance of the task. The greater female- male performance differences in the ladder climb, under all load conditions but especially at higher load conditions, may be related to differences between genders in upper body strength.

Laubach (1976) noted the relative strength of women compared to men varies considerably depending upon the area of the body under consideration. It was shown that female – male strength differences were significantly greater for the arms than for the legs. The heaviest load of 37 kg was added in the form of a frame-backpack system, which tended to restrict arm movements and thereby placed a greater demand on the upper extremity musculature.

Bassan et al., (2001) examined the relationship between load carriage and time to complete an obstacle course. The 500-meter long obstacle course included 20 individual obstacles representative of manoeuvres performed by soldiers during assaults and other battle drills. A substantial ($r^2 = 0.59$) linear relationship was found between total load carried and time and time to complete the obstacle course, with a slope of 7.88. That is, each additional kg carried increased completion time on the course by 7.88 sec or 4.5%.

Increasing the load carried will strongly diminish the self-paced speed of soldiers (Haisman, 1988, based on data of Hughes and Goldman, 1970).

As the load weight increases, the speed decreases proportionally, and the average energy cost per unit distance marched was found to be lowest for 30 – 40 kg of load (Table 3-19).

Table 3-19: Weight of Load and Speed when Self-Pacing Over 6.4 km

Weight of Load (kg)	0	20	30	40	50	60
Self-paced speed (km/h)	8.0	6.5	5.8	5.2	4.3	3.7
Energy cost kcal/h	587	469	457	448	395	386
Energy cost per unit distance Kcal/kg.m	1.04	0.83	0.79	0.79	0.84	0.84

3.10 LOAD MANAGEMENT

A very early report of a British Royal Commission in 1867 (cited by Soule et al., 1978) recommended a maximum load, for sustained operations, of 18 kg. In 1966 the United States Army Research Institute of

Environmental Medicine (USARIEM) concluded that loads of 35 to 45 percent of a soldier's body weight are the most desirable for sustained non-contact movements. Loads with 20 to 30 percent of a soldier's body weight are the most realistic for combat missions (from Perkins, 1986; and O'Connor et al., 1990). In determining which end of this weight range to select, leaders should also consider a soldier's physical condition. There is no absolute rule for this.

Haisman (1988) argued that there is clearly a case for setting an upper limit to the weight carried. If the load is not going to impair efficiency to a marked extent this weight limit ought to be less than 30 kg. He added that it is more logical to relate the load to the body weight. In an attempt to define the optimal load he stated that it might be impossible to define it in isolation from other relevant factors such as the velocity, grade, climate, clothing, and nature of the terrain. Also other factors like load carriage system, load distribution, and personal characteristics such as height, fat free mass, and VO_2max determine the optimal load.

Dean (2004) recommended – based on his observations in combat in Afghanistan – that units must continue their emphasis on minimising the loads that their soldiers are carrying while ensuring that their missions can still be accomplished. He recommended that units should set a maximum load of 1/3 of a Soldier's body weight and then enforce that weight as the Soldier's maximum Approach March Load. Any equipment that exceeds the maximum weight should be brought forward to the Soldier through unit transportation assets.

According to the findings of operations in Grenada, Falklands and Afghanistan, the dismounted infantryman is heavily loaded while conducting modern combat operations. Fighting loads up to 36 kg in operations in Afghanistan and Approach March Loads of 54 to 68 kg in operations in Falklands, Grenada and Afghanistan (McCaig and Gooderson, 1986; Dublik, 1987; and Dean 2004) are reported. Emergency Approach March Loads went up to 78 kg during the Afghanistan mission (Dean, 2004).

These excessive weights on the backs of the soldiers, coupled with the harsh environments proved detrimental to maximizing Soldier's performance. Despite the fact that units were going to great lengths to minimize the loads that their Soldiers were carrying, the weight of the Infantry's combat load was far too great and considerably exceeded the upper envelopes established by current Army doctrines (Dean, 2004).

There seem to be two persistent notions that lead commanders to overload their soldiers (General Burba, Chief of Infantry, 1986):

- "**Be-prepared**" – Some commanders feel their soldiers must be prepared to meet every imaginable contingency.
- "**The Supply System Will Fail**" – Other commanders conclude in advance of an operation that the supply system will fail and therefore decide that their soldiers should carry twice as much of everything.

Ideally, the commander establishes a maximum soldiers' load on the basis of his analysis of mission, enemy, troops, terrain, and time (METT-T). In doing so, the subordinate commanders have four basic risk variables to work with: minimum essential equipment, climate protection, threat protection, and mission (Mayville, 1987). Added together, these should weigh no more than the established maximum.

A soldier's minimum essential load includes his uniform, assigned weapon, and load carrying equipment. A minimum essential load is made up of the items a soldier always needs, regardless of his mission. Climate protection includes all the equipment designed to enable the soldier in severe temperature and rough terrain. Threat protection refers to equipment that guards the soldier from expected ballistic, armor, and nuclear-biological-chemical threats. The mission load is made up of munitions, food, and all the equipment required accomplishing the mission. Typically, this equipment includes ammunition, communication tools, and vision aids.

Mayville (1987) argued that to determine the right combination of climate, threat and mission equipment in addition to the essential equipment demands adequate risk-analyses of the mission and its tactical environment. The risk equation forces commanders to take along only the most important items. It implies that the success of the mission depends upon agility and a proper balance of firepower and maneuverability.

Clearly the load carried by the soldier will always be a compromise between what is physiological sound and what is operationally essential. Recent information of operations indicates however, that the modern dismounted soldier is over-burdened during combat field actions.

Dean (2004) recently warned the military leadership to take action. “If an aggressive Soldier equipment weight loss program is not undertaken by the Army as a whole, the Soldier’s combat load will continue to increase and his physical performance will continue to be even more severely degraded by the loads that he carries in the world’s harshest environments.” He suggested that the weight of the combat load carried by the dismounted warrior can only be reduced through a combination of providing the soldiers with lighter systems while also off loading any and all equipment that is not immediately needed in a firefight, to alternate forms of transportation. His recommendations are listed in Appendix 3A-3.

In a series of articles O’Connor and Bahrke (1990) offer guidance on the various factors a commander must consider when planning the operational loads their soldiers will carry (see Appendix 3A-1). They discussed a number of approaches, based on the work of the Army Development and Evaluation Agency (ADEA) to lighten the soldier’s load and increase his ability to carry his mission essential equipment:

- Lighter weight components.
- Special load-handling equipment.
- Re-evaluation of current training doctrine.
- Better soldier load-planning models.
- Special physical training programs.

Commanders should concentrate their efforts on those areas in which they can exert influence – the load planning and physical training approach. Research on load bearing has established the fact that rate at which a soldier expands energy will determine how long he can carry a given load. Commanders must therefore consider energy expenditure in determining their soldier’s ability to sustain movement, while marching with heavy loads. Section 3.10.1 gives research-based guidelines for planning of loaded movements.

A properly designed and executed physical training program will have a major influence on the soldier’s physical readiness for loaded road marching. A fit soldier is able to carry a heavier load, and carry it longer with less fatigue, than an unfit soldier. Also, a fit soldier will perform their critical tasks better while on the move and on arrival at the spot of destination.

3.11 CONCLUSIONS

1) Foot marches can be defined as the movements of troops and equipment mainly by foot with limited support by vehicles. They are characterized by combat readiness, ease of control, adaptability to terrain, slow rate of movement, and increased personnel fatigue. A successful foot march is when troops arrive at their destination at the prescribed time and they are physically able to execute their mission.

2) Military load carriage capacity is critical to soldier's mobility and sustainability, and ultimately, to soldier performance and survival on the battlefield.

3) Field Manual 21-18 (Department of the Army, 1990) provides guidance about recommended maximum loads and prescribed rates of march in different conditions. The combat load is the minimum mission-essential equipment required for Soldiers to fight and survive immediate combat operations. Combat loads consists of three categories: Fighting Load (limit 21.7 kg), Approach March Load (limit 32.7 kg), and Emergency Approach March Load.

4) An additional guidance states that a soldier's weight must be taken into account. The optimal load for a soldier has been determined to be 20 to 30 percent of their body weight for combat missions. The maximum load should not exceed 45 percent of the soldier's body weight for sustained non-contact movements.

5) The dismounted infantryman is heavily loaded while conducting modern combat operations. Fighting loads up to 36 kg in operations in Afghanistan and Approach March Loads of 54 to 68 kg in operations in Falklands, Grenada and Afghanistan are reported. These excessive weights on the backs of the soldiers, coupled with the harsh environments proved detrimental to maximizing soldier performance. The weight of the Infantry's combat load was far too great and considerably exceeded the upper envelopes established by current Army doctrines.

6) There are many factors that influence the ability of a soldier to carry load and road march. These include mass of load, speed of march, terrain factors such as gradient and surface type, distribution of the load, volume of the load, and the physical condition of the soldier.

7) Energy cost of backpack load carriage increases in a systematic manner with increases in body mass, load mass, velocity, grade, and type of terrain. Pandolf et al., developed an equation for predicting energy costs of locomotion with backpacks. It can provide commanders with valuable information about the physical strain of a certain loaded traverse. Choosing the right combination in load carried and speed, given certain characteristics of terrain and distance, dictates soldier's mobility and the capacity of the soldier to continue their job for an extended period of time.

8) For fairly fit individuals walking at a given speed and grade the energy cost/kg is independent of the extra weight carried. Up to limits of 30% of body weight the energy cost/kg is found to be the same for weight load and live weight. Within the range of 0 – 30 kg each kilogram carried load accounts for an average increase in oxygen uptake of 0.335 $ml \cdot kg^{-1} \cdot min^{-1}$ and a heart rate of 1.1 beats per minute.

9) Higher lean body mass and height are associated with faster load carriage.

10) Load carriage ability is not well predicted by unloaded running. Absolute VO_2max is much better related to march performance than relative VO_2max.

11) Multiple regression models to predict march performance include absolute VO_2max, muscular strength of leg extension and upper body, core strength, lean body mass and height. Explained variance of loaded march performance is in the range of 56 – 71 percent.

12) Testing of physical fitness and readiness of soldiers and units is essential for military field practice and training. The most important reasons are to identify weaknesses, monitor progress, provide feedback, and educate commanders and soldiers.

13) Several road march tests are currently in use by NATO-countries. Basically three types of tests are used:

i) Loaded march time trials with loads varying between 5 to 68 kg over distances of 5 to 20 km. The loads are chosen to approximate the different types of combat loads – Fighting Load, Approach March Load and Emergency Approach March Load;

ii) Incremental loaded road march tests; and

iii) Submaximal testing in which pass/failure scores based on operational task or job specialities are imposed.

14) In military training and operational setting the loaded-march task varies greatly. Depending on the task variables a different mix in fitness components – muscular strength, muscular endurance and aerobic fitness – is stressed. This should be borne in mind when selecting a specific road marching test to monitor or evaluate the physical readiness and training of a unit.

15) The optimum training to improve marching performance appears to be a combination of resistance training, endurance training and task repetition. Programs that only focus on aerobic fitness or muscular strength were not effective.

16) When planning training schedules, units should regard 2 times per month as a minimum frequency for road march training. A 10-day cycle appears to be optimal.

17) Training effects for loaded road marching, time trials, are moderate and in the order of 5 – 15 percent. Probably the capacities to continue the task for prolonged time – given a certain load, speed and terrain – is much more improved.

18) Excessive marching may be costly in terms of training time and increased risk of injuries. Depending on the operational requirements, short but intensive training is a very cost effective approach and the benefits in terms of progress in road marching performance with heavy weights are substantial.

19) Medical problems and injuries associated with load carriage can adversely affect an individual's mobility, and in military operations, reduce the effectiveness of an entire unit. Common types of injuries include blisters, plantar fasciitis, achilles tendonitis, shin splints, stress fractures, anterior compartment syndrome, chondromalacia patellae and low-back strain.

20) Factors commonly implicated in marching injuries include training program parameters, footwear, training surface, initial low level of fitness/inactivity, anatomical anomalies, inappropriate flexibility, excess body fat, gender and age, health factors, and prior injury history.

21) Preventive strategies related to march injuries that have gained acceptance in the military:

- Gradual progressive increases in frequency, duration and intensity of training activities, including loaded marching;
- Adequate rest given between training sessions;
- Use of adequate shoes;
- Warming-up and stretching prior to exercise sessions;
- Run or speed march on soft, even surface; and
- Avoid excessive overtraining.

22) Performance in the context of load carriage means the ability to complete the road march as rapidly as possible, and the ability to complete essential soldiering tasks at the end of the march.

23) Men are significantly faster (about 20%) than women in completing maximal effort marches of 10 km in distance with loads of 18 kg, 27 kg and 36 kg.

24) Evidence-based guidelines are developed to assist field commanders in planning movement while marching with loads.

25) The average male and female soldier could perform prolonged work over 8 – 9 hours at a relative intensity of 36 percent of VO_2max. The average male soldier could perform at an average energy expenditure rate of 430 kcal/h and the average female soldier at a rate of 285 kcal/hour. If the march duration is about 2 – 3 hours the suggested relative intensity is 40% of VO_2max and the energy expenditures are 477 and 317 kcal/h for respectively male and female soldiers. A burst of energy expenditure of 900 to 1000 kcal per hour can only be sustained for 6 to 10 minutes.

26) Based on these energy expenditure levels, field commanders can calculate optimal combinations of load carried and velocity of unit movements given certain terrain factors, as grade and surface.

27) As velocity increases, the efficiency of walking becomes lower than running. Above a speed of about 8 km per hour, unloaded running is more efficient than unloaded walking. With a load of 20 kg representing the average load in practice during marches, the breaking point is 7.8 km per hour. Smaller subjects had a breaking point between walking and running (with 20 kg load) at a lower speed (6.5 km/h) than more robust subjects (8.3 km/h).

28) During marching with heavy loads, soldiers need to be individually loaded, relative to their own Maximum Load Carry Capacity. This loading strategy resulted in a more homogeneous march performance, endurance time, for a group of soldiers, compared with carrying the same absolute load by each soldier.

29) Redistributing the load according to body weight which is a more practical criterion in the field, is also a better option than loading soldiers with the same absolute load.

30) When soldiers perform a strenuous road march with a heavy load, leaders could expect mood changes and decrements in essential soldier skills – e.g. marksmanship, and grenade throwing – which may have significantly impact on military effectiveness.

31) Load carriage has a fairly consistent negative momentary effect on military physical task activities like sprinting, jumping, agility, ladder climbing. In general, the decrease in performance is approximately linearly related to the increase in load.

32) An aggressive combined approach is needed to lower the weight of the combat load worn by the dismounted soldier. It can only be reduced through a combination of providing the soldiers with lighter systems while also off loading any and all equipment that is not immediately needed in a firefight, to alternate forms of transportation.

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Appendix 3A-1

Factors to consider during planning of operations in which soldiers loads could have definite bearing on the outcome of the mission (O'Connor et al., 1990).

Mission Characteristics	Soldier Characteristics	Load Characteristics
1) Movement route ▪ Open march (roads/trails) ▪ Movement in cover ▪ Type of movement (walk, crouch, crawl)	1) Physical (anatomical, physiological, medical) ▪ Height/weight ▪ Body type ▪ Physical condition ▪ Nutrition/hydration status ▪ State of rest/fatigue ▪ Condition of the feet	1) Load ▪ Weight ▪ Bulk ▪ Multi-soldier loads
2) Clothing (MOPP-level, patrol)	2) Psychological ▪ Level of motivation ▪ Mood state ▪ Self-confidence ▪ Fatigue	2) Load bearing equipment ▪ Rucksack ▪ Hand carry requirements ▪ Yoke/sling ▪ Man carts
3) Schedule requirements ▪ Distance travelled ▪ Rate of movement ▪ Rest/move schedule ▪ Feeding schedule (planned, on-the-move) ▪ Post-march recovery plan ▪ Sleep plan	3) Training/conditioning ▪ Tr in preparing loads for movement ▪ Use of load bearing equipment ▪ Condition of boots and socks ▪ Experience in, arch and water discipline ▪ Experience in carrying combat loads ▪ Move/rest cycle experience under loaded condition	3) Load configuration ▪ Balance ▪ Stability ▪ Distribution

Appendix 3A-2

Factors to consider during planning of operations in which soldiers loads could have definite bearing on the outcome of the mission (O'Connor et al., 1990).

Mission Characteristics

1) Physical demands on the engagement (MOUT, obstacles, and the like)

2) Environmental characteristics
   - Visibility
     - Day/night
     - Vegetation/terrain features
   - Weather
     - Temperature
     - Humidity
     - Wind (speed/direction)
     - Wind chill
     - Precipitation
   - Terrain characteristics
     - Altitude
     - Grade
     - Surface characteristics
     - Vegetation
   - Natural irritants
     - Insects
     - Plants
     - Animals
   - Artificial irritants
     - NBC considerations
     - Noise
     - Smoke
   - Potable water supply

Appendix 3A-3

Factors to consider in reducing the load on the soldier's back, findings of military operations in Afghanistan (Dean, 2004).

Major Findings:

- Increased capabilities continue to increase physical burdens.
- Fit Soldiers are easily exhausted by their modern loads while operating in extreme environments.
- Body armor needs to continue to be lightened and made much more flexible.
- Unit transportation assets need to carry the bulk of the Soldier's load.
- Units need more small unit ground vehicles.
- Army level effort needs to go into reducing the Combat Load through doctrine and equipment changes. Needs unified action.

Reduce the Weight of Soldier Worn Technologies:

- All Soldiers have different jobs and carry different loads.
- Recognize that the need for most gear will not go away. Soldiers have basic needs that will remain over time.
- Make all attempts to create lightweight Soldier carried gear.
- Look to lighten ALL the gear that Soldiers carry, not just an item here or there.
- Make attempts to develop multi-functional gear to replace current one-task items.
- Follow industry and buy off the shelf, state-of-the-art gear to replace Army clunkers (GPS as example). Throw it away when it dies.
- Reinvent many staple items to shed weight (machine gun tripods, ammunition (all types), batteries, body armor, and more).
- Re-design or purchase commercial load carriage systems that support all job specialties (example = RadioTelephone Operator – no load carriage system that meets his needs).

And Take the Weight **OFF** the Soldier's Back:

- Re-think the logistical practices that the Army has been using since WWII and consider novel ways to re-supply the dismounted Soldier, to include possible daytime re-supply.
- Provide the platoon and squad with small unit logistics vehicles that can follow closely behind the unit during combat operations. Place most of the contents of the Soldier's Assault Rucksack on these vehicles. Place some of the Soldier's basic load of ammunition on these vehicles as well as specialty items.

Chapter 4 – COMMON MILITARY TASK: DIGGING

by

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ABSTRACT

Digging trenches, filling sand-bags, and shovelling debris have been shown to be common military tasks (CMTs) during land-based, military operations throughout the Armed Forces of NATO. The role of digging and shovelling has been considered to be a critical requirement of these CMTs. Screening protocols have been developed that reflect the physical demands of such critical requirements and which enable the physical abilities of new recruits and incumbents alike, to be assessed against the same criteria that have been shown to best-predict CMT performance (i.e. criterion-tests). A popular approach in the development of valid screening protocols has been to design simulations that were representative of the most physically demanding digging CMTs (i.e. content-based). However, the reported reliability of such protocols, when screening for digging-based abilities, has been variable (ranging in r^2 from 0.81 (worst) to 0.99 (best)) and lacked adequate agreement with CMT performance (ranging in r^2 from 0.14 (worst) to 0.72 (best)). Association with lower back injuries and the lack of validity as discriminator tests have often resulted in the withdrawal of digging-based tests from screening protocols. However, research to develop valid methods of assessing digging performance continues and this chapter provides a summary of developments from the early 1900's to research programmes that were active during 2005 within the NATO membership.

4.1 INTRODUCTION

Members of the HFM-080 RTG-019 were asked to review the research that had been conducted concerning common military tasks (CMTs) and the role that these tasks had placed on the development of screening protocols to assess physical fitness for effective performance on military operations. The RTG agreed to compile a report to summarise its findings. Digging trenches, filling sand-bags, and shovelling debris have been shown to be CMTs during land-based, military operations throughout the Armed Forces of NATO. Furthermore Stickland 1995 concluded that:

> *'Manual excavation will continue to play an important role in the construction of field defences … even the wider scaling of digging plant equipment will not remove the need for large numbers of military personnel to manually dig trenches on the battlefield'.*

Screening protocols have been developed that reflect the physical demands of digging (and shovelling) and which enable the physical abilities of new recruits and incumbents alike, to be assessed against the same criteria that have been shown to best-predict CMT performance (i.e. criterion-tests). A popular approach in the development of valid screening protocols has been to design simulations that were representative of the most physically demanding digging CMTs (i.e. content-based). This chapter provides a review of the literature concerning digging CMTs and discusses the research that has been conducted to develop valid methods of assessing digging performance within the NATO membership.

4.2 OBJECTIVE

This chapter was intended to:

- Provide a review of the literature concerning manual digging and shovelling tasks;
- Identify CMTs in which digging or shovelling was required; and to
- Summarise the research that had been conducted within NATO to assess the ability of military personnel to conduct these CMTs (i.e. physical fitness screening protocols).

4.3 THIS REVIEW: SCOPE AND FOCUS

This chapter was concerned solely with non-mechanised methods of material excavation (i.e. digging and shovelling CMTs[1]) that have been used (or implicated) in the development of protocols to assess physical abilities that were essential for effective task performance. Furthermore, only those data that have been rated as *'unclassified'* and which were obtained by the search mechanisms described in Table 4-1 have been discussed. The focus for this chapter was on research that bore relevance to manual excavation tasks performed by the Armed Forces, and the scope was limited to NATO and those participants within the *Partnership for Peace.*

Table 4-1: Method and Criteria Used to Review the Literature Concerning Manual Digging Tasks

Serial	Source	Search Criteria (Keywords)
1	Web*CAT*® *STRSI*	*Authors:* Bensel, Haisman, Rayson, van Dijk, Jaenen, Lee, Knapik, Sharp, Hodgdon, Vogel, Gledhill, Deakin *Keywords:* Digging, entrenchment, shovel, shovelling, trench, foxhole, excavation, manual handling, materials handling, military, NIOSH, RPE, spade, design, occupational tasks, entrenching, shell scrape
2	Web of Science	
3	Defence Reports Abstracts MOD Edition (UK) 2000 – 2004	
4	NATO HFM technical reports database http://www.rta.nato.int/Abstracts.asp?RestrictPanel=HFM	
5	Science and Technology Information Network (USA) http://www.dtic.mil/dtic/prodsrvc/stinet.html	
6	PUBMED (Medline) http://www.ncbi.nlm.nih.gov/entrez/query.fcgi	
7	NATO HFM-080 RTG-019 E-mail to members: request for information	
8	NATO HFM-080 RTG-019 meeting #1 (Warendorf, Germany, Jun 03) Proceedings CD (Research Update for NATO members)	
9	NATO HFM-080 RTG-019 meeting #2 (Austria, Jun 04) Proceedings CD (Research Update for NATO members)	
10	Biomech-L internet mailing list	
11	Sports science interest group http://sports.groups.yahoo.com/group/sportscience/	
12	Health and Safety Labs, UK	
13	Health and Safety Executive, London	
14	Information services, Royal Engineers School of Engineering, Gibraltar Barracks, UK	

[1] Excavation involving explosives or powered vehicles/tools have been excluded from this chapter on the basis that such methods tend not to influence the design of physical fitness tests or standards that have been used throughout the military.

Serial	Source	Search Criteria (Keywords)
15	Defence Standards (DEFSTAN) http://www.chots.mod.uk/defence_standards/	
16	Human Sciences Research database, Research Acquisition Organisation, UK	
17	IEEE *Xplore*® unclassified network	
18	Taylor & Francis online journals database (*includes:* Applied Ergonomics, Ergonomics, etc.)	
19	Individual Deployment Training course manual, RAF Innsworth, UK	
20	Science Direct e-journals http://www.sciencedirect.com/science?_ob=JournalListURL&_update=y&_auth=y&_acct=C000056583&md5=15afcab5847a4295130fabec91c03cfc&subjColl=all&stype=title&type=subscribed&x=11&y=7	
21	MoD Engineers Disk, Quick Finder http://corporate/mod/bgodad7/disk5/nav/qfind/qwk_find.htm	
22	NATO STARNET website http://starnet.rta.nato.int/	

4.3.1 Searches Conducted and Criteria Used

The methods and criteria that were used to obtain the information that has been discussed in this chapter have been summarised in Table 4-1.

4.4 DIGGING AS A BONA FIDE OCCUPATIONAL REQUIREMENT

A Bona Fide Occupational Requirement (BFOR) has been defined by the Canadian Human Rights Act (1982) as a condition of employment which is enforced with the belief that is it essential for safe, efficient and reliable job performance. The importance for an employer to establish a BFOR has been evident within case law when assessing the legitimacy of screening programs to select new employees or to assess incumbents for their fitness to work. The BFOR affords the benefit of enabling employers to match employees to the work that they are capable of performing, and to define specific training requirements in order to best prepare their staff to meet the demands of their occupational role.

Canadian Human Rights Legislation (CHRC, 1985; CHRC, 1988) identifies three key factors (a to c) which underpin the existence of a BFOR:

a) Classification of the essential components of the job;

b) Requirements for safe, efficient and reliable performance of the job tasks; and

c) A means of assessment to determine whether an employee has the capability to meet the job requirements.

The policy in Canada for the development of a BFOR required that the evidence used to develop a BFOR were objective and supported by expert opinion and scientific evidence when available. However, where it can be demonstrated that the existing work environment could be changed to accommodate an individual's ability to perform the job, then a BFOR does not exist. Subsequently a BFOR is not a static condition, and it may change in time with advances in technology. A pre-requisite in the process to establish the validity of screening military personnel for their ability to perform digging and shovelling tasks must be based upon a BFOR. In order to establish a valid screening protocol to assess military personnel for their ability to perform digging and shovelling tasks it must be shown first that digging (and shovelling) fulfils the requirements of a BFOR.

Digging was found to be the eighth most frequently conducted task of all the physically demanding tasks (from a table of 20 physical tasks) within the US Army. During a study to develop criterion performance tasks for the purpose of establishing 'physical abilities' standards for entry to the US Army, Myers et al., 1984 analysed 1,999 critical tasks across all job categories and reported digging to occur in 1% of all US Army job tasks that were considered to incur a 'very heavy physical demand' (on a scale of light to very heavy), and 2% of all moderately heavy tasks.

4.4.1 Military Relevance (Infantry and Engineers)

Survivability is a term that has been used throughout the Armed Forces of NATO to describe the fundamental aspects of protecting military personnel, weapons and materiel from enemy and detection systems. Digging has been universally identified as a fundamental skill that is required by tasks which enhance military survivability (ATP-52(A) 1997). A number of tasks have been proposed within the context of survivability (NATO 2001) which require manual digging, and these include:

- Preparation and construction of field fortifications;
- Camouflage, concealment and deception; and
- The clearance of fields of fire.

Stickland 1995 suggested that; 'the better your digging, the better your chance of survival'. The soldier, when under fire, very rapidly learns or re-learns the enormous value of a 'good' hole in the ground, as a means of protection. The hole in the ground may take many forms, from the "natural opening shell crater, ditch or gully, to a carefully constructed bunker system". The main protection element of the hole is that provided by the earth itself. This is reinforced by the low profile and subsequently reduced target area. Each type of hole will serve a purpose. The individual on the ground needs to be aware of the local threat to allow the correct defensive measures to be taken considering the length of time the area is liable to be occupied and for what purpose. The effectiveness of the hole means that any alternative to digging is a second choice.

As society has advanced and machines replace manual labour everywhere, the number of people with previously learnt digging skills joining the Armed Forces has reduced dramatically. Lack of basic skill or training can lead to inefficient excavation, poor trench structural properties or medical problems such as lower back compression injuries for the individual performing the digging task. Therefore hand digging should be included at an early stage in the training programme (Stickland 1995).

Hand held power tools have a place in the military inventory for many tasks. However, their benefits for trench construction are limited by the signature that is evident when using them, and the effort required just to move the tool(s). This energy would in most cases be more effectively used with the pick and shovel. Only the hardest of soils requires the use of the mechanical breakers (Stickland 1995).

Wright 1993 reviewed the field manuals and working procedures for soldiers in the British Army, and identified a number of digging[2] and shovelling tasks that were required within the basic military role. These included the actions of digging and shovelling to:

[2] For the purpose of this review *digging* has been defined as the act of penetrating or loosening a material (e.g. breaking up earth in a trench) when using a digging tool, whilst *shovelling* is the act of transporting the loose material from its original position to an alternative location whilst using a spade of shovel.

a) Construct shell scrapes;

b) Build trenches (of various shape, size and functional purpose);

c) De-turf grassed areas;

d) Place explosives;

e) Clear debris; and

f) Fill sand-bags.

These tasks have also been identified by a number of researchers and summarised in Table 4-8. Furthermore Wright 1993 defined the equipment and the methods that were used by the British Army to dig in various types of terrain (hard rock, gravel, sand, etc. (See Appendix 4A-1)).

The media have reported a number of military operations during which the use of digging and shovelling tasks were shown to have been essential to the success of each mission. Such reports included operations undertaken by Canadian forces in:

a) Manitoba (clearing debris with shovels, digging trenches, setting up shelters, building dykes and filling sand-bags during the floods);

b) Rwanda (1994 – 95);

c) Bosnia, Croatia and Cambodia;

d) Saguenay (entrenchment dig and filling sand-bags); and

e) Ontario (filling sand-bags during an ice storm).

Data from the British military have shown that UK Armed Forces have dug trenches, filled sand-bags, constructed sangars, dug wells and sanitation, and cleared debris using shovels as part of their operational role all over the World (including Mozambique (1991 – 92), FRY (1993 – 95), Montserrat (1996), Kosovo (1999), East Timor (1999), and Kuwait and Iraq (2003+)).

Commonplace in military training and policy manuals throughout the Armed Forces within NATO is the reminder to service personnel that despite their current specialisation or trade, in the event of an emergency, and when circumstances dictate, they are all soldiers, sailors or airmen first and foremost. Accordingly all operational personnel within the Armed Forces who are issued with a weapon are expected to be able to perform the basic skills (Common Core Skills, Survive to Operate, etc.) that have been identified as bona fide occupational requirements (BFOR). In order to establish a BFOR (Constable and Palmer 2000) several Armed Forces within NATO have developed 'Mission Essential Task Lists (METL)' which can be used to define selection and maintenance criteria (Nevola et al., 2003a) and to match training to the specific 'needs' of tasks within the operational role.

Three of the 14 core operational tasks that were defined as a BFOR for RAF combined incident teams involved digging or shovelling actions (Nevola et al., 2003b), and were conducted for (mean (1SD)) 16.5 (14.5) % of the total duration of these core operational tasks. Digging was identified as one of four critical tasks that were required by land-based personnel within the Netherlands military services, during a project to develop criterion-based physical fitness standards (MOMRP 1999).

During a project to develop a bona fide Minimum Physical Fitness Standard (MPFS) for Canadian Forces personnel[3], the ergonomics research group at Queen's University (Canada) identified an entrenchment dig task as one of the five most common tasks applicable to military duty. To establish the five tasks Deakin et al., 2000 conducted a review of the literature and the media which related to military exercises during

[3] This was intended to comply with the requirements of the Canadian Human Rights Act.

peace keeping and emergency duties, they re-assessed the findings of their earlier studies (dated 1988) and consulted an expert advisory panel. Following this process the entrenchment dig was considered to be 'representative of military tasks performed by the Canadian Forces today'.

It is known that soldiers in the US Army dig foxholes to protect themselves from enemy fire. Eighteen different military occupational specialities (MOS) identified digging as a critical task in the effective performance of their role. Blade loads that were reported for these MOS' ranged from 4.5 to 15.0 kg and the volume of material that was dug ranged from 1.0 to 55.0 m^3 (Sharp et al., 1998).

During a study in which 212 trained personnel from the US Marine Corps were asked whether they had operational experience of digging with an entrenching tool and a conventional shovel (Davis et al., 1986) it was shown that all (100%) had used an entrenching tool to dig in jungle operations, and 7% had used a conventional shovel during amphibious operations[4].

4.5 INTENSITY AND DURATION OF COMMON DIGGING TASKS

The digging tasks reported in the literature involve shovelling 0.5 to 1.0 m^3 of sand, earth or pea gravel from one container into another (Sharp et al., 1998). These tests tend to be poorly correlated with measures of physical fitness (Visser et al., 1996). Future development of an effective and reliable means of assessing digging and shovelling performance must understand the factors that underpin the physical demands that are imposed when conducting such tasks. Paragraphs 4.5.2 to 4.5.29 discuss those factors that influence the physical demands of tasks that involve digging and shovelling. The factors that have been reviewed are limited to those that have been reported in the media that were searched and listed in Table 4-1. It is likely that not all of the factors that would be expected to influence the physical demands of digging have been addressed. However, the review is intended to reflect the level of understanding that was evident at the time that this chapter was written (2005) and upon which extant physical screening protocols have been based. For the purpose of this review, evidence from the literature was sought with which to consolidate the body of knowledge that described (at the time of writing this chapter) the intensity and duration of digging (and shovelling) (Section 4.5), the physiological requirements for completing such tasks (Section 4.8), tests that have been proposed to assess task performance (Section 4.9) and physical training that may improve an individual's ability to complete such tasks (4.10). Sections 4.6 and 4.7 have summarised the common military tasks which concerned digging (and shovelling) and identified the equipment that has been used by NATO forces to complete such tasks.

4.5.1 Results of Laboratory and Field Studies

Scientific analysis of digging tasks were first reported in the open literature in the early 1900's (Taylor 1913) following research at the Bethlehem Steel Works in 1898. By simply allocating shovels of different blade sizes to work with low- or high-density materials (i.e. rice coal and iron ore respectively) it was possible to standardise the weight of the blade load to a manageable 9.7 kg. This action alone enabled 140 men to complete the task that had previously taken more than 400 men to complete with the former single-sized shovel that had been used for all materials. An impact such as this, with the financial implications that ensued concerning occupational performance and total productivity, provided the momentum for further research.

Developments in manual digging strategies have focused upon re-designing equipment to reduce the energy cost incurred by the individual performing the task. A number of design features which may influence the energy cost (or efficiency) of digging with a shovel (or shovelling) have been investigated. Such features include:

[4] It was also shown that 64% of US Marines had used an entrenching tool during cold climate operations, 50% during desert operations and 14% during amphibious operations, whilst only 22% had used a conventional shovel in the jungle, and only 14% had used the shovel in desert operations.

a) The weight of the shovel;

b) Handle type and length;

c) Lift angle; and

d) Blade size, shape and thickness, etc.

However, only a few of these features (and other proposed influential factors) have been investigated under controlled conditions. Consequently the results that have been reported in the available literature have been inconclusive. Some of the prime factors that have been known to influence shovelling task performance such as[5]:

i) Shovelling rate;

ii) Blade load;

iii) Throw height;

iv) Properties of the material in which to dig;

v) Throw distance; and

vi) Posture (or technique) have been generally well reported.

The following sections (4.5.2 to 4.5.9) provide an account of those studies which have attempted to address these prime factors, and which also discuss the research that concern the less well understood effects of the shovel's design features.

4.5.2 Throw Height and Throw Distance

The higher that the blade load must be raised above the surface from which it was dug, the greater the energy expenditure (Freivalds 1986). Spitzer 1950 showed that by reducing the throw height from 2.0 m to 0.5 m effectively reduced the rate of energy expended during a repetitive shovelling task by 50%. Stephenson and Brown 1923 concluded that shovelling performance was 'reasonably constant' up to a throw height of 1.3 m. They recommended 1.0 to 1.3 m as a throw height that should be considered to be 'acceptable' for a prolonged shovelling task. However differences in the way data were analysed and the use of alternative performance criteria may explain the large variance that was evident when attempting to compare the results reported by different investigators[6].

As expected, Spitzer 1950 found that the further the distance that material was thrown from the original point at which the material was dug, the greater was the associated energy cost (Table 4-2). Distances greater than 1.22 m were found to incur significantly greater energy costs than for those thrown <1.22 m (horizontal distance). Freivalds 1986 considered these results together with the data of Stephenson and Brown 1923 and concluded that the optimum throw distance (in terms of the maximum distance that a specified volume of material could be displaced at a given shovelling rate without incurring a significantly greater energy cost) was 1.2 m.

[5] Clarification of the terms and phrases that have been used in this chapter to describe digging and shovelling has been provided within Figure 4-5.

[6] Some studies have used the time taken to displace a given volume of material as the measure of *'gross efficiency'*, (so any factor that improved the rate at which material could be displaced was considered to be 'more efficient' by some researchers (Wenzig 1928, 1932)) whilst other studies have considered a low *energy cost* attributed to the shovelling task as the prime success criterion (i.e. energy economy). Between studies the specification and conditions of the shovelling task differs. No standard digging protocol has been reported against which isolated factors can be compared and assessed.

Table 4-2: The Effect of the Blade Load, Throw Distance and Throw Height on Energy Expenditure (KJ•min^{-1}) Observed for Every 100 kg of Material Shovelled (Adapted from Spitzer 1950)

	Throw Distance (m)								
	1.0			2.0			3.0		
	Blade Load (kg)								
Throw Height (m)	*5.0*	*7.5*	*10.0*	***5.0***	***7.5***	***10.0***	***5.0***	***7.5***	***10.0***
0.5	21.7	18.9	19.5	32.5	27.8	26.6	48.7	36.5	32.5
1.0	30.8	24.4	25.4	41.8	36.5	34.4	53.1	41.8	39.0
1.5	39.0	30.8	32.5	48.7	41.8	41.8	53.1	45.0	45.0
2.0	41.8	34.4	39.0	53.1	45.0	48.7	58.5	45.0	48.7

4.5.3 Blade Size and Shape

The size of the blade (of the shovel) that afforded the best results with respect to the time taken to displace a given volume of material, was found to be dependent upon the density of the material that was being shovelled.

A large blade size was preferable (in terms of energy economy and shovelling efficiency) when digging in materials of low density (Kirsch 1939). Lehmann 1953 provided recommendations for choosing the blade size of a shovel (Table 4-3).

Table 4-3: Recommended Blade Size of Shovels Used to Dig Based upon the Density of the Material Displaced (Taken from Lehmann 1953)

Material Displaced (Shovelled)	Density of Material (kg·m^{-3})	Blade Size (m^2)
Iron alloys	3700	0.05
Iron ore	2500	0.07
Sand, dirt (moist)	2000	0.09
Basalt	1800	0.09
Sand, dirt (dry)	1500	0.12
Coal	800	0.18
Coke	400	0.20

Kirsch 1939 and Vennewald 1939 studied the effect of the shape of the blade on the time taken to dig a specific volume of material. A square, flat blade with raised edges was reportedly best employed for digging coarse-grained material, whilst a round pointed, curved blade with slightly raised edges was found to be best with sand and soil. These results were consistent irrespective of the thickness of the blade when comparing shovels of the same weight.

4.5.4 Shovelling Rate and Blade Load

The results of several studies tended to agree (Kommerell 1929, Lehmann 1953) that for a given rate of work (as defined by a standardised rate of energy expenditure) it was more efficient to dig (and shovel) at a faster rate using more frequent rest intervals in order to maintain the faster shovelling rate, than to adopt a continuous, slower alternative regime (Table 4-5).

Freivalds 1986 concluded that for non-constrained conditions when the prime performance criterion was to attain the most efficient use of energy, high rates of shovelling (18 to 20 scoops•min^{-1}) were recommended for light- to moderate-weight blade loads (5.0 to 7.0 kg). However, low rates of shovelling (6 to 8 scoops•min^{-1}) afforded a greater work efficiency when the blade load was high (>8.0 kg). Table 4-4 provides a summary of the studies that were considered by Freivalds 1986 when establishing this conclusion.

Table 4-4: Summary of Findings for Recommended Rates of Shovelling and Blade Load when Considering Work Efficiency

Shovelling Rate (scoops·min^{-1})	Blade Load (kg)	Throw Height (m)	[β] *Source*
n/a	9.7	*n/a*	*Taylor 1913*
18	4.5	*n/a*	*Stevenson and Brown 1923*
5 to 8	11.0	*n/a*	*Kommerell 1929*
8	7.0 to 8.0	2.0	*Wenzig 1928, 1932*
15 to 20	8.0	*n/a*	*Spitzer 1950, Dressel et al., 1954*
15 to 20	5.0	*n/a*	*Műller and Karrasch 1956*
[*] 5 to 6	6.8	*n/a*	*Wyndham et al., 1969*
[*] 7	7.0 to 10.0	*n/a*	*Buskirk et al., 1972, 1975*

[*] *Data for working in constrained mining conditions.*

[β] *Data from these studies were reported in Freivalds (1986).*

Table 4-5: Gross Efficiency and Shovelling Time as a Function of Shovelling Rate and Blade Load for Work Conducted at a Standardised Rate of Energy Expenditure (13.9 KJ•min^{-1}) (Adapted from Lehmann 1953)

		Rate of Digging (Number of Shovel Scoops·min^{-1})													
		20		**15**		**12**		**10**		**6.67**		**5**		**4**	
		Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)
Blade Load (kg)	**3**	3.58	34.0	3.43	43.3	3.30	52.2	3.16	60.0						
	6	4.64	22.0	4.53	28.7	4.41	34.9	4.32	41.0	4.00	57.0				
	9	5.15	16.3	5.06	21.3	4.95	26.1	4.90	31.0	4.64	44.0	4.39	55.6		
	12	5.45	12.9	5.39	17.1	5.31	21.0	5.25	24.9	5.03	35.8	4.78	45.3	4.60	54.6
	15	5.66	10.7	5.59	14.1	5.53	17.5	5.41	20.5	5.27	30.0	5.08	38.5	4.92	46.7
	18	5.80	9.2	5.75	12.1	5.68	15.0	5.62	17.8	5.48	26.0	5.25	33.2	5.06	40.0

Studies were inconclusive with respect to the effect of the weight of the entire shovel on the total energy cost of a shovelling task. Although lifting a shovel of lesser mass (kg) would incur a lower energy cost compared to a heavier alternative (Kirsch 1939) for the exact same task (shovelling technique, posture, rate, duration, material, blade load, throw height and distance, etc.) it was not clear from the literature whether a lighter shovel would actually reduce the energy cost of shovelling[7].

However, in terms of the time to displace a set volume of material it had been reported that use of a heavier shovel (2.27 to 4.00 kg) was more efficient than a lighter alternative by virtue of the greater load-carrying capacity of the blade (Stevenson and Brown 1923). An optimum shovel weight of 1.5 to 1.8 kg was proposed at which energy economy was believed to be improved for a standard shovelling task (Műller and Karrasch 1956). However it was unclear whether sufficient control measures had been implemented in the studies that were used to support this proposal.

4.5.5 Posture and Technique

Research investigating digging technique and posture has tended to report data for work efficiency or energy expenditure as the 'criterion measure' when comparing performance on standardised digging tasks.

Table 4-6: The Effect of Blade Load, Weight of the Shovel and the Shovelling Rate on Energy Expenditure Observed for Every 100 kg of Material Shovelled (Adapted from Műller and Karrasch 1956)

Blade Load (kg)	Shovel Weight (kg)	Shovelling Rate (scoops•min^{-1}) mean (1SD)	Energy Expenditure (KJ•min^{-1}) mean (1SD)
3.0	1.3	30.0 (0.0)	20.9 (0.0)
4.0	1.5	22.5 (2.5)	20.8 (1.2)
5.0	1.8	18.0 (2.0)	19.0 (0.9)
7.0	2.0	9.0 (2.6)	26.2 (5.3)
11.0	3.5	4.5 (0.7)	31.4 (1.3)

Therefore an increased task efficiency (as reported in the open literature), attributed to a specific digging technique may actually incur a greater energy cost when compared to an alternative technique performed on a standardised task (i.e. investigators have tended not to normalise their criterion measure of efficiency for energy expenditure). When the energy cost of digging was used to assess performance as the criterion measure it was found that the energy expended during shovelling increased with the decrease in working space (i.e. constraining[8] an individual's shovelling posture incurred the greater energy cost when comparing performance for the same task and technique under conditions where posture was not constrained). Work efficiency was shown to reduce as shovelling posture was increasingly constrained (Kommerell 1929 (see Figure 4-1)).

[7] Data which quantified the energy cost of digging and shovelling using heavy or light tools had not controlled for the differences in material conditions, rates of work, differences in tool design etc. It had not been established whether a spade of very low total weight would require greater force generated by the individual, or a larger number of digging actions (and hence greater energy) in order to penetrate and loosen the material than a heavier alternative.

[8] The term 'constraining' has been used to describe an environment that has limited space available within which to work (e.g. low-seam mining) and therefore results in a cramped posture.

Figure 4-1: The Effects of Confined Space on the Posture that can be Adopted During Digging and Shovelling Tasks in the Military.

Lowering the seam height (and hence the headroom) from 1.2 to 1.0 m was reported by Kommerell 1929 to increase the energy cost of shovelling as a result of the cramped posture that subsequently resulted[9]. Morrissey et al., 1983 reduced the working height for their participants from a self-selected, upright, erect standing posture (i.e. 100%) to 60% of erect height (i.e. bent forward with 40° flexion at the waist). This was shown to increase the energy expended for their standard shovelling task by 13%.

A kneeling posture was found to require 6.5 to 10.0% less energy than an erect standing posture (Buskirk et al., 1972, 1975). However this was only true for shovelling tasks where the throw height and distance was not constant. Humphreys et al., 1962 conducted a regression analysis with their data to develop predictive equations for the energy expenditure of kneeling[10] and standing[11] when shovelling coal from ground level to a 0.23 to 0.30 m tall conveyor belt which required a throw distance of 0.91 m.

The technique that was used to perform a standard shovelling task was shown by Wenzig 1932 to influence the total energy cost (and the rate of energy expenditure). A technique that involved facing the material whilst shovelling (aligning the material in the mid-sagittal plane) and throwing the blade load

[9] These results were not normalised with respect to stature of the participants (i.e. the effect of the reduction in seam height for taller vs. shorter participants).

[10] Energy expenditure of shovelling coal onto a conveyor belt when kneeling (Kcal·min^{-1}) = 1.34 + 0.19 (shovelling rate) Humphreys et al., 1962.

[11] Energy expenditure of shovelling coal onto a conveyor belt when standing (Kcal·min^{-1}) = 4.91 + 0.06 (shovelling rate) Humphreys et al., 1962.

over the shoulder to a destination located behind the individual (i.e. the person digging), incurred the lowest energy cost for a standing posture (this was found to incur 18% less energy than shovelling side-ways to the material (with the material in the mediolateral plane)).

The length of the shovel's handle and shaft (together with its general design) has been shown to determine which technique and posture an individual will adopt when digging the same material (Freivalds 1986). Shovels with a long shaft (~2.5 m) may reduce the degree to which an individual may stoop when digging (Partridge 1973) (i.e. reducing the angle of flexion at the waist). Shaft/handle lengths ranging from 0.48 m (Wenzig 1928) to 0.84 m (Wenzig 1932) have been investigated and for constrained work environments (i.e. digging in a low seam height, such as in mining) a length of 0.66 m has been found to require up to 10% less energy than the longer shovels (Kommerrell 1929). However, too few data have been reported for unconstrained environments to make a general recommendation on the optimum (for energy economy) length of the shaft (shovel). Grandjean 1971 had reported that digging in a stooped posture was only 3% efficient (in terms of energy economy for a defined work load) compared to 6% efficiency in a less stooped posture. Bridger et al., 1997 suggested that their levered spade, which reduced the flexion angle at the waist (i.e. stooping posture) by as much as 40% may similarly be expected to reduce the energy cost of digging when compared to the standard spade.

Use of a 'scraping technique' to move material onto the blade of the shovel prior to throwing it to the target spoil was found to require less energy than using force to penetrate the material when shovelling material of a grain size which ranged from 7 to 15 mm diameter (Stevenson and Brown 1923). Dressel et al., 1954 reported a 15% reduction in the energy cost of digging when using this scraping technique by comparison.

4.5.6 Nature of the Material

The energy cost of shovelling was greater as the coarseness (and granularity) of the material increased for tasks that were standardised for rate and duration (Freivalds 1986). The rate of energy expenditure was shown (Table 4-7) to increase when shovelling more coarse materials (as defined by the diameter of the grain of the shovelled material). This finding was attributed to the greater force that was required to penetrate the material during the dig phase (see Figure 4-3).

Table 4-7: The Effect of the Coarseness of the Shovelled Material and Throw Height on Energy Expenditure (KJ•min^{-1}) Observed for Every 100 kg of Material Shovelled (Adapted from Dressel et al., 1954)

Throw height (m)	Material used to shovel				Energy expenditure (EE) (KJ•min^{-1}) **mean** *(1SD)*	Relative change in EE from preceding throw height (%)
	Sand	Split brick *(< 5 mm diameter)*	Gravel *(7 to 15 mm diameter)*	Gravel *(15 to 30 mm diameter)*		
0.5	18.6	22.6	23.9	27.8	**23.2** *(3.8)*	*n/a*
1.0	22.6	26.1	27.8	32.1	**27.2** *(4.0)*	17.0
1.5	26.1	29.8	30.9	34.8	**30.4** *(3.6)*	12.0
mean	**2.4**	**26.2**	**27.5**	**31.6**		
(1SD)	*3.8*	*3.6*	*3.5*	*3.5*		
	Relative change in EE (%) from preceding material type					
(%)	*n/a*	16.8	5.3	14.7		

Dressel et al., 1954 reported a 57% increase in energy expended when shovelling gravel compared with sand (however it was not clear whether a standard volume or mass was used to compare shovelling these materials). In general shovelling split brick required 17% more energy than shovelling an equal mass of sand, whilst shovelling large grain (15 to 30 mm diameter) gravel required 37% more energy than shovelling an equivalent mass of sand.

4.5.7 Subjective Assessment of Strain During Digging

Carrasco et al., 1992 reported data for:

a) Rating of Perceived Exertion ((RPE) 6 (very, very light) to 20 (very, very heavy) scale, Borg 1973);

b) Body map of perceived physical strain;

c) Postural load (using the Ovako Working Posture Analysing System); and

d) Heart rate when one very experienced male miner (the 'participant', a 34 year old with a body mass of 95 kg, and standing height of 1.96 m) conducted 80 repeated digging tasks in an Australian colliery (dry bulb temperature 17°C and relative humidity of 81%).

The participant shovelled 1000 kg of coal in 6.5 min from ground level in a working colliery, over his shoulder to the height of a conveyor belt, at a self selected (but realistic) work rate (reported to be 85% of his estimated maximum heart rate). He completed this task twice with the same shovel, but on one occasion he wore his full coal mining equipment (which included a protective helmet and equipment belt worn about the waist) and on the second occasion he was allowed to select light-weight clothing.

Results showed that in both dress conditions the subject completed the digging task standing up with a blade load that did not exceed 10 kg. However, when he wore his miners' clothing be spent 20.5 % of his total work time supporting his full body mass on one leg, he assumed a forward bent posture (flexed at the waist) for 60% of his total working time whilst a further 19.2% time was spent in a bent and twisted posture. RPE was 13 for both dress conditions and the areas of the body that were perceived to suffer the greatest physical strain (back, arms and legs) were the same for both dress conditions. However when RPE was used to assess local physical strain at these body areas, data were reported as follows:

Lightweight clothing	: Back: 15; Arms: 14; Legs: 7;
Miners' clothing	: Back: 14; Arms: 11; Legs: 9

Freivalds 1986b found that the shoulders, arms and lower back suffered the greatest physical strain during shovelling as reported by participants who were asked to provide an RPE rating for the areas of the body (body map (Wilson and Corlett 1995)) that they considered to have been exposed to the greatest physical stress. When shorter shovels were used by these participants their RPE subsequently increased signifying a greater perceived physical strain.

Frievalds 1986b proposed that this increased RPE which had resulted from using shorter shovels was a result of the greater flexion at the waist (i.e. participants were excessively bent-over in a stooped posture). However, when the length of the shovel was constant, RPE was higher (at the same body map areas) when heavier shovels were used (i.e. as the mass of the shovel increased).

In a later study Freivalds and Kim 1990 developed a prediction equation for RPE when conducting shovelling tasks:

$$\text{RPE (6 to 20 scale)} = 7.83 + 0.0282\ L + 2.37\ W \qquad (r = 0.47)$$

(Where RPE = rating of perceived exertion (Borg 1973); L = blade load shovelled per minute ($kg \cdot min^{-1}$); W = shovel weight (kg))

Sen and Sahu 1996 reported RPE values of 11 to 12 when participants in a study to evaluate two types of shovel were asked to rate their perceived exertion at the shoulders, arms and back. In agreement with the findings of Frievalds 1986b, it was shown that RPE increased with the decrease in the length of the shaft and handle for the shovel. This was believed to be a consequence of the greater flexion angle at the waist that resulted when digging with a short- as opposed to a long-shovel. When the length of the shovel was maintained RPE was found to increase with an increased mass of the shovel's blade.

Degani et al., 1993 obtained RPE data on the category-ratio scale developed by Borg 1982 (0 (nothing at all) to 10 (very, very strong)) to assess the perceived physical exertion (for 10 body areas[12]) of 8 male industrial workers (the participants) every 15 minutes throughout a 95 minute shovelling task. Participants used a standard shovel to dig a trench in dry sand that was 0.60 m wide, 0.90 m deep and 4.50 m long. The task was self paced and conducted in a posture that was preferred by the participant. Mean RPE when combining data reported for each body area was 2.7 (weak to moderate), whilst the greatest perceived exertion (mean data) was reported for the lower back (RPE 3.5), and the upper back (RPE 2.2). RPE at the lower back generally increased by 0.5 for every 15-minutes of continuous digging within the total 95-minute time for the task.

4.5.8 Clothing (Dress Order)

During operations military personnel are expected to be equipped and ready to conduct their military duties at all times. Such a requirement has resulted in service personnel conducting their digging and shovelling tasks whilst wearing their combat clothing and full fighting order (including a weapon or fire-arm and helmet) (Gribble 1971). Operational equipment and clothing has been shown to increase the burden on dismounted service personnel by as much as 25.0 kg (Nevola et al., 2003a). The addition of such a large mass on the body (and the restriction that such equipment imposes on the range of movement that could be achieved) whilst conducting digging and shovelling tasks, may partly explain the distinct difference in the data when comparing civilian and military occupations.

The development of job-based task simulations with which to assess the physical fitness of fire-fighters in Canada (Gledhill and Jamnik 1992) required individuals to wear the standard protective clothing (which added a further 48 lb or 21.8 kg to the total mass of the individual) that was a requirement of this occupation's operational role.

4.5.9 Lift Angle

When a series of lift angles[13] (0°, 16°, 32° and 48°) were used in a controlled digging task[14] the energy efficiency (calculated from expired gases which were analysed using an MM1 Metabolic Monitor (Freivalds 1986b)) was greater (i.e. preferable, $p<0.1$) for 16° and 32° when compared with the other lift angles. RPE was significantly lower when digging with shovels that had these more energetically favourable lift angles (i.e. 16° and 32°) in preference to the shovels with 0° or 48° lift angle. The increased flexion at the waist that was required to use a shovel with a 0° lift angle was proposed as an explanation of the comparatively high energy cost of the digging task. However, although use of the shovel with a 48° lift angle effectively reduced the flexion angle at the waist (compared with the lesser lift angles) Freivalds 1986b noticed that more sand was actually lost from the blade and hence the higher energy cost was incurred as a consequence of the increased number of scoops required to dig an equivalent quantity of

[12] Corlett and Bishop 1976 body map was used and the 10 body areas were: hands, forearms, upper arms, shoulders, left and right aspects of the trapezius muscles, upper back, lower back, left-leg hamstrings and right-leg hamstring muscles.

[13] For an illustrated definition of the *lift angle* see *Figure 4-5*.

[14] Digging foundry sand which had been moistened to 2.5 to 4.0% water content from ground (0.0 m) to 0.7 m height and throwing it a distance of 1.4 m at a shovelling rate of 18 scoops·min^{-1} (set by a metronome) lasting 2 hours at a work: rest regime of 5 min work : 5 min rest.

sand. Participants in a digging study conducted by Montazer et al., 1989 provided their lowest RPE values when they used shovels with a lift angle in the range 0° to 30°.

4.5.10 Biomechanics: Effect of Posture and Technique on Task Performance

Stickland 1995 provided a definition of the various phases observed during a digging and shovelling task in the British Army. This definition has been adapted into an illustrated format in Figure 4-3 and Figure 4-4 respectively and in the absence of a comprehensive kinematic analysis within the scientific literature it has been adopted as the 'standard' procedure for the purpose of this document.

Measurement of the vertical displacement of the centre of mass of the body during a standard digging task have been made using a LIDOKAS (Loredan Biomedical Ltd, USA) posture measurement system (Bridger et al., 1997). The results described a vertical displacement of 16.5 cm for a conventional spade (Figure 4-9) and 9.4 cm for a novel variant 'levered' spade which had 2 handles.

Lower-back compressive forces (F_{comp} [15]) during a standard digging task (Freivalds 1986b) tended to increase linearly with the decrease in lift angle of the spade of the shovel (i.e. F_{comp} was low at a lift angle of 48° and high at 0°).

Freivalds 1986b proposed an equation to estimate F_{comp} for a specific digging protocol (footnote #15, Section 4.5.9 provides a description of the task) based on the lift angle of the shovel:

$$F_{comp}\ (N) = 4102 - 7.74 \times (\text{lift angle } (°))$$

The highest values for F_{comp} that Freivalds 1986b obtained during their shovelling tasks was 4000 N, and it occurred with a shovel that had a lift angle of 0° and a shovel load of 9.0 kg (which included the mass of the shovel's blade). Axial compression tests on the vertebrae of cadavers have shown stress fractures to occur at F_{comp} of 6750 N for adults under the age of 40 years, and at 3000 N for adults older than 60 years. Sonoda 1962 reported a 17% lower tolerance to F_{comp} with regard to the calculated risk of vertebral stress fracture in women when compared to men. NIOSH[16] 1981 set an upper action limit of 3400 N when considering F_{comp} and the risk of injury to the spine. However, this action limit did not consider the important work-related risk factors such as task repetition, the duration of the task, or the biological age and body mass of employees who were required conducted the work.

Jorgensen et al., 1999 designed a study to investigate the psychophysical criteria that determined the maximum acceptable weight of lift (MAWL) when their fifteen male participants conducted a series of two-handed box lifts from the knee- to waist-height at a rate of 4.3 lifts•min^{-1} adjusting the weight of the box to match their perceived MAWL. A series of physiological and biomechanical parameters were monitored which had been previously identified as risk factors for lower back disorders (LBD). Using a 3D lumbar motion monitor (Marras et al., 1993), bipolar surface EMG (for 10 muscle groups located at the trunk), and a method developed by Fathallah et al., 1997, they were able to calculate the internal moments and forces at the 5th lumbar (L5) and 1st sacral (S1) vertebrae (and the L5-S1 intervertebral disc). Results demonstrated that self selected MAWL was a poor indicator of LBD risk. When a weight that was similar to a heavy shovelling task (i.e. 9.1 kg) was lifted repetitively for several minutes, the average maximum spinal forces of: 561.5 N (lateral shear force); 1091.1 N (anterior/posterior (A/P) shear force); 5174.4 N (compressive force) at the L5-S1 intervertebral disc were evident. Although these forces were considered by the participants to be acceptable, according to NIOSH 1981 microfractures of the vertebral endplates would be expected in 50% of the working population in the USA at compressions of

[15] F_{comp} were estimated (using the University of Michigan 3-D biomechanical strength prediction model (Chaffin and Baker 1970)) from postural angles that were evident from still photographs of actions that had been conducted during a standard digging task (Frievalds 1986b).

[16] National Institute of Occupational Safety and Health (NIOSH).

only 6400 N. Furthermore McGill 1996 estimated that the shear force tolerance of L5-S1 was only 1000 N, which was exceeded in Jorgensen et al., 1999's calculations for A/P shear force when lifting only 9.1 kg in their study. The compressive forces for lifting the same weight from ground level, whilst standing flexed at the trunk (a typical posture evident in digging tasks), has been shown to exceed MAWL for LBD (Jorgensen et al., 1999). Furthermore, this study concluded that factors which appeared to be associated with the voluntary regulation of repetitive lift weight were heart rate and sagittal moment.

Degani et al., 1993 placed bipolar surface electrodes over the lumbar paraspinal muscles of seven male participants in their study. The full-wave rectified integral (FWRI) EMG[17] value for 3 shovelling conditions were assessed for each participant. Conditions involved holding one of two shovel loads (4.5 kg and 6.8 kg) for a 6 s period at three different heights above ground level (0.025 m, 0.28 m, and 0.56 m). Comparison of the FWRI for each condition and treatment identified that shovel load and height were statistically significant ($p<0.05$) influences on the electrical activity of these muscle groups. FWRI remained at approximately 600 µV for each lift height when raising the 4.5 kg shovel load, however for the heavier (6.8 kg) load FWRI increased from 700 µV (0.025 m height) to 950 µV (0.56 m height).

Methods involving the analysis of digitised video recordings (kinematic analysis[18]) and basic measurements of equipment weight were used to assess back loads during trench digging and shovelling soil in a study that was conducted for a Dutch municipal drinking-water distribution department (Van der Grinten 1987). Back load was found to be greatest at the beginning of the lifting action (the 'extract (lift)' phase 'f', Figure 4-3) observed prior to the throw phase, when the trunk was at its most flexed posture. Use of a simple model enabled compression and torsion moments at the L5-S1 to be estimated. Van der Grinten 1987 calculated moments about L5-S1 of 200 Nm during digging, and 185 Nm for shovelling, with an average shovel load of 7.5 kg and 5.0 kg respectively. Data to describe twisting and forward flexion moments at L5-S1 were also reported (see Figure 4-2).

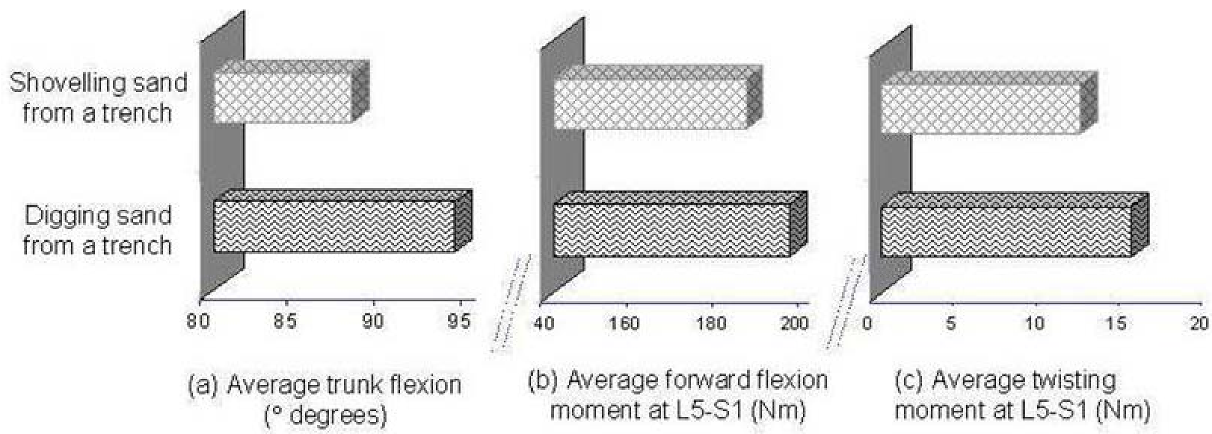


Figure 4-2: Data Reported by Van der Grinten 1987 for Digging and Shovelling Sand from Trenches (at the beginning of the lifting action): (a) Average forward flexion of the trunk; (b) average moment in the lower back at L5-S1; and (c) average twisting moment at L5-S1.

[17] EMG: Electromyography.

[18] Analysis of posture was conducted for still imagery and goniometry when measuring angles between markers that had been placed adjacent to joint centres of motion.

A: Set position B: Dig (place) C: Dig (cut)

D: Extract (loosen) E: Extract (pre-lift) F: Extract (lift)

G: Pre-throw H: Throw I: Recover

Figure 4-3: Standardised Digging with a Shovel in Accordance with British Military Procedures (Stickland 1995).

(i) Shovelling technique observed at the *'recover and set'* phases.

(ii) Alternative kneeling technique observed to dig material.

Figure 4-4: A 'Recover and Set' Phase Variant Observed During Shovelling Tasks, and an Alternative Kneeling Method that has Been Used by Military Personnel.

Hansson and Öberg 1996 estimated the time course and size of the dynamic compression and shear forces at L5-S1 and within the musculature that supported the L4-L5 lower back[19] during digging and shovelling with a standard shovel (weight 6.5 kg, shaft length 1.0 m and a lift angle of 45°). They found that all variables that were analysed had their 'peak' values during the initial extract (lift) phase when moving the shovel. The size of the dynamic forces in the lower back were decreased when the shovel began to move in the horizontal direction. Shear forces at the spine reached a maximum (approximately 425 N) at the

[19] A 3-D biomechanical model developed at the University of Michigan 1993 was used to calculate these forces. Data obtained from an infrared camera system (50 Hz, Mac-Reflex, Qualisys 1993) which tracked the movement of retroreflective markers that had been placed at specific anatomical landmarks on participants provided the data that were required to generate the force estimates.

start of the lift when the trunk was at its most flexed posture. Maximum compression force at L5-S1 (approximately 2700 N) was reached[20] when the trunk was flexed to 90°. Peak forces calculated at the right Erector spinae and Latissimus dorsi during shovelling were approximately 1000 N and 220 N respectively. In both muscle groups the peak forces occurred when the spine was at its most compressed. A simple relationship between trunk flexion angle and spinal load was proposed by Hansson and Öberg 1996. They found that maximum compression forces appeared when the trunk was in the horizontal position (i.e. 90° flexion) but the shear forces continued to increase when the trunk exceeded 90° flexion. Hence they suggested that use of longer shovels would effectively incur lower compression and shear forces when compared with shovelling from ground level using a shovel which had a very short shaft (common in military entrenching tools). However, longer shovels incurred a greater lateral moment loading the trunk as a result of the need to place a hand much further down the shaft to lift the shovel. This moment was considered to be counteracted by the increased muscle action of the Erector spinae.

Forces at the intervertebral disc between the 3rd (L3) and 4th lumbar (L4) vertebrae were calculated by Öberg 1993 for an 80.0 kg participant during a shovelling task with a conventional 1.5 kg shovel (blade load of 5.0 kg, dry sand) to be:

a) Tensile force: 3754 N;

b) Compressive force: 4087 N; and

c) Shear force: 310 N.

The anthropometry of the individual user (the ‘participant’) was an important factor when considering the physical strain during a standard shovelling task (Hansson and Öberg 1996). When using a 6.5 kg shovel (length 1.0 m) participants who were small (height 1.69 m, body mass 63.0 kg) demonstrated less flexion at the trunk when compared with large participants (height 1.87 m, body mass 92.0 kg), and they had a smaller body mass with which to load the spine and consequently they were reported to experience smaller compressive forces at L5-S1. They concluded that handling heavy material with a shovel resulted in disc compression and shear forces that may be harmful to the operator. The often repetitive nature of shovelling was considered to compound the risk. A shovel with a longer shaft than normal decreased the operator’s trunk flexion when beginning to lift the shovel from the ground. The maximum shear forces at the spine were also decreased. However, the lateral moment loading the trunk was increased and the maximum force at the right Erector spinae muscle was also increased. Use of a shovel with a lift angle greater than 10° appeared to decrease the maximum spine compression and shear forces when lifting the shovel from the ground. When lifting the shovel, the load on the spine and on the back muscles was much greater for tall and heavy operators when compared with short and lightweight operators.

4.5.11 Shovel Design

(Additional information may be obtained from Section 4.5.10 concerning the influence of equipment design features on the biomechanics of digging and shovelling).

Matching the physical properties of the shovel to the type of material for which it is to be used, is essential, e.g. a heavy-weight, high-density, stiff metal (high Young’s Modulus), blade would arguably be more effective at shovelling a material composed of heavy clay, or broken rock in preference to a lighter-weight, low density, malleable equivalent of equal dimensions. However, when considering compliance with the human user, managing local muscle fatigue as a result of extended periods of bending is one of the principal concerns facing designers of manual digging equipment. Local muscle fatigue in shovelling is affected by the type of shovel, the height of the task, how high the shovel must be raised, and the weight of the material on it (cited in Degani et al., 1993). Spades have been intended to be used to cut turf and to lift soil (referred to as the ‘material’) during the task of digging a hole, ditch or trench.

[20] This occurred within the first 0.2 to 0.5 seconds of applying force on the shovel.

The shaft of the spade has typically been straight and has traditionally been made from wood. The length of the entire spade has been adjusted to meet the 50th percentile standing elbow height, or waist height of the male user population (Drillis 1963).

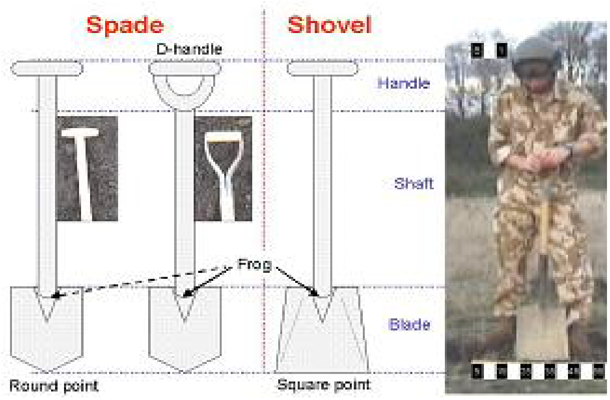
Features of the equipment (please refer to Figure 4-5, and Figure 4-7 to Figure 4-9) have a direct impact on task performance, sustainability and the risk to the user of acute and chronic injury. A number of discrete features of shovel design have been investigated in the open literature with the intention to:

a) Improve work productivity (shovelling efficiency);

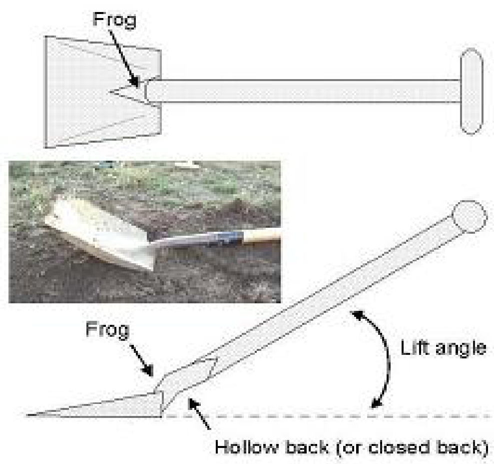
b) Improve energy economy (and thereby sustainability of work throughout the required shift and at the expected work rate); and

c) Reduce the risk of task-related injury.

Research tended to focus upon only one of these 'intentions' for influencing the design of the shovel. Hence there is no single design that achieves all three intended targets. Furthermore, manual digging equipment is rarely provided to fit the individual user, hence the in-service design may favour short employees and disadvantage taller individuals.



(i) A standard spade and shovel.



(ii) A standard shovel.

(iii) Classification of terms used to describe digging tasks.

Figure 4-5: Standard Equipment, Terms and Dimensions Commonly Used to Describe Digging and Shovelling Tasks.

Research to investigate individual design features of digging and shovelling equipment can be readily found in the ergonomics-based journals. The characteristics of the shaft and handle were often investigated, and similar results were reported. McGorry et al., 2003 investigated the shaft configuration on shovelling performance in the snow and they found that increasing the lift angle of the shovel significantly reduced the trunk flexion required to effectively complete an 8-minute digging task.

Pheasant and O'Neil 1975 found that the maximum shear force at the handle of the shovel during the cut phase of shovelling (see Figure 4-4 part (i)) was greatest when the diameter of the handle was 30 to 50 mm. EMG[21] analysis of the flexor and extensor muscles at the elbow found that during the performance of repetitive manual tasks a stronger grip could be achieved when the handle diameter was 38 mm (Ayoub and Lo Presti 1971). Forces evident at the handle of a 'standard' shovel during a digging task were estimated using piezoelectric strain transducers (Lehmann 1953). Peak force in compression occurred at the point then the blade penetrated the target material, whilst tensile forces reached a peak during the recovery swing of the shovel shortly following the throw phase.

4.5.12 External Work and Energy Expenditure of Digging Tasks

Following a meta-analysis of the available data, two equations were proposed by Freivalds 1986 to estimate the external work (W) conducted during shovelling and the expected rate of energy expenditure ($\dot{E}$):

$$\text{(eq1): } W\ (\text{kg}\bullet\text{m}) = 0.514 + 0.38\ L + (0.448\ L \times D) + (0.646\ L \times H) \qquad r^2 = 0.984$$

$$\text{(eq2): } \dot{E}\ (\text{kcal}\bullet\text{scoop}^{-1}) = 0.1795 + (0.0436\ H \times L) + (0.0169\ D \times L) - (0.036\ H2) \qquad r^2 = 0.942$$

(where: W = external work; L = Load (kg); H = throw height (m); and D = throw distance (m))

Moss (1923, 1924a, 1924b) first measured the energy expenditure (using Douglas bags) of shovelling for coal miners who were loading slack. Although the shovelling rate and blade loads were not reported, the rate of oxygen utilisation at the self selected work rate were found to range from 1.59 L•min^{-1} (Moss 1934) to 1.95 L•min^{-1}. During a 2-year study by the Max Planck Institute for Work Physiology the average energy expenditure for miners shovelling coal was found to be 14.3 KJ•min^{-1} and 13.1 KJ•min^{-1} for construction workers shovelling gravel (Lehmann 1950).

Passmore and Durnin 1955 used expired gas analysis to assess the energy expenditure of shovelling for a population of coal miners. Shovelling yielded a rate of expenditure in the range 29.7 to 32.2 KJ•min^{-1}. Åstrand and Rodahl 1986 summarised the results of studies which had assessed the energy expended by coal miners whilst shovelling (working with a pick and shovel) and they reported a typical range from 25.0 to 29.0 KJ•min^{-1}. Research which had been cited to have investigated the oxygen utilisation during shovelling for a number of different postures ranged from 1.0 to 2.0 L•min^{-1}. Åstrand and Rodahl 1986 classified the corresponding 'work intensity' evident during digging and shovelling tasks as heavy (1.0 to 1.5 L•min^{-1}) to very heavy work (1.5 to 2.0 L•min^{-1}). This was similar to data reported by Chakraborty et al., 1974 for Indian coal miners (28.8 KJ•min^{-1}) but much lower than the 39.3 KJ•min^{-1} reported for an equivalent shovelling task in a population of Italian coal miners (Granati and Busca 1941) and the 38.9 KJ•min^{-1} reported by Ayoub et al., 1981 for a similar population. However, Ayoub et al., 1981 found that when their participants were allowed to work a self selected shovelling rate, they maintained these

[21] EMG: Electromyography studies the size and pattern of muscle recruitment (specifically measuring the electrical activity of the observed muscle group).

high energy expenditures for only 3.8 min with a shovelling rate of 25 scoops•min^{-1} which suddenly dropped to a more sustainable 16 scoops•min^{-1} for continuous shovelling.

Pradhan et al., 1987 investigated 3 methods of using 2 variants of the common agricultural spade (spades A and B[22]) within a sample of seven male agricultural (mean (1SD) age 27.4 (5.9) years) workers in India. The 3 methods involved:

i) Digging soil from a standing posture with a 40 degree flexion at the waist, without raising the spade above shoulder height;

ii) Standing upright and using the spade as a pick axe by striking the soil with an overhead swing, and not shovelling the soil at all; and

iii) Shovelling loose soil from a standing posture (flexed at the waist) and throwing the material a distance of 1.5 m.

The results of expired gas analyses identified work rates that afforded the most efficient use of oxygen for each of the three methods and spade variant. Work rates of 38 scoops•min^{-1}, 22 and 17 scoops·min^{-1} were found to be physiologically most efficient for a sustained digging protocol when conducting methods i, ii and iii respectively. Method iii incurred the highest oxygen cost of the 3 methods despite the lower work rate, with method ii being the next most aerobically demanding. Regression analysis to predict VO_2 for the 2 spade variants produced the following equations:

Spade A: VO_2 (L·min^{-1}) = 0.03 x Digging rate (scoops·min^{-1}) +0.83

r = 0.66

Spade B: VO_2 (L·min^{-1}) = 0.02 x Digging rate (scoops·min^{-1}) + 1.20

r = 0.62

Method iii was conducted at a high relative work intensity (up to 89% VO_2max) and required a mean (1SD) rate of oxygen utilisation of 37.3 (4.9) ml•min^{-1}•kg^{-1} for a work rate of 31 to 34 scoops·min^{-1} (the depth with which the spade cut the soil was 12.7 and 13.3 cm respectively for each work rate). In all methods of digging Pradhan et al., 1987 found that the force exertion per scoop was less as the work rate increased (irrespective of the spade variant).

Bridger et al., 1997 reported a mean (1SD) rate of energy expenditure of 43.9 (7.4) KJ•min^{-1} when eleven male participants shovelled 1815 kg of sand at a controlled work rate of 25 scoops•min^{-1} (conducted to the beat of a metronome[23]) using a shovel which weighed 2.1 kg and had a shaft length of 0.60 m. The task was completed in 11.42 (1.58) min (mean (1SD)) and required a steady-state rate of oxygen utilisation of 27.2 (4.8) ml•min^{-1}•kg^{-1}.

Brouha 1960 reported an energy expenditure of 25.1 KJ•min^{-1} for a standard digging task. One study from the USA (TNC Fire 2000) estimated the mean aerobic demand for several standard tasks that were commonly conducted during wild-land fire-fighting. A VO_2 of 22.9 ml•min^{-1}•kg^{-1} was reported for a typical shovelling task. This estimate was based upon the use of the participants' estimated VO_2max

[22] Spade **A**: blade weight 1.3 kg, length of blade 21.4 cm, blade thickness 2.0 mm, length of shaft 0.68 m and total mass of the spade 1.75 kg: Spade **B**: blade weight 1.4 kg, length of blade 22.5 cm, blade thickness 2.5 mm, length of shaft 0.74 m and total mass of the spade 2.05 kg.

[23] The mean blade load was 7.0 (0.7) kg for each scoop.

(indirect assessment of maximum VO_2 to volitional exhaustion) and the relative proportion of their maximum heart rate at which the task was conducted[24].

Ainsworth et al., 1993 have quantified the energy cost of several common digging tasks and reported a predicted MET[25] value for each:

- 4.0 MET: Digging worms with a shovel;
- 5.0 MET: Digging a sand box or domestic digging (i.e. gardening);
- 6.0 MET: Light shovelling (less than 4.5 kg•min^{-1});
- 7.0 MET: Moderate shovelling (more than 4.5 to 7.0 kg•min^{-1});
- 8.5 MET: Shovelling and digging ditches;
- 9.0 MET: Heavy shovelling (more than 7.3 kg•min^{-1}).

When a 1.33-kg shovel (handle length: 1.3 m, blade size: 0.0891 m^2, blade to weight ratio: 0.067 m^2•kg^{-1}) was used to conduct a 1-hour digging task (work rest routine of 5 minutes of digging following by a 5 minute rest and so on) using foundry casting sand (moistened to 2.5% saturation) that originated in a pile at ground level and was shovelled into a barrel of 0.7-m height at a horizontal distance of 1.4 m, the energy expenditure from expired gas analysis of 5 male participants (mean (1SD) age 23.0 (3.6) years; body mass 77.0 (12.2) kg; and height 1.8 (0.1) m) was calculated as 21.8 (7.4) KJ•min^{-1} (Freivalds and Kim 1990). This study used expired gas analysis to assess the energy expended by their participants for five variants of shovel[26], and using an ANCOVA design they reported several equations to best predict the energy expenditure of shovelling. The equation that they recommended for the 1.33-kg shovel was:

E = -103 + 0.0147 L + 2.64 Ws – 0.0159 W2s – 0.244

(r = 0.907)

(Where E = energy expended (kcal); L = blade load shovelled per minute (kg•min^{-1}); and Ws = subject body mass (kg))

When energy expenditure was normalised to the participants' body mass and the blade load, stepwise regression analysis resulted in the following equation (Freivalds and Kim 1990):

E = 10.2 – 0.0057 + 0.0323 Ws – 5.74 H – 24.5 B/W + 177 B/W2

(r = 0.906)

(Where E = energy expended (kcal); H = subject height (m); Ws = subject body mass (kg); B/W = ratio of blade size to shovel weight)

As the size of the blade increases beyond[27] that which affords the optimum 21.6 KJ•min^{-1} rate of energy expenditure (for a sustainable shovelling rate in an 8-hour work shift (Freivalds and Kim 1990)) it has been shown that the total load increased concomitantly with the increased weight of the shovel. Consequently the energy that was expended increased beyond acceptable levels (Freivalds and Kim 1990) and participants experienced an earlier onset of symptoms of physical fatigue. Coping strategies in the

[24] Based upon an assumed linear relationship between submaximal heart rate and VO_2 (and relative proportion of heart rate maximum to relative VO_2max).

[25] MET: The metabolic equivalent (assumed to be 3.5 ml·min^{-1}·kg^{-1}).

[26] The mass of the shovel variants that were used ranged from 0.68 to 2.25 kg, with handle length from 1.2 to 1.3 m, blade size from 0.0586 top 0.1184 m^2 and blade to weight ratio from 0.026 to 0.086 m^2·kg^{-1}.

[27] The optimum blade to weight ratio was reported by Freivalds and Kim 1990 to be 0.0676 m^2·kg^{-1}.

work place were seen to involve participants compensating for the additional weight of the heavier shovel by reducing the blade load (only shovelling half scoops) when using the larger bladed shovels. In addition to the influence of the weight of the shovel and the blade load, Freivalds and Kim 1990 reported that the weight and height of the participant (i.e. the individual who was digging) were also important predictors for the total energy cost of shovelling.

4.6 COMMON MILITARY TASKS (CMT)

Digging and shovelling tasks have been cited within military training, survival and field-craft manuals since records commenced. Common tasks that require military personnel within NATO to manually displace material using non-powered, equipment have been summarised in Table 4-8.

Table 4-8: Digging Tasks that are Common to the Military Role

Military Task Name	Task Specification *(in unfrozen terrain)*	Occupational Role	Equipment	Source Reference
Database of 18 digging tasks, representing 18 MOS'	1.0x1.0x183.0 ft trenches to emplace piping – shovelling a mean (1SD) load of 18.2 (6.6) lbs from a mean (1SD) volume of 48.9 (45.5) ft^3	US Army (laundry and shower specialists MOS 57E)	n/a	Sharp et al., 1998
Standard 4-man trench	12 x 2 x 4.5 ft (*light sand:* 88 to 65 min: *clay:* 257 to 299 min) *Work : rest cycle of 52 min digging and 8 min rest for each hour*	1st Royal Norfolk regiment, British Infantry	Pick and entrenching tool (UK)	Gould 1957
Digging pilot holes to lay explosives for excavation	Digging a (30 to 48) x 1.5-inch hole within which to deploy explosives	Royal Engineers (British Army)	Hand-held auger	Briosi 1980, Stickland 1995
2-man battle trench	1.5 m (H) x 0.75 m (W) x 3.45 m (L) With elbow rests of 0.45 m (W) x 0.3 m (H) Fill 12 to 45 sandbags for protective cover and place (and compact) 0.45 m earth above the shelter *Digging rate * per man:* $0.3\ m^3 \cdot hour^{-1}$ *(*$0.15\ m^3 \cdot hour^{-1}$ *for chalk or rock) or 20 sand-bags*$\cdot$*hour*$^{-1}$ *per man*	Royal Engineers (British Army)	Shovel, pick axe, sand-bags, and trench materials	Briosi 1980, Military Engineering 1993 (Figure 4-14)
4-man battle trench	1.5 m (H) x 0.75 m (W) x 7.75 m (L) With elbow rests of 0.45 m (W) x 0.3 m (H) Dig five anchor wire channels 0.3 m (H) x 0.3 m (L) Fill 36 to 110 sandbags for protective cover and place (and compact) 0.45 m earth above the shelter	Royal Engineers (British Army)	Shovel, pick axe, sand-bags, and trench materials	1993 Military Engineering 1996 (Figure 4-15)

Military Task Name	Task Specification (in unfrozen terrain)	Occupational Role	Equipment	Source Reference
	*Digging rate * per man: 0.3 m^3•$hour^{-1}$ (0.15 m^3•$hour^{-1}$ for chalk or rock) or 20 sand-bags•$hour^{-1}$ per man. Expected 4-hours to complete by hand whilst revetting and camouflage will incur a further 4.5 hours.*			
Fox hole	1.80 (L) x 0.60 (W) x 0.45 (H) m crushed gravel	US Army and Canadian Infantry	Entrenching tool	Deakin et al., 2000
Shell scrape	2.0 (L) x 1.0 (W) x 0.4 (H) m sand	Armed Forces (dismounted land) (UK)	Entrenching tool	Nevola et al., 2003a (Figure 4-6a)
Shell scrape	1.9 (L) x 0.6 (W) x 0.5 (H) m sandy soft clay	Infantry (Canadian Army)	Entrenching tool	Deakin et al., 2000
Sand-bag sangar	2.5 (L) x 1.0 (W) x 1.2 (H) m sand	Armed Forces (dismounted land) (UK)	Pick axe shovel, entrenching tool	Nevola et al., 2003b
Sand-bagging	20 sand-bags filled within 60 minutes	Armed Forces (dismounted land) (UK)	Entrenching tool	Nevola et al., 2003b (Figure 4-6b)
Augering	1.3 m (H) x 0.24 m (W)	Royal Engineers and Specialist Infantry trades (UK)	Independent powered auger weighing 27 kg (Atlas Copco Pionjar, Sweden)	Stickland 1995
Rapid protection trench	0.6 m (H) dig with 0.6 m (H) wall of sandbags to afford a combined H of 1.2 m protection.	Armed Forces (dismounted land) (UK)	Pick axe and entrenching tool	Stickland 1995
Weapon emplacement, vehicle protection, and anti-tank ditches	Various	Various	Manual and powered digging tools, and trench support materials	Military Engineering 1993
Slit trench, latrine, de-turfing, fire trench		Armed Forces (land) (UK)	n/a	n/a

Where the dimension have been reported as: H (height), W (width) and L (length);

** Time to dig the allocated volume of material per man is increased by a factor of: (a) 1.4 when wearing NBC protective clothing (category 2 dress) in warm weather; (b) 1.3 when working at night; and (c) 1.8 for tired or inexperienced troops.*

4.6.1 CMT Analysis

Stickland 1995 described a standard operating procedure for a common military digging task using a conventional (in-service) shovel. This technique has been illustrated in Figure 4-3.

(a) (b)

(c)

Figure 4-6: Common Military Tasks (a) Digging a Shell Scrape, (b) Filling Sandbags (Sandbagging), and (c) Digging Trenches.

Army code no.71271 (Pam 2) 1993 provided guidance to Royal Engineers (soldiers) in the British Army concerning the occasions when manual digging was expected, the target rates of work and some advice on best operational practice in-theatre. The pamphlet recommended that soldiers dug in pairs, and faced the same direction when digging. Discarded material (the spoil) was required to be placed above the trench and on the side that was closest to the enemy position. Filling sandbags was expected to be completed at a rate of 20 bags•hour^{-1}·man^{-1} and when 'combat digging' soldiers were advised to aim to dig 40 m•hour^{-1} (or 40 m•hour^{-1} if the trench construction was located on the side of a hill).

The digging and shovelling required to construct a 4-man trench was expected to be completed in a target time of 4-hours. During user trials to assess the effectiveness of several variants of the military entrenching tool (hand) (ETH), Walker 1979 found that the mean (1SD) time for 4 soldiers to dig a 4-man trench was 5.1 (0.2) hours (data were compared for trench digging in the chalk ground of Salisbury Plain (UK) and the soft clay soil in Germany).

4.7 DIGGING EQUIPMENT (MANUAL LABOUR)

Shovels have been designed to lift and move loose material. The shovel consists of a square, flat blade with raised edges, connected to a shaft at the end of which there is a handle. Drillis 1963 stated that the length of the entire shovel had been based upon the standing height of the user's xiphoid process (50th percentile stature for the male user population). When a handle was present on the shovel it had often been shaped to a 'T' or 'D' grip (see Figure 4-5). The angle of the shaft to the horizontal was called the 'lift' and provided the shovel with added leverage. In a survey of digging tools that were most often used by Swedish workers, the 'standard' shovel was found to have a straight shaft of 1.0 m in length, a 35° lift angle, with a total weight of 6.5 kg (un-laden) (Hansson and Öberg 1996).

The most common non-powered, manual equipment that has been used by personnel within NATO during military operations have been described in Figure 4-7, Figure 4-8, and Figure 4-9.

	Pickaxe (Lightweight)	**Earth Auger**	**Folding Spade**	**Pickaxe** (General Service)	**Pickaxe** (General Service)
Mass (kg)	2.00	6.00	1.16	3.23	2.70
Length (m)	0.66	1.06	0.58	0.91	0.95
Max. Width (m)	0.40	0.11	0.24	0.47	0.50
	UK	*UK*	*NATO*	*UK*	*Austria*

Figure 4-7: Equipment Used to Break or Loosen Ground Material within the Armed Forces of NATO.

	Entrenching Tool Hand (ETH) (Lightweight)	**Entrenching Tool**	**Entrenching Tool**	**S-Pick** (Combined Spade and Pick)	**Entrenching Tool Hand**
Mass (kg)	1.18	1.70	1.13	~0.25	1.25
Length (m)	0.59	0.60	0.60	0.65	0.65
Max. Width (m)	0.15 *(blade)*	0.17	0.16	0.40	0.15 *(blade)*
	UK	*USA*	*Germany*	*UK*	*Austria*

Figure 4-8: Equipment Used to Cut and Displace Ground Material within the Armed Forces of NATO (Part 1).

	Shovel ***(General Service)***	**S-Pick** ***(Spade Configuration)***	**S-Pick** ***(Pick Configuration)***	**Spade**	**Shovel**	**Spade**
Mass (kg)	2.50	~0.25	~0.25	2.00	1.80	1.90
Length (m)	0.92	0.95	0.65	0.85	1.53	1.21
Max. Width (m)	*0.25 (Blade)*	0.20	0.40	0.18	0.28	0.25
	UK	*UK*	*UK*	*UK*	*Austria*	*Austria*

Figure 4-9: Equipment Used to Cut and Displace Ground Material within the Armed Forces of NATO (Part 2).

Dismounted land forces serving in the UK military have 5 types of equipment available to conduct manual digging tasks:

a) Pick axe (General Service) (Figure 4-7);

b) Shovel (General Service) (Figure 4-9);

c) Pick axe (lightweight) (Figure 4-7);

d) Spade (Figure 4-9); and

e) Entrenching tool hand (ETH) (Figure 4-8).

4.7.1 Tools Used to Loosen the Ground Surface

Tools commonly used by military personnel within NATO to break and loosen material have been described in Figure 4-7. Although it is beyond the scope of this report to discuss explosive excavation techniques, the setting of charges that are used in such methods have an initial requirement for drilling or digging holes within which the explosives may be placed. These holes are often dug by hand using one of two methods:

i) Drill kit impact manual (weighing 28 kg); and

ii) Kit Explosive Digging Aid (KEDA L12A1, weighing 1.62 kg).

Augers were considered by Briosi 1980 to offer advantages in terms of time and energy over the use of shovels and pick axes when digging in cohesive materials such as silts and clays (which are likely to be the most difficult (unfrozen) soils in which to dig holes). Excavation (of small holes or trenches) in sand or gravel were considered to be more rapidly completed using a shovel.

4.7.2 Tools Used to Cut and Displace Material

The tools that were commonly used (until 2004) by military personnel within the 26 Nations of NATO to cut and displace material have been described in Figure 4-8 and Figure 4-9.

Reference to the S-Pick concerns the prototype digging tool that had been developed within the UK for British troops to use on operations and which could be configured into a lightweight pick axe or a spade.

4.8 PHYSICAL DEMANDS OF CMTs: PHYSIOLOGICAL REQUIREMENTS

According to the calculations of Stickland 1995 a battalion in the British Army required the equivalent of 113, four-man trenches to be dug in accordance with military procedures. Each trench occupied a total of 6.912 m^3 which was often dug from a clay-based material (the estimated density of clay was reported to be 1.768 $kg{\bullet}m^{-3}$). Stickland 1995 calculated that during Exercise Bold Grouse, the battalion in which he served had dug 12.2 tonnes of material for each of the 113 trenches that the commanding officer had ordered to be excavated by hand (and completed within a 24-hour period). In total the battalion dug 1380 tonnes of material by hand, 183 tonnes of which was also used to fill 14,342 sand-bags. A simple estimate of the work required by each soldier was reported by Stickland 1995 as follows:

Work = (Total mass of material excavated x g x mean height to which the dug material was lifted) x (mass of the shovel x the number of digging actions conducted x the mean height of each excavation)*

Following a number of assumptions Stickland 1995 estimated that each soldier would conduct approximately 124,969 digging actions (see Figure 4-3), and incur an estimated energy cost of 19.62 MJ

* Where ‘g’ represents the acceleration of a mass due to Earth’s gravitational force (constant acceleration of 9.8 $m{\cdot}s^{-2}$).

for this task alone. This value has been found to be typical of the daily energy expended during military field exercises, and on the lower side of the normal range for simulated military operations (and regarded to be representative of 'operational tempo') (Tharion et al., 2005).

Davis et al., 1986 reported that when personnel, who were working at operational tempo in hot dry desert environments with the US Marine Corps, conducted tasks which involved running there was a demand for VO_2 which was in excess of 50 ml•min^{-1}•kg^{-1}. They also cited work by Goldman 1965 who had stated that the upper limit in energy expenditure for soldiers involved in combat operations in a tropical environment was 1.7 to 1.9 MJ•hour^{-1}.

Deakin et al., 2000 assessed the aerobic demand incurred (using a KB1-portable metabolic cart) by 5 male soldiers (mean age of 28 years) who each dug a shell scrape (0.6 m wide, 1.9 m long and 0.5 m depth) at simulated operational tempo. A mean VO_2 of 30.2 ml•min^{-1}•kg^{-1} was reported with the five participants working at 58.6% VO_2max (mean data). During the same study the mean aerobic demand (VO_2) of an entrenchment dig (1.8 m x 0.6 m x 0.45 m, designed by the Canadian research team as a common military task simulation) was reported to be 30.6 ml•min^{-1}•kg^{-1} (which was conducted at a mean 64.2% VO_2max for the 16 male soldiers (mean age 28 years) who participated).

A sand-bagging task (shovelling sand into sand-bags which weighed 26 to 28 kg each (dry weight) when full) within the British Army was first assessed using heart rate monitors and oxylog portable expired gas analysers by Rayson et al., 1994. They reported a mean VO_2 of 30.7 ml•min^{-1}•kg^{-1} (range 22.0 to 34.7 ml•min^{-1}•kg^{-1}) for participants at steady-state, who shovelled dry, medium-grain sand into bags which were held by a colleague at waist height, and at an undefined, self-selected pace. However these data were obtained from 4 male participants (experienced, trained British soldiers) who were subsequently using the sand-bags to construct a sand-bag sangar. These data included the physical demands of lifting the filled sand-bags to a maximum height of 1.8 m. During phase two of a project that was designed to develop evidence-based, operationally-related physical fitness standards for the Royal Air Force (RAF) Nevola et al., 2003b used the Cosmed K4b2 portable, breath-by-breath analyser to assess the aerobic demand of a standardised sand-bagging task[28] (Figure 4-6b). The specification for this task had been defined by military experts from the British Army and the RAF and exploited the information that had been obtained from the first phase of the project (which had used stable isotope analysis to quantify the energy expended during a large-scale military training exercise conducted at simulated operational tempo). Wet sand was shovelled into a bag that was held at waist height and which weighed 28 kg when filled. When 20 bags had been filled with sand, they were carried by-hand (two bags at a time) a distance of 50 m. The entire task was completed in 32 minutes. Unfortunately the mean data that were reported included the aerobic demand of carrying the sand-bags. The mean (1SD) [29] VO_2 of the task was 19.5 (8.8)[30] ml•min^{-1}•kg^{-1} (conducted at a mean (1SD) 45.6 (8.6) % VO_2max).

Construction of a shell scrape (Figure 4-6a) in wet sand (2.0 m length, 0.8 m width, and 0.3 m depth) at simulated operational tempo (shovelling rate of 20 scoops·min^{-1}) was assessed by Nevola et al., 2003b and mean (1SD) data to estimate VO_2 (from relative heart rate reserve in relationship with VO_2max) were

[28] The standardised task required participant to dig sand and fill 20 sand-bags, then carry them to location 50m from the digging position within 60 minutes. Shovel load was approximately 5.0 kg raising the load from ground position (0.0 m) to 0.5 m height, and at an average rate of 20 scoops·min^{-1}.

[29] Where 1SD described 1 standard deviation.

[30] When the aerobic demand of sand-bagging was estimated using the relationship between relative heart rate reserve and the rate of oxygen uptake for submaximal work Nevola *et al.,* 2003b reported a mean (1SD) VO_2 of 23.5 (4.4) ml•min^{-1}•kg^{-1}. The highest value for VO_2 that was observed for a single subject performing this task at a self selected work rate was 39.3 ml•min^{-1}•kg^{-1} (61.0% VO_2max), peak RPE 17.

reported as 23.3 (8.4) ml•min^{-1}•kg^{-1} (at an estimated relative work intensity of 55.3% VO_2max)[31]. The task was completed in 14.0 minutes. (For a summary of simulated criterion-test CMTs please refer to Table 4-11).

Davis et al., 1986 suggested that the US Marine Corps MOS 0311 conducted a digging task with an entrenching tool at VO_2 of 22.5 ml•min^{-1}•kg^{-1}. They also reported RPE data for US Marines who had experience of digging with an entrenching tool on jungle operations (RPE 13), cold climate operations (RPE 17), and desert operations (RPE 13). Digging with a conventional shovel was similarly rated to the entrenching tool for RPE in jungle and cold climate operations but was found to be greater when digging on operational duty in the desert (RPE 16).

Sharp et al., 1998 compiled a database of digging tasks that were conducted by MOS within the US Army. The database identified 18 tasks which represented 18 different MOS'. The reported shovel loads ranged from a minimum 4.5 kg (for 6 tasks) to a maximum 14.9 kg (for 1 task) with a mean (1SD) of 8.3 (7.5) kg. The volume of material dug ranged from 0.08 m^3 (minimum) to 5.2 m^3 (maximum), with a mean (1SD) of 1.4 (1.3) m^3. Frequency distributions for the shovel load and volume of material dug have been presented in Table 4-9 and Table 4-10.

Table 4-9: Frequency Distribution of Shovel Load (kg) During Digging Tasks in the US Army (Adapted from Sharp et al., 1998)

Shovel Load (kg)	Tasks (Number of MOS Tasks)	Proportion of all MOS Tasks (%)	Cumulative Percentage of Tasks (%)
4.5	6	33.3	33.3
9.1	1	5.6	38.9
9.5	9	50.0	88.9
11.3	1	5.6	94.4
14.9	1	5.6	100.0
Total	*18*	*100.0*	

Table 4-10: Frequency Distribution of Volume of Material Moved (m^3) During Digging Tasks in the US Army (Adapted from Sharp et al., 1998)

Volume Dug (m^3)	Tasks (Number of MOS Tasks)	Proportion of all MOS Tasks (%)	Cumulative Percentage of Tasks (%)
0.08	2	11.1	11.1
0.70	1	56	16.7
1.02	11	61.1	77.8
1.50	1	5.6	83.3
1.90	1	5.6	88.9
4.30	1	5.6	94.4
33.50	1	5.6	100.0
Total	*18*	*100.0*	

[31] The highest value for VO_2 that was observed for a single subject performing this task at a self selected work rate was 31.4 ml•min^{-1}•kg^{-1} (74.3% VO_2max).

Table 4-11: Summary of Criterion-Tasks that have been Developed to Predict Digging Performance for Civilian and Military Occupations

Criterion Task	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Test : re-test Repeatability	Source
Entrenchment dig (shovel 0.5 m^3 of dampened, crushed rock from one box to another based on trench dimensions: 1.82 m x 0.61m x 0.46 m)	Best-effort time to complete the task (seconds (s))	481 *(75th percentile)*	Infantry soldiers (Canada)	r^2 = 0.93 to 0.99	Stevenson et al., 1992; Stevenson et al., 1994
Sledge hammering (30, two-handed overhead swings with a 10-lb hammer) Simulated shovelling task (lift 20 x 15 lb shovel loads from ground (0) to 4 feet above the ground)	Best-effort time to complete the task (seconds (s))	n/a	Gas company workers (Canada)	n/a	Jamnik and Gledhill 1992
Dig a slit trench using a standard issue shovel	Best-effort time to complete the task (seconds (s))	n/a	Armed Forces (Canada)	n/a	Lee 1992
Dig a slit trench using a standard issue shovel	Best-effort time to complete the task (seconds (s))	360.0	Infantry soldiers (Canada)	r^2 = 0.86	Chahal 1993
Digging (shovel 1.0 m^3 of sand from one box to another, over a barrier using an entrenching tool)	Best-effort time to complete the task (seconds (s))	n/a	Royal Netherlands Army	r^2 = 0.81 to 0.93	Visser et al., 1996a
Digging 1-man emplacement in 45 minutes	Best-effort time to complete the task (seconds (s))	45 min	Military Occupational Speciality ECHO cluster (MOS, US Army)	n/a	Vogel et al., 1980
Construct a defensive position ~5 ft deep with en entrenching tool. A standardised task required marines to dig a fighting hole in the snow that occupied a volume equivalent to 6 large 20-gallon cans in a best-effort time (self-paced).	Best-effort time to complete the task (minutes (min))	A good time was proposed as 12 to 15 min $^{\theta}$	MOS 0311 (infantryman) US Marine Corps	n/a *this was conducted within a battery of consecutively performed criterion tasks*	Davis et al., 1986
Shovel 800 lbs of polyvinyl chloride from the floor to the top of a 3.5-foot wall, at a constant rate.	Best-effort time to complete the task (seconds (s))	n/a	Underground coal mining (USA)	n/a	Jackson et al., 1991

Criterion Task	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Test : re-test Repeatability	Source
Database of 18 digging tasks, representing 18 MOS', shovelling a mean (1SD) load of 18.2 (6.6) lbs from a mean (1SD) volume of 48.9 (45.5) ft^3 (typically digging 1.0x1.0x183.0 ft trenches to emplace piping)	n/a	n/a	US Army (laundry and shower specialists MOS 57E)	n/a	Sharp et al., 1998
Entrenchment dig (simulation of digging a one person foxhole): 1.80 m x 0.60 m 0.45 m, digging from a material composed of 1.9 cm diameter, crushed gravel (the 1999 protocol conducted in Petawawa and Halifax used pea stone)	Negative reciprocal square root of the time taken to complete the task	10 min 03 s *(developed from a study involving 207 women and 416 men where 52.7% women failed to meet this cut-off time, with only 2.9% of men failing)*	Canadian Forces	n/a	Deakin et al., 2000
Dig task (representative service task #3: digging dry sand from one box to another at a dig:rest cycle of 60 s digging (12 scoops•min^{-1} to a metronome) : 30 s standing rest for the first 12 minutes then dig at a rate of 20 scoops•min^{-1} for a further 12 minutes. A 2-minute rest was then taken and participants resumed this dig: rest protocol until volitional exhaustion (i.e. recommencing at the original, slower shovelling rate).	Time to exhaustion (minutes (min))	n/a	Royal Air Force UK (excluding aircrew)	***β*** 95% limits of agreement > 50%	Nevola et al., 2003b, Du Ross 2003
Modified (v1) dig task (representative service task #3:shovelling 0.25 m^3 of pea shingle with a spade over a barrier of 1m and from one box to another (1.15 m long x 0.87 m wide x 0.25 m deep boxes)	Best-effort time to complete the task (seconds (s))	n/a *(however, expected time limit was 10.0 minutes)*	Royal Air Force UK (excluding aircrew)	***β*** Inter class correlation = 0.937	Rayson et al., 2004a, Rayson et al., 2004b
Modified (v2) dig task (representative service task #3:shovelling 0.25 m^3 of gravel with a spade from one box to another, through a 0.2 m diameter hole at a height of 1.0 m, in a 1.2 m barrier which separated the 2 boxes (1.15 m long x 0.87 m wide x 0.25m deep boxes)	Best-effort time to complete the task (seconds (s))	n/a	Royal Air Force UK (excluding aircrew)	***β*** Inter class correlation = 0.913	Rayson et al., 2004b

β Bland-Altman 95% limits of agreement were used to describe the poor test-retest data that were obtained during this study.

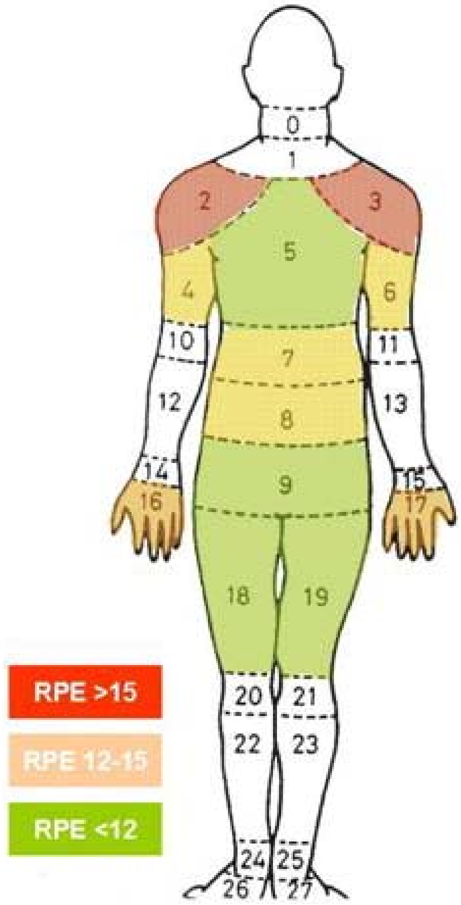
θ The defensive hole dig was performed in a mean (1SD) time of 17.2 (5.6) min (fastest: 5.0 min, slowest: 43 min).

Figure 4-10 identifies the areas of the body and the associated RPE that was reported by Royal Air Force personnel as they conducted the following common military digging tasks:

a) Sand-bagging;

b) Sangar construction; and

c) Digging a shell scrape (Nevola et al., 2003b).



AREAS OF THE BODY PERCEIVED TO INCUR THE GREATEST STRAIN (Nevola et al., 2003b)

SAND-BAGGING	SANGAR CONSTRUCTION	SHELL SCRAPE
5, 4, 6, 18, 19, 2, 3	4, 6, 5, 7, 8, 18, 19	8, 9, 6

Figure 4-10: Body Map to Locate Areas Reported to Suffer the Greatest Perceived Strain During Digging Tasks.

In 1981 NIOSH published guidelines for 'acceptable' rates of work that were considered to be 'sustainable' for an 8-hour work shift in an industrial setting. Their criteria for defining a sustainable rate of work was to recommend a threshold of 33% VO_2max as the mean work intensity during an 8-hour period. Snook and Ciriello 1991 used these guidelines to quantify, in real terms, the threshold limits for a number of work-based, criterion tasks which included lifting and pushing (physical actions that were also associated with shovelling tasks). They analysed the data from twelve women and ten men who each performed 51 variations of lifting and pushing actions[32]. From these data a series of tables were produced

[32] These actions were conducted under conditions of 21.0° dry-bulb temperature and 45% relative humidity.

which proposed threshold limits for percentiles of the normal industrial population within USA for stature and gender. Their data suggested that when the 50th percentile (stature) man was required to exert a two-handed, horizontal pushing force, at a height of 0.61 m above ground level, every 6 seconds (equivalent to a 10 scoops•min^{-1} shovelling task) throughout an 8-hour period, 31.0 kg was recommended as the threshold limit[33]. The equivalent maximum acceptable force for the 50th percentile (stature) woman[34] who performed this pushing task was 16.0 kg. Understanding these recommended limits may help to explain the variance in the findings of studies which have investigated digging performance in ground materials of different properties.

It is common for manual digging tasks to require personnel to lift the loads that are on the blade of their shovel from ground level to knuckle height. Snook and Ciriello 1991 proposed threshold limits for a sustainable rate of repetitive lifting actions (one lift every 5 seconds (12 scoops•min^{-1}) to a vertical height of 0.71 m) throughout an 8-hour shift. The maximum acceptable weight of the lift for this task when performed by a 50th percentile (stature) man was 12.0 kg (a weight that may be evident when digging with a standard 'heavy' shovel with a full load on the blade).

However no load at this high rate of lifting (one lift every 5 seconds[35]) was considered to be sustainable for an 8-hour period[36]. Maximum acceptable weight of lift for the equivalent lifting task for a 50th percentile (stature) woman[37] was 8.0 kg. Once again the guideline threshold for women was considered not to be sustainable for an 8-hour period.

4.8.1 Physiological

Deakin et al., 2000 used a KB1-C portable metabolic cart to assess the aerobic demands of a CMT (an indoor simulation of an entrenchment dig). The task simulation complied with Royal Canadian Regiment Battle School regulations for constructing a standard shell scrape. The intention was to simulate digging of a realistic shell scrape at a pace that was consistent with that required when exposed to a 'nearby enemy threat' (i.e. at operational tempo). The terrain was fairly sandy with some areas of soft clay and a few small trees. The outline for the shell scrape was marked ready to be dug (width: 0.6 m; length: 1.9 m).

When a revised version of the CMT entrenchment dig task was conducted using two adjacent boxes (see Appendix 4A-2) (one empty, the other filled with 0.486 m^3 of crushed rock) VO_2 whilst shovelling the contents of the filled box into the empty one at a self-selected pace (intended to simulate operational tempo) was an average 23.9 ml•min^{-1}•kg^{-1} (66.4% VO_2 max) for a population of female[38] Canadian Forces personnel, and 30.6 ml•min^{-1}•kg^{-1} (64.2% VO_2 max) for an equivalent population of men[39].

RPE of a CMT shovelling task for the RAF (Rayson et al., 2004b) was rated as 17 (very hard) on a scale of 6 (very, very light) to 20 (very, very hard) (Borg et al., 1973). Peak RPE data for digging actions

33 For 10th and 90th percentile (stature) men this threshold pushing limit was 43.0 and 19.0 kg force respectively.

34 For 10th and 90th percentile (stature) women this threshold pushing limit was 21.0 and 11.0 kg force respectively.

35 Equivalent to a shovelling rate of 12 scoops·min^{-1}.

36 For 10th and 90th percentile (stature) men this threshold lifting limit was 18.0 and 6.0 kg force respectively.

37 For 10th and 90th percentile (stature) women this threshold lifting limit was 11.0 and 5.0 kg force respectively.

38 Mean age 31 years with an average VO_2 max of 36.0 ml•min^{-1}•kg^{-1}.

39 Mean age 28 years with an average VO_2 max of 47.7 ml•min^{-1}•kg^{-1}.

conducted during sand-bagging, digging a shell scrape and sangar building tasks were also rated as 17 during a study with RAF personnel in the UK (Nevola et al., 2003b)[40].

4.8.2 Biomechanical

Wright 1993, a captain in the British Army, studied digging and shovelling tasks that were conducted by British soldiers in the infantry and Royal Engineers during his MSc thesis. The initial 'cutting' force that was required to dig soil, with a shovel that was commonly used by service personnel, was calculated as 570 N (for the 50th percentile (body mass) soldier in the British Army), which was found to be closely correlated with data obtained from laboratory studies that Capt Wright subsequently conducted using a Kistler force platform.

Video-based analysis of the postures adopted during the construction of shell scrapes, sand-bag sangars and when filling sand-bags with dry sand during a study involving RAF personnel in the UK, found that 37.5% (minimum) to 75.0% (maximum) of the total task time was spent flexed at the waist by 90°. Only 10.0% (minimum) to 25.0% (maximum) of the total task time was spent in an upright standing posture. Digging and shovelling actions occupied from 37.5% of the total task time (sand-bagging) to 86% when constructing a sand-bag sangar (Nevola et al., 2003b).

4.8.3 Factors that Influence the Physical Demands of CMTs

Stevenson and Brown 1923 studied trench digging tasks within the Army using imagery analysis (stroboscopic photography) and expired gas analysis. They found that shovelling performance was most efficient (in terms of the time to move a volume of material) when soldiers worked at a rate of 19 to 21 scoops•min^{-1} with a throw height of <1.3 m (as shovelling performance time increased by 20% with every 1 m rise in vertical throw height above 1.3 m, and by 16% for each 1 m increase in horizontal throw distance beyond 1.2 m). Best results[41] were observed when soldiers digging the trenches first scrapped loose material onto the shovel (which had a shaft length of 0.71 m, weighed 2.27 kg, and had a blade size (area) of 0.0792 m^2) in preference to thrusting it into the target material.

The use of gloves when shovelling was found to result in an 8% increase (~0.1 kcal•kg^{-1}) in the total energy cost of performing an agricultural shovelling task (Derlitzki and Huxdorff 1927). The investigators proposed that the increased energy may be attributed to the added difficulties in securing a firm grip of the shovel when wearing the gloves as compared to an un-gloved grip.

Modifications to the shovel which effectively reduced the frictional resistance when digging into a target material was shown to reduce the total energy cost of shovelling by up to 9.5% (Vennewald 1939).

Deakin et al., 2000 cited a number of studies that had reported an increase in the energy cost of conducting various tasks as a result of the environmental conditions and the effect of different types of protective clothing that were worn by the individual. They reported a 26% increase in the energy cost of running when it was conducted over rough, forest terrain as opposed to a smooth road surface, an increase of 10% for tasks conducted in cold air temperatures as compared with performance under thermoneutral conditions, and a 15% increase in oxygen utilisation during simulated operational (combat) stress as compared with non-stress conditions. However, individual variability was high. Factors that were known to influence the rate and extent to which individuals suffered fatigue (prolonged physical activity, high relative work intensity, high levels of heat stress, dehydration, sleep deprivation, food restriction,

[40] Mean (1SD) proportion of the total time spent conducting digging or shovelling actions in the 3 of the 14 core operational tasks within the RAF was 58.6 (24.7) %.

[41] 'Best results' referred to the quickest time taken to dig the trench.

noise and vibration, etc.) had often been considered to be responsible for less efficient or poorer task performance when compared with a control condition.

Sharp et al., 1998 stated that the prime determinants of the difficulty of a digging task were the volume of material moved, and the conditions of the material (e.g. dry sand vs. frozen or rocky soil). They suggested that although it was less realistic the material used in a standardised digging task should not be influenced by changes in humidity or temperature and should present the same physical challenge to each test participant.

MOMRP 1999 reported an 8 to 18% Improvement in digging CMT performance with increased physical conditioning that could be gained from task-based physical training.

The recommendations based upon the results of a user trial conducted by Gould 1957 (where entrenching tools from the UK and USA were used as well as lightweight alternatives to the standard shovel and pick axe) stated that it was important to military personnel to dig a shelter quickly and efficiently, and that equipment that was provided to achieve this should be:

a) Acceptably low in weight;
b) Enable individual soldiers to use them;
c) Easy to use with different soil types;
d) Acceptable to the user;
e) Portable; and
f) Compatible with personal load carriage equipment.

4.9 TESTS TO PREDICT ‘DIGGING’ PERFORMANCE

Direct methods to assess the energy cost of physical work during military operations is problematic and (at the time of writing this chapter) has not been achieved. However, Tharion et al., 2005 summarise the data that have been obtained during several days of military (Navy, Army and Air Force) training exercises that were conducted at operational tempo and under conditions that effectively simulated operational stress for diverse missions. By reviewing the literature they were able to report a range (minimum to maximum) in energy expenditure from 13.0 to 29.8 MJ•day^{-1} (mean (1SD) 19.3 (2.7) MJ•day^{-1}) that was incurred during military exercises which lasted from 2.25 to 69.0 days (mean 12.2 days). It may be suggested (arguably) that performance standards that are intended to assess an individual’s ability to meet the physical demands of their operational role must also consider whether that same individual is able to sustain a rate of work which would result in such an energy expenditure within the expected time scale.

In 1976 the general accounting office (USA) recommended that the US military services developed physical fitness standards that encouraged service personnel to maintain a level of physical conditioning that afforded effective operational performance. Furthermore it was suggested that the standards should be job specific with no differentiation between men and women. Knapik et al., 2004 reviewed the research that was conducted subsequently and they described how jobs were categorised and assigned to ‘clusters’. Clusters matched jobs which shared a common requirement for specific physical competencies and standards of performance. Representative tasks and criterion fitness tests were developed for each of the 5 clusters that were defined. Echo cluster (the 5th cluster which accounted for 26% of US military personnel and included 184 MOS’) included a representative digging task. This digging task was conducted by individuals and entailed the use of a standard issue shovel to construct a 1-person emplacement as fast as possible (a 45-minute time limit was set). With respect to ‘operational performance’ it was assumed that an individual was capable of sustaining a physical work load of up to 45% VO_2 max for an 8-hour period. Therefore, development of an operational standard (maximum aerobic power) for the most physically demanding tasks conducted by the US Army could use this assumption to recommend a standard for each cluster[42]. Gruber et al., 1965 proposed a method of screening soldiers in the US Infantry for their ability to dig 'hasty fighting positions'. Their method required individuals to perform a series of 100-yard sprints followed by a best effort time to 'excavate a specified weight of earth'. NATO working groups established a criterion military task that involved digging (Knapik et al., 2004). This task required individuals to shovel 1.0 m^3 of dry sand from one container to another in as fast a time as possible using a standard entrenching tool.

The MPFS 2000 (Deakin et al., 2000) was developed as a single standard for Canadian Forces personnel regardless of age, gender or service. A compensatory model was created for the implementation of the single standard and it was based on achieving a minimum composite score based on 6 fitness tests[43] identified as significant predictors of physical performance on 6 common emergency tasks (see Table 4-12). The composite score (ZSUM) for the compensatory model was computed as the sum of standard scores (Z-scores) for each of the 6 fitness tests (giving equal weight to each test). An appropriate performance standard was selected from data obtained by assessing a target sample of service personnel (the Target Performance Group). An overall score of 100 points or greater on the MPFS 2000 was set as a pass mark. This method allowed candidates to achieve the standard in a number of ways by trading off their strengths and weaknesses. However, in accordance with the requirements for a BFOR the MPFS standard had to avoid allowing candidates who fell short of a performance criterion that was directly linked to task success from compensating with an outstanding score in another test. Therefore, minimum passing floors were established for VO_2max (32.6 $ml \cdot min^{-1} \cdot kg^{-1}$), sit-ups (n = 15), push-ups (n = 9) and combined handgrip strength (50 kg) (see Table 4-12). Performance below the floor on any one of the 4 tests resulted in an automatic failure regardless of the overall performance. In addition, minimum Cut-off Levels (CoL) were established for the vertical jump test (0.26 m), and leg dynamometry (79 kg) whereby performances below the CoL received a score of zero points (but was not an automatic failure).

[42] For example, a task that required 8 $kcal \cdot min^{-1}$ would therefore require a maximum rate of energy production of 17.8 $kcal \cdot min^{-1}$ (i.e. 8 $kcal \cdot min^{-1}$ / 0.45) or a VO_2max of 3.6 $L \cdot min^{-1}$.

[43] The fitness tests assessed: VO_2max (20m shuttle run), sit-ups, push-ups, combined handgrip strength, vertical jump, and leg dynamometry.

Table 4-12: Summary of Physical Assessments that have been Developed to Predict Digging Performance for Civilian and Military Occupations

Physical Assessment Used to Predict Digging Performance	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Correlation to Dig Task	Source
Leg extension strength Dynamic shoulder extension endurance (10 contractions•min^{-1} at 21 kg force, repeated to exhaustion)	Force (kg) Repetitions	203.0 74.0	Infantry soldiers (Canada)	r^2 = 0.28	Chahal 1993
Static trunk flexion VO_2max, Leg peak power	Force (kg) L•min^{-1} Power (W)	145.0 3.1 630.0	Infantry soldiers (Canada)	r^2 = 0.36	Singh et al., 1991
Leg maximal power output, VO_2max, arm power decline, leg power decline	n/a	n/a	Infantry soldiers (Canada)	r^2 = 0.39	Lee 1992
Isometric hand grip (sum of both hands) Sit-ups (number conducted in 1-minute) Push-ups (number conducted in 1-minute) Step test (estimate of VO_2max)	Force (kg) n n ml•min^{-1}•kg^{-1}	Men $^{\beta}$ / Women $^{\beta}$ **75** (73) / **50** (48) **19** (17) / **15** (12) **19** (14) / **13** (7) **39** (35) / **32** (30)	Infantry soldiers (Canada)	Men / Women -0.32 / -0.30 -0.04 / -0.20 -0.02 / -0.27 -0.26 / -0.16	Stevenson et al., 1992; Stevenson et al., 1994 (EXPRES)
Isometric strength (sum of several tests) Arm cranking test (estimated VO_2max)	Force (kg) ml•min^{-1}	n/a	Underground coal mining (USA)	r^2 = 0.71 r^2 = 0.68	Jackson et al., 1991
20 m shuttle run (VO_2max (ml•min^{-1}•kg^{-1})) Combined hand grip strength (kg) Push-ups (number) Sit-ups (number) Vertical jump (m) Leg dynamometer (kg) *(UBSD-push, and chin-ups were dropped from the test battery)*	MPFS 2000 fitness test battery	32.6 50 9 15 26 79	Canadian Forces	Men / Women r^2 = 0.19 / r^2 = 0.21 r^2 = 0.02 / r^2 = 0.06 r^2 = 0.02 *Combining results from all tests* [44]: r^2 = 0.22 / r^2 = 0.30	Deakin et al., 2000 [45] Total sample (all participants) r^2 = 0.64

[44] The r^2 value that was reported when regressing all test data (prior to rationalising the number of tests in the MPFS 2000 battery) with trench digging performance by Deakin et al., 2000 for men and women respectively was $\mathbf{r^2}$ = 0.26 (*men*: VO_2max, vertical jump, leg dynamometer, UBSD-push, UBSD-pull, combined handgrip, and back dynamometer) $\mathbf{r^2}$ = 0.33 (*women*: VO_2max, vertical jump, and back dynamometer).

[45] When Deakin et al., 2000 analysed the data for all of their participants (i.e. pooling data for men and women) those test variables which afforded the greatest predictive power for the trench digging task were as follows: (1st) VO_2max; (2nd) combined hand grip; (3rd) upper body strength device (UBSD-push); (4th) back dynamometer; (5th) chin-ups; (6th) leg dynamometer.

Physical Assessment Used to Predict Digging Performance		Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Correlation to Dig Task	Source
Hill dash time (min) (*150 m sprint up a 6% incline*)		min	n/a	US Marine Corps	0.79	[46]Davis et al., 1986
Sit-ups (n)		n		(MOS 0311	-0.58	
3-mile run time (min)		min		Infantryman)	0.42	
long jump (m)		m			-0.42	
perceived exertion (RPE)		RPE (6 to 20 scale (Borg 1973))			0.4	
Isometric muscle strength (5 muscle groups) Vertical jump test Body fat Cyclo-ergometry (estimated VO_2max)		n/a	n/a	n/a	n/a	Bertina 1997 ('Assessment of Physical Capabilities' APC)
Entrance tests Step test (Heart rate) Upright pull (kg)	*On-the-job tests* 2-mile run (min) Push ups (n) Sit-ups (n) Squat thrusts (n)	(As indicated in brackets)	n/a	MOS ECHO cluster (US Army)	n/a	Vogel et al., 1980

[46] US Marines in the original research conducted each critical task one after the other with only a 2-minute rest between tasks. Performance time was taken for completion of the entire battery of critical tasks under conditions of cold weather/high altitude following acclimatisation. Standardised canonical coefficients of physical fitness test data to performance on the battery of critical tasks have been reported (the *defensive fighting hole dig task* had a reported canonical correlation coefficient of 0.39 with the task battery).

Deakin et al., 2000 performed separate principal component analyses with varimax rotations on their CMT and fitness test data for their male vs. female participants. It was found that the pattern of test variable loadings was the same for men and women, which provided evidence of similar correlation patterns among the tests between men and women despite the differences in performance level. This finding was interpreted by Deakin et al., 2000 to further justify the development of a single minimum physical fitness standard for men and women.

When RAF personnel conducted a shovelling CMT the results of a questionnaire to assess the relevance of the CMT to task-based, operational requirements found that the majority of participants acknowledged that use of a digging CMT was an effective method to discriminate between individuals who were capable of conducting core operational tasks from those who were incapable (Rayson et al., 2004b). Furthermore, RAF personnel who had experience of working on operations reported that the digging CMT that was used by the RAF was indeed an effective means of discriminating between those individuals who were capable of digging a slit trench from those who were not capable (Rayson et al., 2004a).

4.9.1 Content (Criterion-Based Tests and Simulations)

One of the studies that was conducted by Deakin et al., 2000 assessed the performance of 623 participants (416 men and 207 women)[47] on an entrenching dig CMT[48]. Participants were representative of military personnel in the Canadian Forces with respect to physical fitness for each of 4 quartile ranges in age[49], and who afforded equal representation across the three services (Army, Navy and Air Force). Best effort times (mean (1SD)) for digging the 0.486 m^3 volume of crushed rock were 11 min 11 s (4 min 12 s) for women[50], and 5 min 445 s (1 min 41 s) for men. There were significant disparities between male and female performance scores on most of the MPFS 2000 tests and CMT tasks.

Pearson product moment correlation between fitness test and CMT performance ranged in absolute value between 0.42 and 0.89 ($p<0.001$) when gender was combined (it was generally found that when correlation between fitness test and CMT performance was assessed separately for men and women there was a much larger variance). Deakin et al., 2000 found that performance on one of the 5 CMTs was more closely correlated to performance on another CMT than any single fitness test. They explained that this was probably due to the proximity of the physical abilities that each CMT required in order to achieve the desired performance.

When men performed the entrenchment dig CMT (Deakin et al., 2000) the closest correlations were reported for:

a) VO_2max ($r = -0.44$);

b) CMT sea evacuation ($r = 0.55$);

c) CMT land evacuation ($r = 0.53$): and

d) CMT low/high crawl ($r = 0.43$).

When women performed the entrenchment dig CMT the closest correlations were reported for:

a) VO_2max ($r = -0.46$);

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47 The age range of the total sample was 19 to 53 years.

48 The entrenchment dig was intended to simulate *'self protection in the face of the enemy'* and each subject was required to dig a 1.8 m long, 0.6m wide, and 0.45 m deep trench using a standard shovel. The ground material was a fixed amount of crushed rock which was transported from one box to another and completed in a *best effort* time.

49 Age categories were: (a) 29 years and under; (b) 30 to 33 years; (c) 34 to 37 years; and (d) 38 years and over.

50 Performances ranged from fastest to slowest were: 5 min 52 s to 28 min 45 s for women; and 3 min 32 s to 14 min 40 s for men.

b) CMT sea evacuation (r = 0.55);

c) CMT land evacuation (r = 0.54): and

d) Vertical jump test (r = –0.45).

Visser et al., 1996 assessed a digging task which had been designed to simulate work that was commonly undertaken by the Armed Forces within the Netherlands. Their digging task involved shovelling 1.0 m^3 of dry sand from one box to another, over a barrier. This was a best-effort, timed task and performances averaged approximately 21 minutes[51]. Male participants tended to record an improved performance time (by approximately 36 seconds) on their second attempt at this task when compared with their initial time. When performance times for the two attempts at this task by each participant were compared, correlation coefficients (and coefficient of variation (%)) for the men, women and grouped data were 0.81 (6.1%), 0.94 (4.1%) and 0.93 (5.4%) respectively.

(a) (b)

Figure 4-11: An Example (a) of a Soldier Conducting a Digging Task in the Canadian Forces, and (b) the Subsequent Slit Trench Digging Task that was Initially Developed.

Nevola et al., 2003a identified digging as an action that was essential to several 'core' tasks that had been agreed by subject matter expects to be requirements of the 'generic' operational role for RAF personnel. They later defined the specification of the tasks that required digging and subsequently analysed the associated physical demands (Nevola et al., 2003b). The results of a notational analysis of the actions conducted during 3 of the fourteen core operational tasks (matched to their physical demands) enabled Nevola et al., 2003b to design a Representative Service Task (RST) (content-based) that could be used to establish evidence-based, physical fitness standards for RAF personnel. One of the four RSTs targeted digging/shovelling performance and involved shovelling 0.5 m^3 of sand (this volume equated to that required to fill 20 sand-bags or an individual's expected quota (within a team of four personnel) when

[51] Men on average completed the task in 21 minutes, whilst women took 32 minutes to dig the 1.0 m^3 of sand.

digging a sand-bag sangar or trench). During a follow-on study that was conducted at RAF Marham (UK) involving 33 male and 4 female RAF personnel[52] Du Ross 2003 assessed the repeatability[53] of all four RSTs that had originally been proposed by Nevola et al., 2003b.

It was recommended that the format of the digging RST (Figure 4-12) was revised (Figure 4-13) in order to reduce the test vs. re-test variability and to reduce the risk to the participant of incurring a back injury (i.e. to conform to existing health and safety requirements).

Figure 4-12: The Original Protocol for the Representative Service Task Digging Conducted During the Assessment of 'Repeatability' by Du Ross 2003.

[52] These personnel (mean (1SD) age 26.6 (6.7) years; height 1.74 (0.09) m; body fat 18.7 (7.4) %; Hand grip strength 47.0 (9.1) kg) were eligible for deployment on operations with the RAF, they were familiar with the core operational tasks, and they included *junior* (aircraftsman) to *senior* (squadron leader) ranks. Sixty-three percent of the participants had shovelled sand into sand-bags on operations and forty-one percent had experience of digging whilst on deployment.

[53] Repeatability was assessed for test vs. re-test data for the same participants conducting the same RSTs. Pearson product moment correlation, coefficient of variation and Bland-Altman 95% limits of agreement were calculated for data on 3 successful repetitions of the RSTs.

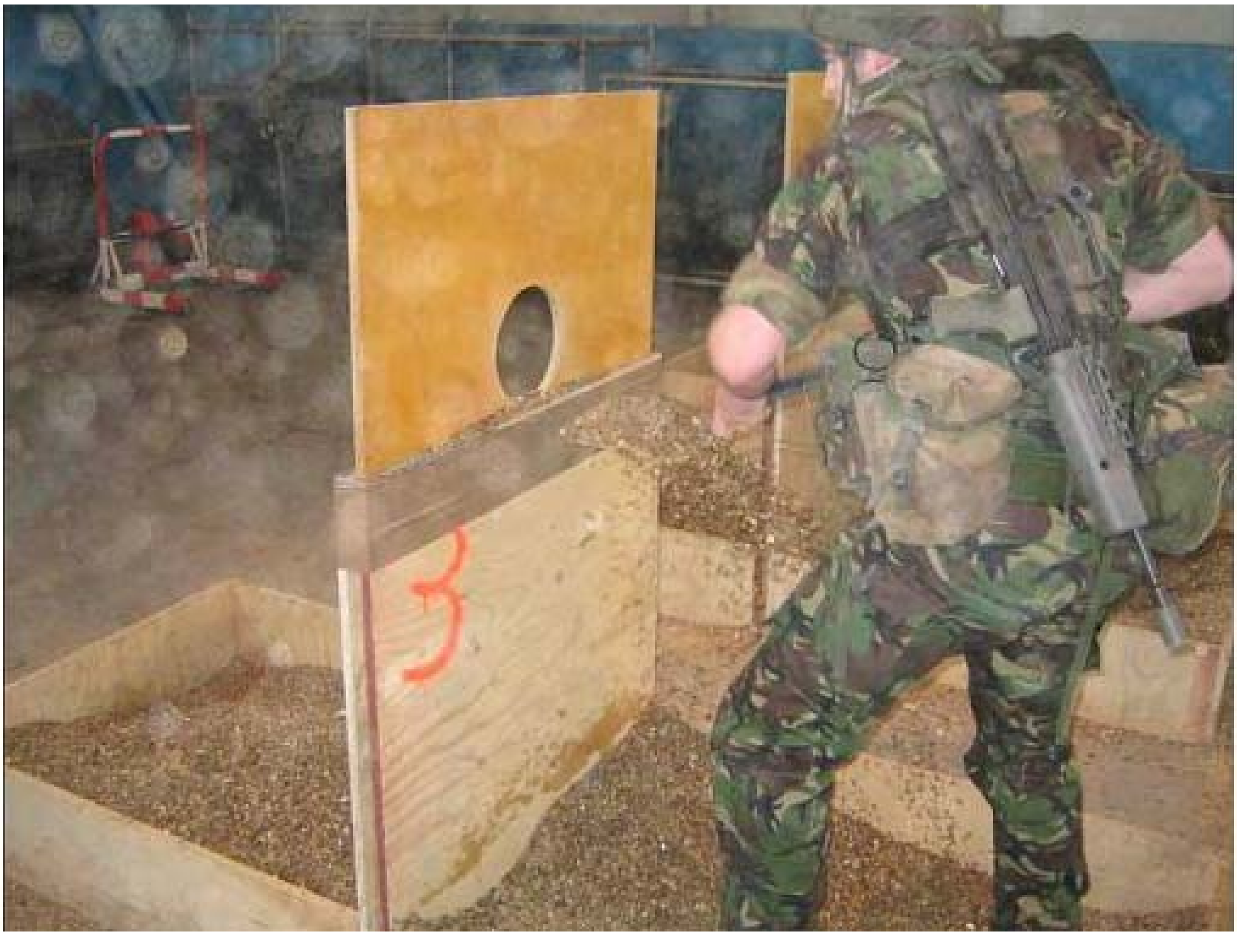

Figure 4-13: The Modified (v2) Protocol for the Representative Service Task Digging Conducted During the Assessment of 'Repeatability' by Rayson et al., 2004a.

In its original format the digging RST required participants to wear full operational clothing (including webbing, helmet and the weapon secured to the back by a sling[54]) whilst shovelling dry sand from one large container (2 m x 2 m grid) to another (2 m x 2 m grid). Participants commenced shovelling at a rate of 12 scoops•min^{-1} (in time with pre-recorded metronome bleeps)[55] for 60 seconds and then stood rested for the next 30 seconds. This work : rest cycle continued for 12 minutes after which the rate of work increased to 20 scoops•min^{-1} for a further 12-minute period. At the end of this period participants rested for 2 minutes before re-commencing the entire 24-minute routine.

This continued until participants could no longer maintain the desired work rate, or until they requested to stop. Performance was assessed by the length of time that the RST was conducted for each participant. Unfortunately complete sets of data were obtained for only 6 male participants, which raised doubt concerning the legitimacy of the analysis to assess this RST. A negative correlation coefficient was reported as a result of participants recording their best performance times on their first attempt at the RST. Poor 'reliability/repeatability' was attributed to changes in the environmental conditions between test vs. re-test, learning effects, fatigue, and a lack of standardisation in the shovelling techniques that had been used by the participants. Du Ross 2003 recommended that the RST digging protocol was modified and re-assessed in-doors during a larger study.

[54] The total load added to the participant's body mass was approximately 20 kg.

[55] However the blade load was not standardised.

The modified (v1) RST digging task involved shovelling 0.25 m^3 of dry pea shingle over a 1.0 m high barrier from one container (1.15 m long x 0.87 m wide x 0.25 m high) to another of similar dimensions, using a spade in a best effort time (Rayson et al., 2004a). Data from 43 participants at RAF Honnington (UK) (representing of a range of trades within the RAF) were obtained for performance on the modified (v1) digging RST conducted on 3 occasions over a 2-week period.

Heart rate was recorded every 5 s throughout each RST and participants provided a rating of their perceived exertion (RPE (Borg 1973)) immediately following completion of each RST performance. Rayson et al., 2004b described a statistically significant bias in the data between the three performances of the modified (v1) digging RST. Participants significantly improved their test times[56] with each subsequent modified (v1) digging RST performance (test 1: mean (1SD) 593 (162) seconds; test 2: 511 (140) s; test 3: 478 (128) s). Analysis of the effect of RAF trade on performance time was not statistically significant (p = 0.223) and cardiovascular strain between repetitions of the modified (v1) digging RST showed no significant difference in mean heart rate data. When comparing test 1 to test 3 performance times the Intraclass Correlation Coefficient (ICC) was 0.937. However, Bland-Altman 95% limits of agreement were 163 s or 30.9% which Rayson et al., 2004b described as being unsatisfactory when seeking reliability/repeatability in test data. It was concluded that modified (v1) digging RST demonstrated poor reliability and substantial improvements in performance occurred with subsequent re-tests. Further modifications to the RST protocol were recommended.

In an attempt to eliminate the learning effect between test performances modified (v2) digging RST was proposed and a small study was conducted to assess its reliability (Rayson et al., 2004b). The modified (v2) digging RST entailed shovelling dry gravel through the centre of a hole (0.2 m diameter)[57] (see Figure 4-13) which stood at the 1.0 m point in a 1.2 m vertical barrier that separated two containers of equal dimensions (1.15 m long x 0.87 m wide x 0.25 m deep). Fourteen participants from the RAF (11 men and 3 women) performed this modified (v2) digging RST on 3 occasions within a 5 day period. The results were similar to the previous study for the modified (v1) digging RST.

There was a statistical bias between test performances ($p<0.001$) with an average 13.4% improvement between test 1 and test 2 (p = 0.006). However, the improvement in performance time between test 2 and test 3 (7.8%, p = 0.073) did not reach statistical significance[58]. The ICC was 0.913 with a 95% limits of agreement of 250 s (or 34.2%)[59]. Analysis of heart rate data collected during the tests (and used as a method of assessing the cardiovascular strain during each test performance) found no difference in mean heart rate between tests (p = 0.67). Rayson et al., 2004b suggested that the improvement in test times was attributed to a skill learning effect and was not related to any difference in physical effort or strain between tests.

Rayson et al., 2004b concluded that the digging RST (all versions) had poor reliability. No plateau in performance times had been observed within any of the tests and repetitions, which was interpreted as evidence that a reliable result could not be achieved without at least two or more full practice sessions (for complete familiarisation with the test protocol).

[56] Mean improvement of 82 seconds (or 13.8%) between test 1 and test 2 ($p<0.01$), and 33 seconds (6.5%) between test 2 and test 3 (p = 0.01).

[57] The intention of shovelling through a hole was to prevent participants from throwing the gravel in an uncontrolled manner, over the barrier. It was hoped that this approach would ensure that each shovel load would be deposited in a more purposeful and consistent manner (reducing inter- and intra-variability in shovelling technique).

[58] It is possible that this may in-part have been due to the relatively small sample size. A power calculation was not conducted for this study.

[59] Test results were as follows (mean (1SD)): *test 1*: 820 (231) s; *test 2*: 710 (194) s; *test 3*: 654 (138) s.

Additional research has been conducted (at the time of writing this chapter) which targeted approximately 50 to 100 RAF participants from a range of trades and specialisations. A further revision to the v2 RST protocol was developed which used a reduced volume (0.125 m^3) of moistened pea gravel (for reasons of health and safety). The draft performance standard for this RST was considered by an expert 'select' panel, and one suggestion proposed an interpretation of data from the previously reported physical demands analyses (Nevola et al., 2003a and b)[60].

Stevenson et al., 1992 assessed the performance of military participants (66 men and 144 women under the age of 35 years) on several CMTs and physical fitness tests, during a 3-year study to develop physical performance standards for the Canadian Armed Forces. An entrenchment dig task (see Table 4-11) was designed and used within the study. Participants completed the best effort entrenchment dig task[61] in a mean (1SD) time of 252.8 (49.8) s (men) and 507.8 (133.9) s (women). Test, re-test correlation to assess repeatability was reported to be r = 0.99. Pearson product moment correlation coefficients for EXPRES test results with entrenchment dig task performance were:

Men: (a) –0.26 (VO_2max); (b) –0.32 (maximum handgrip strength);

(c) –0.04 (sit-ups); and (d) –0.02 (push-ups);

Women: (a) –0.16 (VO_2max); (b) –0.30 (maximum handgrip strength);

(c) –0.25 (sit-ups); and (d) –0.27 (push-ups).

A common (i.e. same for men and women) cut-off score for the entrenchment dig task was proposed by Stevenson et al., 1992 and accepted at the 75th percentile (performance score) of the representative sample, as 481 seconds (or 8 minutes). Fifty percent of women who were tested were unable to achieve (or better) this cut-off score, whilst 100% of men met this performance threshold.

4.9.2 Construct (Indirect Tests to Predict CMT Performance)

(See Table 4-12 for a summary of the data reported in the available literature).

Performance tests (construct-based) that have often been used by the military to screen trained personnel or new recruits, tend to have been quick and easy to implement gym- or field-based tests that were economical to administer in terms of time and resources. As such they tended to provide a broad estimate of the physical construct that was being targeted (e.g. use of the 20 m shuttle run test to assess aerobic power). Test, re-test reliability has been a critical factor when evaluating the efficacy with which the physical abilities of individuals may be appropriately classified (Deakin et al., 2000). Aerobic power has been regarded as the single best indicator of physical fitness and an important determinant of physical work capacity (Åstrand and Rodahl 1986) for physically demanding occupations. Research has been conducted to ensure that the popular 20 m shuttle run test afforded acceptable test, re-test reliability ($r = 0.95$, $p>0.05$) and a reasonably accurate[62] prediction of aerobic power when compared with the gold standard measure (Léger and Gadoury 1989). Deakin et al., 2000 conducted a stepwise regression analysis to compare fitness test data with CMT performance. Estimated VO_2max from a 20 m shuttle run test to

60 On the basis that 100 scoops were required to transfer 0.125 m^3 of moistened pea gravel using a general service spade, and that the mean rate of shovelling during the study by Nevola et al., 2003b observed RAF personnel working at 14 $scoops \cdot min^{-1}$ (minimum: 6 $scoops \cdot min^{-1}$; maximum 20 $scoops \cdot min^{-1}$) at operational tempo, an option existed for a performance standard of (100 scoops / 14 $scoops \cdot min^{-1}$) 7 minutes 8.5 seconds. However, a robust validation process was required with the necessary impact analysis (including rates of misclassification for RST vs. core operational task performance).

61 Shovelling 0.5 m^3 of dampened, crushed rock from one 1.82 m long x 0.61 m wide x 0.46 m deep container to another.

62 In a study by Bilzon et al., 2000 it was reported that the size of the 95% confidence interval for the 20-m shuttle run test may reflect an observed performance range (for an individual with a $\dot{V}O_2$max of 41 $ml \cdot min^{-1} \cdot kg^{-1}$) from level 6 shuttle 3 to level 10 shuttle 4.

volitional exhaustion was found to be the best individual test predictor of task time for the entrenchment dig (CMT) for both male and female participants[63]. When the results of 6 fitness tests were compared with CMT entrenchment dig performance for the entire sample (combining the data from male and female participants) $r^2 = 0.64$. The second most important predictor of the entrenchment dig task was combined hand grip strength. The test, re-test reliability of performance tests[64] were reported for handgrip strength ($r = 0.84$), sit-ups ($r = 0.85$), and push-ups ($r = 0.98$) (cited in Deakin et al., 2000).

Lee 1992 obtained performance data from 99 male soldiers in the Canadian infantry who conducted a series of physical fitness tests and a task which involved digging a slit trench using a General Service shovel. Stepwise multiple linear regression analysis was used to design an equation to predict digging task performance for these participants from a combination of 'best predictor variables' within the battery of fitness tests. Lee 1992 reported a correlation of $r^2 = 0.39$ when data from tests to assess maximal leg power output, maximum aerobic power, arm decline power, arm peak power and leg power decline were used to predict digging task time. Chahal 1993 followed-on from Lee 1992's research incorporating measures of body composition, muscle strength and muscle endurance. Analysis of data from 116 soldiers in the Canadian infantry afforded a test, re-test reliability for the slit trench digging task of $r^2 = 0.86$. During this study an equation to predict trench digging task performance used a combination of results from leg extension strength, and tests of dynamic shoulder extension endurance ($r^2 = 0.28$)[65]. Cut-off scores (minimum acceptable performance) were proposed for the slit trench digging task and the associated criterion physical fitness tests (slit trench digging task time: 360 seconds; leg extension strength: 203 kg; dynamic shoulder extension endurance: 74 repetitions (see Table 4-12)). Further development of the physical performance standards for the Canadian infantry found that maximum aerobic power, static trunk flexion and leg peak power afforded the best prediction of slit trench digging task performance ($r^2 = 0.36$ (Singh et al., 1991)). Revised cut-off scores were recommended for the criterion tests that best predicted trench digging task performance[66].

Stevenson et al., 1992 continued the progress of developing BFOR performance standards for Canadian Forces by designing the EXPRES[67] program. An entrenchment dig task was used (see Table 4-11) as a BFOR test against which criterion physical fitness tests were assessed. Subsequent studies which had investigated performance standards for two age categories (individuals younger than 35 years separate from individuals who were 35 years or older) had used an upper limit of 'allowable' heart rates to achieve during the tasks and criterion tests. When the restrictions on allowable heart rate limits for participants (100 men, 66 women) who were aged 35 years or older were removed a 38% improvement in entrenchment digging task performance was observed.

Separate equations for men (n = 137 male soldiers) and women (n = 61 female soldiers) were developed by Visser et al., 1996 to predict performance of a criterion digging task for the Royal Netherlands Army. The results of tests to assess maximum aerobic power (cyclo-ergometry), static leg extension strength, fat free mass and 12-minute run distance afforded the highest correlation with the criterion digging task for men ($r^2 = 0.30$). However, the combination of test data that afforded the best correlation with the criterion digging task for women ($r^2 = 0.45$) were fat free mass, estimated maximum aerobic power (arm-ergometry), elbow flexion isometric strength, and estimated maximum aerobic power (cyclo-ergometry).

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63 However overall correlation for the best combination of fitness test scores and entrenchment dig performance produced an $r^2<0.34$ when data for men and women were assessed separately.

64 Sometimes referred to as *'physical abilities testing'*.

65 Standard error of estimate was 38 seconds for the time to complete the slit trench digging task.

66 Cut-off scores recommended by Singh et al., 1991 were: VO_2max 3.1 $L \cdot min^{-1}$; leg peak power 630 Watts; static trunk flexion 58 kg.

67 EXPRES test was the Canadian Standardise test of fitness known as the exercise prescription test.

4.9.3 The Relationship Between CMT, Criterion-test and Job Performance

In order to assess the relationship between CMTs, fitness (or criterion) tests and the physical demands of the occupational tasks Deakin et al., 2000 reviewed the results of their preliminary studies and designed a validation study for their selected 'target performance group' (these were participants whose VO_2max was 39.4 $ml•min^{-1}•kg^{-1}$ or higher). They established their physical fitness standard on the basis of the performance levels of this target performance group. They sought to develop a single fitness standard using a compensatory model on the basis that an individual participant may not have great physical strength but might have a very high aerobic power which may allow for successful completion of tasks by using alternative legitimate techniques.

The target performance group (TPG) consisted of 321 men (mean (1SD) aged: 31.1 (6.2) years; body mass: 80.1 (9.9) kg; VO_2max: 46.6 (4.2) $ml•min^{-1}•kg^{-1}$) and 42 women (mean (1SD) aged: 30.6 (6.1) years; body mass: 62.3 (8.1) kg; VO_2max: 42.7 (2.3) $ml•min^{-1}•kg^{-1}$) from the Canadian Forces[68]. The performance times of this group when conducting a CMT entrenchment dig task were as follows:

	n	Mean Time (min : s)	1SD (min : s)	Coefficient of Variation (%)
Men	*321*	5 : 27	1 : 27	26.6
Women	*42*	8 : 46	2 : 11	24.9
Entire group	*363*	5 : 50	1 : 53	32.3

Deakin et al., 2000 opted for a ZSUM model[69] in preference to a CANTEST approach when developing their criterion target scores and subsequent performance standard. They compared the number of participants within the TPG who passed and failed on ZSUM scores at both 1.5 and 2.0 standard deviations from the mean. It was found that although there was little difference in the CMT performance scores between the ZSUM quantiles at mean ($\tilde{x}$) minus 1.5 versus mean minus 2 standard deviations, there was a large impact on the percentage of women passing the fitness criterion tests (10% pass at $\tilde{x}$-1.5SD, versus 20% pass at $\tilde{x}$-2.0SD). On the basis that there was no demonstrable improvement on CMT performance scores between $\tilde{x}$-1.5SD and $\tilde{x}$-2.0SD Deakin et al., 2000 selected the more lenient criterion of $\tilde{x}$-2.0SD. Cut-off scores and floor values were established for the MPFS criterion tests such that individuals who were assessed possessed the essential physical competencies that were evident from the physical demands analysis of CMTs. Gold standard passing levels were also recommended for each of the CMTs. The CMT entrenchment dig was assigned a gold standard pass score of 10 min 03 s (which resulted in 2.9% of men (n = 416) and 52.7% of women (n = 207) in the target performance group failing to meet this standard).

[68] The entire sample of 363 participants had mean (1SD) age: 31.1 (6.2) years; body mass: 78.1 (11.2) kg; VO_2max: 46.2 (4.2) $ml•min^{-1}•kg^{-1}$.

[69] The pass score (referred to as the MPFS 2000 score) using the ZSUM model was calculated as ((ZSUM + 18) x 6.784) and has a single passing score of100 points which has been summed from the performance on each of the criterion fitness tests.

Table 4-13: Summary of Research that has been Conducted within NATO to Develop Physical Assessments which Predict CMT or Criterion Task Performance for Occupations with a BFOR to Dig

Criterion test or CMT	Predictor Variables	Relationship to CMT	Occupational Population (& Nation)	Sample Size	Men (M) / Women (W)	Source
Shovelling earth and slag	Isometric arm test	r^2 = 0.67 to 0.72	Steel workers (USA)	n/a	n/a	Arnold et al., 1982
Sledge hammering Simulated shovelling task	Aerobic power (physical demands of shovelling: 1.2 to 3.3 L•min^{-1}, or 28 to 79% VO_2max)	2.0 to 2.7 *Likert scale 1 (best fit to CMT) to 7 (no fit to CMT)*	Gas company workers (Canada)	n/a	n/a	Jamnik and Gledhill 1992
Dig a slit trench using a standard issue shovel	Leg maximal power output, VO_2max, arm power decline, leg power decline	r^2 = 0.39	Infantry soldiers (Canada)	99	***n/a***	Lee 1992
Dig a slit trench using a standard issue shovel	***n/a***	r^2 = 0.28	Infantry soldiers (Canada)	116	***n/a***	Chahal 1993
Slit trench digging	That maximum aerobic power, static trunk flexion and leg peak power	r^2 = 0.36	Infantry soldiers (Canada)	**n/a**	45 W	Singh et al., 1991
Dig one man emplacement in 45 minutes	<u>Entrance</u> (1) Heart rate from step test and %body fat (2) 38-cm upright pull <u>Maintenance</u> (1) 2-mile run (2) Push ups (3) Sit ups (4) Squat thrusts	***n/a*** ***(Standards: Aerobic fitness < 1.5 L·min^{-1}; Strength <30 kg to lift from ground to waist height)***	Echo cluster (56% of all MOS', ~26% of all US Army)	228	184 M, 44 W	Vogel et al., 1980
Digging sand	Models were based on muscle strength and aerobic endurance	r^2 = 0.3 M r^2 = 0.45 W	Netherlands Armed Forces (Army)	188	137 M, 61 W	Visser et al., 1996a
Entrenchment dig	Isometric hand grip Sit-ups Push-ups VO_2max	r^2 = 0.14 to 0.48 M r^2 = 0.14 to 0.41 W	Canadian Forces	210	66 M, 144 W (aged <35 years)	Stevenson et al., 1992

Criterion test or CMT	Predictor Variables	Relationship to CMT	Occupational Population (& Nation)	Sample Size	Men (M) / Women (W)	Source
Entrenchment dig	Isometric hand grip Sit-ups Push-ups VO_2max	$r^2 < 0.49$M $r^2 < 0.55$ W	Civilians and soldiers (Canada)	166	100 M, 66 W (aged >34 years)	Stevenson *et al.*, 1992

4.10 TRAINING TO IMPROVE 'DIGGING' PERFORMANCE

No direct evidence could be found within the available literature to describe a physical training regime that had been designed with the necessary specificity with which to improve digging performance (during CMTs). However, it may be reasonable to assume that those physical constructs (i.e. aerobic power, and isometric arm strength and endurance) which had been shown to best predict CMT (digging) performance would be prominent within such a task-specific training regime. This assumption remains to be established.

4.11 CONCLUSIONS

Bona Fide Occupational Requirements (BFOR) or 'military occupational specialities' (or their equivalent) have been adopted by the Armed Forces to match personnel to the work that they are physically capable of performing, and to define specific training requirements which best prepare individuals to meet the demands of their operational military role. Historically, the establishment of a BFOR has tended to involve the identification and analysis of the most physically demanding, common military tasks (CMTs). Digging and shovelling actions have been shown to be essential requirements of such CMTs. A summary of CMTs involving digging and shovelling has been provided. The physical demands of digging and shovelling tasks have been investigated and a review of the literature was discussed within this chapter. It was shown that the energy cost of digging and shovelling was influenced by factors such as:

a) Throw height and distance;

b) Blade size and shape;

c) Shovelling rate and blade load;

d) Posture and technique;

e) Nature of the material displaced;

f) The physical state and anthropometry of the individual;

g) Lift angle; and

h) The design of the shovel.

A light-weight shovel with a relatively large-sized blade, and a blade to weight ratio of approximately 0.0676 $m^2 \cdot kg^{-1}$ has been shown to provide the criteria which define the most efficient shovelling of a sand-like material. Digging with a blade that was too large or with a shovel that was too heavy has been shown to increase the rate of energy expenditure (above 21.6 $KJ \cdot min^{-1}$ which has been considered to be the optimum, sustainable rate for an 8-hour work shift) and reduce shovelling efficiency (as it has been shown that very little useful work was subsequently produced). The material properties of the shovel (e.g. density of the metal used to construct the blade) influence the blade to weight ratio which affords the optimum use of energy for a given shovelling task.

Research has been conducted to identify methods of assessing the physical ability of military personnel to meet the demands of digging and shovelling CMTs. However, the reported reliability of such protocols, when screening for digging-based abilities, has been variable (ranging in r^2 from 0.81 (worst) to 0.99 (best)) and lacks adequate agreement with CMT performance (ranging in r^2 from 0.14 (worst) to 0.72 (best)). Association with lower back injuries and the lack of validity as discriminator tests has often resulted in the withdrawal of digging-based tests from screening protocols. However, research and development to establish valid CMT simulations (which involve digging) and associated gym-based tests continues within the Armed Forces of NATO.

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Appendix 4A-1

Summary of Digging Methods Used by the British Army for Specific Material Types (Taken from Wright 1993).

Group	Types of rocks and soils	Suggested **digging methods**
Rocks	Hard igneous and gneissic rocks	Explosive
	Hard limestones and hard sandstones	Explosive
	Schists and slates	**Pick / spade**
	Hard shales, hard mudstone and soft sandstone	Explosive
	Soft shales and soft mudstone	**Pick / spade**
	Hard sound chalk and soft limestone	Explosive
	Thinly bedded limestones, sandstones and shales	**Pick / spade**
	Heavily shattered rocks	**Pick / spade**
Non-cohesive soils	**Compact gravel, or compact sand and gravel**	Explosive / **pick**
	Medium dense gravel or medium dense sand and gravel	**Pick / spade**
	Loose gravel, loose sand and gravel	**Pick / spade**
	Compact sand	**Pick / spade**
	Medium dense sand	**Pick / spade**
	Loose sand	**Spade**
Cohesive soils	**Very stiff boulder clays and hard clays**	Explosive / **pick**
	Stiff clays	**Pick / spade**
	Firm clays	**Pick / spade**
	Soft clays and silts	**Spade**
	Very soft clays and silts	**Spade**

Appendix 4A-2

Entrenchment Dig Protocol for Canadian Forces Personnel: Minimum Physical Fitness Standards 2000 (Taken from Deakin et al., 2000b).

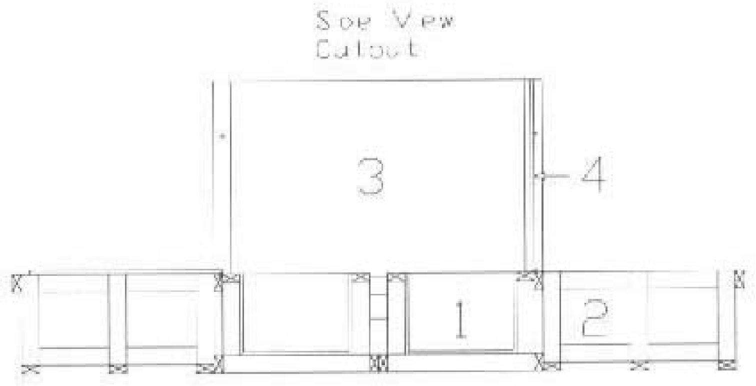
ENTRENCHMENT DIG

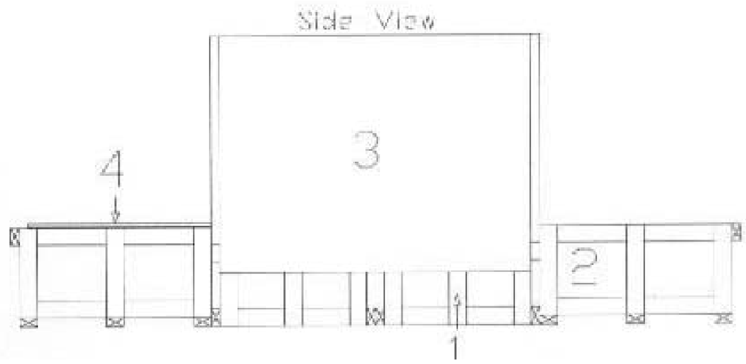
Introduction

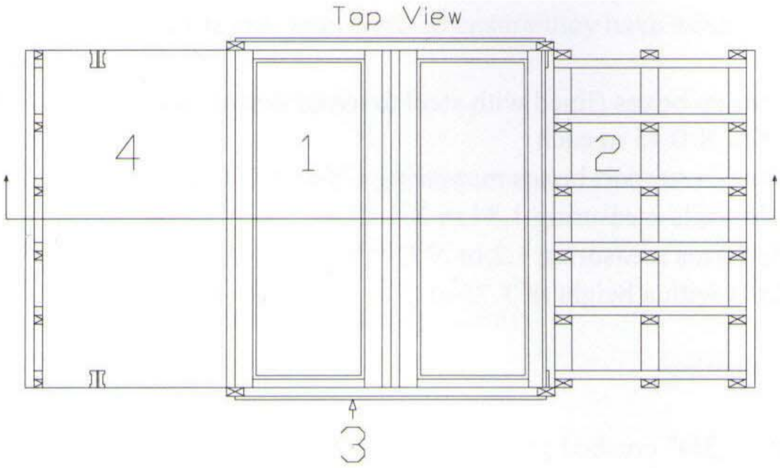
The Entrenchment Dig consists of two boxes to contain the gravel (1), two suppor boxes (2), two side walls (3), and two hinged platforms (4). Prior to testing, one of the sa boxes, measuring 1.8 m x 0.6 m x 0.45 m, is filled with gravel and leveled off.

This task requires the subject to dig out one of the boxes until there is less than on shovel full left in the box. The time required to dig the box will be recorded.

Assembly






Top View
4
1
2
3

Equipment

- Two wooden boxes (lined with steel to avoid destruction of the bottom) measuring 1.8 m X 0.6 m X 0.45 m each
- Two wooden support boxes measuring 1.8 m X 0.6 m X 0.45 m each
- Two side walls measuring 1.84 m X 1.22 m
- Two platforms measuring 1.2 m X 1.95 m
- Four 2X4s with a height of 1.75 m
- Nails
- Rubber matting
- Stain
- Gravel: 3/4" crushed gravel (Trenton); Pea stone (Petawawa, Halifax)

Set up

1. Place the two entrenchment boxes side by side so that the hinged sides open outward from them.
2. Place one support box under the hinged side of each box. Nail each support box to the entrenchment box beside it.
3. Secure the two entrenchment boxes by nailing the 2X4s along the width of both boxes. These 2X4s should form a ledge at a height of 0.6 m.
4. Screw the side walls into the 2X4 wood braces. Do this in a manner such that the holes in the side walls accommodate the sliding bolts in the hinged end pieces of the platform.
5. To prevent gravel form sliding through the cracks, rubber flooring should be stapled to cover any exposed joints.

Maintenance

Daily Maintenance:

1. Check side walls to ensure they are not loose
2. Check wooden platform on which subjects stand to ensure no sign of cracks or failure
3. Check moisture of gravel and add water if needed for consistency.
4. Check the level of gravel and add more until the box is leveled off.

Weekly Maintenance:

1. Clear out any gravel that has become wedged underneath the rubber matting. This may have to be done periodically during the testing session.
2. Check the interior/exterior of the boxes to see if any bowing or splitting of the wooden containers is occurring. Repair as needed.
3. Check the metal liners of the boxes to ensure a tight fit and no gravel has collected beneath the liner.

4. Check the 2X4's supporting the side guardrails to ensure they have not become loose from people leaning on them.

Daily Set Up

Gather the following equipment:

3 shovels: (1.5m high, spade surface area 28cmX 22cm)
gloves
1 stop watch
3 heart rate monitors
water (for HR monitors)
clip boards
towel
2 stable brooms, 1 corn broom
pens

ENTRENCHMENT DIG PROTOCOL

Introduction

The purpose of this task is to dig a trench, measuring 1.8 m X 0.6 m X 0.45 m, as quickly as possible.

The tester is responsible for starting the test with the "go" command and, once the box has been emptied, stopping the test with the command "stop". The tester will record the time taken for the subject to complete the task.

The tester should remind the subject that there is no sitting allowed while digging. The subjects may kneel on the ledge between the boxes or in the box they are digging. It is recommended that subjects start by straddling the box.

Near the completion of the test, it is recommended that subjects use the sides of their feet or their gloved hands, as well as the shovel in a sweeping action.

Instructions to Subjects

The tester will read the following instructions:

1. This task is a simulation of a one-person foxhole dig.
2. You will clear the box, as fast as possible, pitching the crushed rock into the other box.
3. You will start digging on the command "go".
4. (Demonstrate shovel hold and digging technique).
5. The test will end when you are given the command "stop".
6. If you feel that you have reached the end point before being told to stop, you should use the shovel in a "sweeping" action to gather the gravel into piles and continue clearing the box. (Show subject the empty box to demonstrate the end result).
7. Gloves are provided.
8. If you feel this task is too demanding, it may be terminated at any time.
9. Are there any questions?

Appendix 4A-3

Two-man Battle Trench (Taken from Military Engineering Volume Ii Field Engineering Pamphlet No 2 – Field Fortifications, Army Code No. 71271 (Pam 2)).

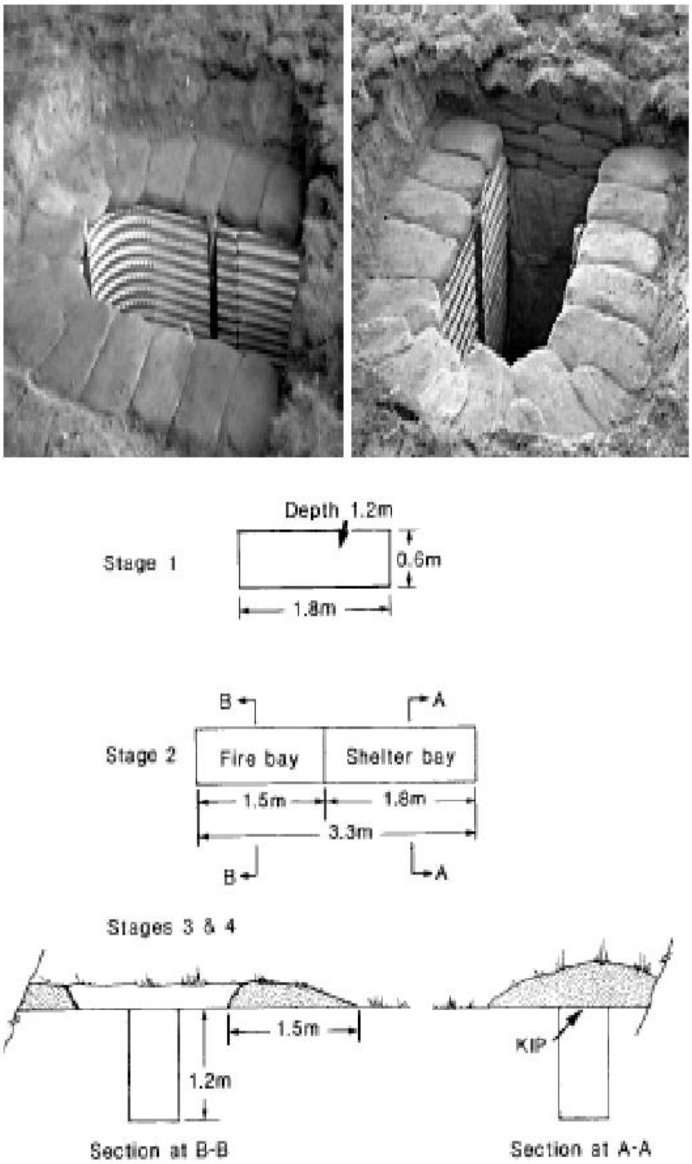


Figure 4A-3-1: Two-Man Battle Trench (One Type that Has Been Used by the British Army).

There are several types of two-man battle trench that are used by military services throughout NATO. Army code no.71271 (Pamphlet 2) 1993 (British Army) specifies the need to use 12 to 24 sandbags, and that all excavation (to the dimensions illustrated in Figure 4A-3-1) conducted by hand using an entrenching tool hand, pick axe and shovel. Approximately 0.45 m depth of material is shovelled and 'compacted[70]' on top of the shelter area within the trench.

[70] The process of compacting material involves striking the material with the blunt aspect of the digging tool or shovel until the material is sufficiently reinforced to avoid noticeable movement underfoot.

Appendix 4A-4

Four-man Battle Trench (Taken from Military Engineering Volume II Field Engineering Pamphlet No 2 – Field Fortifications, Army Code No. 71271 (Pam 2)).

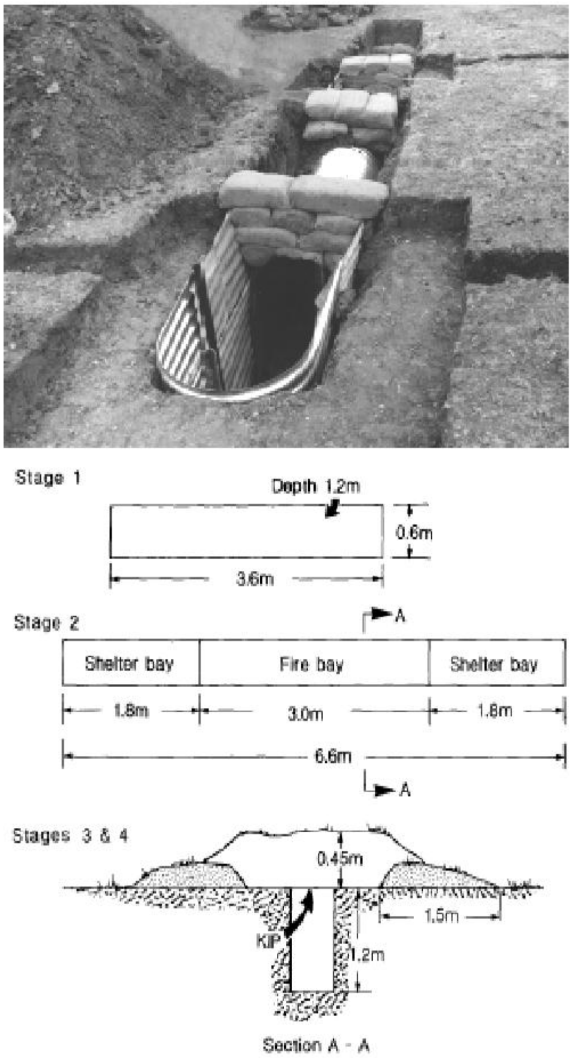


Figure 4A-4-1: Four-Man Battle Trench (One Type that Has Been Used by the British Army).

There are several types of four-man battle trench that are used by military services throughout NATO. Army code no.71271 (Pamphlet 2) 1993 (British Army) specifies the need to use 45 to 110 sandbags, and that all excavation (to the dimensions illustrated in Figure 4A-3-1) conducted by hand using an entrenching tool hand, pick axe and shovel. Approximately 0.45 m depth of material is shovelled and ‘compacted[71]‘ on top of the shelter area within the trench.

[71] The process of compacting material involves striking the material with the blunt aspect of the digging tool or shovel until the material is sufficiently reinforced to avoid noticeable movement underfoot.

Appendix 4A-5

Modified Protocol for the Royal Air Force Representative Service Task (RST) ‘Digging’.

4A-5.1 RST 4 – DIGGING

4A-5.1.1 Aim

To confirm the strength and endurance of the muscles required to shovel 0.25 m^3 of pea shingle (10 mm stone) through a 22 cm radius round hole set into a barrier at a height of 1.1 – 1.3 m (upper and lower arms, shoulder girdle, torso (especially back extensors) and legs). This task represents 2 COTs: digging a slit trench and building a sandbag sangar; and sandbagging. The volume of 0.25 m^3 represents the amount of earth/sand that must be shovelled to fill 10 sandbags. During operations, filling sandbags and digging a slit trench may need to be performed as quickly as possible, which is the rationale behind the task. The height of the hole in the barrier (1.1 – 1.3 m) has been introduced as when filling sandbags the shovel is lifted to around 1.2 m if the sandbags are held fully upright (Rayson MP and Wilkinson DM, 2002) and when constructing a trench or sandbag sangar the earth must be moved up and out of the trench a variable height depending on the depth of the trench. A height of 1.1 – 1.3 m provides a reasonable representation of these variable, heights of lift of the shovel. The hole has since been introduced to ensure standardised technique (stopping people flicking shingle over) and to better reflect the task of sandbagging.

4A-5.1.2 Test Overview

The test should be conducted in groups of up to 6 personnel and consists of shovelling 0.25 m^3 of pea shingle with a spade through a hole set into a barrier at a height of 1 – 1.3 m in the fastest possible time.

4A-5.1.3 Procedure

4A-5.1.3.1 Practice

Personnel should be briefed and shown a demonstration of how to shovel the pea shingle according to the coaching points (4). Each person should then be allowed 5 practice shovels in accordance with the test protocol (3.2), to familiarise themselves with the techniques and to select a sustainable work rate.

4A-5.1.3.2 Test

Personnel must stand in the box at all times, on top of the gravel initially. Using the spade provided, the gravel should be moved from the first to the second box as quickly as possible.

4A-5.1.4 Coaching Points

- The gravel may be moved using any style, provided that the spade is used to move the gravel through the hole into the second box and that the personnel stand within the dimensions of the box.
- Personnel should be provided with the following coaching points by the Instructor (this is advice only and other methods can be used):
  - Demonstrate how to hold the spade and dig into the pea shingle.
  - Show personnel they can kneel in the box while shovelling to ease possible back strain.
  - Emphasise that the shovel must either pass through the hole or touch the barrier when transferring the gravel into the second box, i.e. the shovel cannot be flicked through the hole whilst standing at the back of the box.

  - Indicate that when the gravel level gets lower they can drag the gravel to the front end of the box, to pile it up.
  - When the box is almost empty they can scrape remaining pea shingle to the corner to dig it out.
- Personnel may rest at any time during the test. Personnel must also be briefed that they may withdraw from the test at any stage if:
  - They feel they can not safely start the digging task.
  - They feel they are not capable of finishing the digging task (moving the 0.25 m^3 of gravel).

4A-5.1.5 Dress

Boots, t-shirt, combat jacket (with sleeves rolled down), combat trousers, helmet and black gloves. weapon and webbing?

4A-5.1.6 Equipment

A purpose built digging box internal dimensions 1.15 x 0.87 x 0.25 m, with a 0.20 m diameter hole set into a 1.5 m high barrier at a height of 1.1 – 1.3 m.

- At least 0.4 m^3 of gravel for each box used.
- Data recording sheets.
- Stopwatch to time the digging test.
- Spade (0.72 m long and a blade of 0.19 x 0.23 m).

4A-5.1.7 Test Layout

See Figure 4-13: The modified (v2) protocol for the Representative Service Task digging conducted during the assessment of 'repeatability' by Rayson et al., 2004a.

4A-5.1.8 Recovery

After the test personnel will complete a PTI-led cool down period (approximately 5 min) of low intensity activity (e.g. walking and stretching) as this is the end of the RST tests.

4A-5.1.9 Failures

Personnel who fail to move the 0.25 m^3 of gravel from one box to the other, or personnel who self withdraw or the administrator stops the test for safety reasons.

4A-5.1.10 Data Recording

The result to be recorded is the time taken to complete the task in minutes and seconds, e.g. 3:45 mins.

Chapter 5 – COMMON MILITARY TASK: MATERIALS HANDLING

by

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Photo by Spc. Joshua M. Risner.

Disclaimer: The views, opinions and/or findings contained in this report are those of the authors and should not be construed as official Department of the Army position, or decision, unless so designated by other official documentation.

5.1 INTRODUCTION

5.1.1 Definition of Manual Materials Handling

Manual materials handling (MMH) can be defined as the movement of objects, vertically or horizontally, from one location to another using the body, particularly the hands. This is accomplished through lifting, lifting and carrying, holding, pushing and pulling objects. The manual movement of materials is the most common physically demanding aspect of most non-sedentary occupations, both military and civilian. Lifting and lifting and carrying (L-L&C) constitute the most common physically demanding task performed by the Canadian, US and UK Armies [44, 97, 121, 122]. Although MMH tasks include pushing and pulling objects, the focus of this chapter will be on non-mechanized lifting and lifting and carrying objects, as these types of tasks are the most commonly performed by soldiers.

Both military and civilian studies have focused on manual materials handling from three different disciplines. Biomechanical literature focuses specifically on how the lifting and carrying affect loads placed on the lower spine, where most injuries occur. Physiological literature focuses on understanding fatigue associated with the energy cost of lifting and carrying tasks. Psychophysical techniques include understanding the perception of fatigue as well as the load someone would chose to handle during a work day given a work rate.

5.1.2 Injuries During Manual Material Handling

Heavy L-L&C has long been associated with occupational injury, particularly with lower back disorders [17, 18, 25, 37, 65, 73, 128]. Injury rates from private and public sectors outline the magnitude of injury problems with regard to overexertion in lifting. Overexertion in lifting accounted for 17% of all injuries involving disability, with another 28% of injuries caused by other types of overexertion (wielding, throwing, holding, carrying, pushing and pulling). All types of overexertion combined account for ~24% of lost work time. Men suffered most of the injuries in private industry, and also took longer to recover from work-related injuries than women [77].

The back is the most consistently injured body part. Data from 1994 indicates that a quarter of all workplace injuries are to the back [77]. Back injuries account for 27 – 28% of injuries involving disability, and 11% of lost work time. *"Injuries to the lumbar region of the back were the most numerous in all US industries." (p. 133)* [78]. In the US Army from 1990 to 1994, back-related problems accounted for 20% of all physical disability cases resulting in discharges from service [22]. Data from the Defence Medical Surveillance System indicates that disorders of the back (International Classification of Diseases, Version 9 code 724) had the second highest number of outpatient visits from 1998 – 2005 resulting in 232 visits / 1000 person-years (unspecified disorders of joints ranks number one at 253 visits / 1000 person-years) [data obtained from on-line access of Defense Medical Epidemiology Database, May 2006, amsa.army.mil]. Most back injuries involve sprains and strains. In the civilian sector, approximately 70% of back injuries are associated with overexertion in lifting. Males, workers between the ages of 25 and 34, and White, non-Hispanic workers all had higher injury rates to the lower back than other groups [78].

5.1.3 Variability of MMH Tasks

The important task variables for L-L&C tasks are the load lifted/carried, the height from and to which the object is lifted, the frequency with which the object is lifted, the distance an object is carried, team size (whether the task is performed by an individual or a team of soldiers), and the dimensions and characteristics of the object moved. L-L&C tasks vary greatly and have the potential to stress any of the body's three energy producing systems. L-L&C tasks can be purely strength demanding, stressing the ATP-CP system, as in the case of a single heavy lift. Short duration L-L&C tasks, such as lifting and carrying a heavy object for 30 seconds, stress the anaerobic system. L-L&C tasks that are repetitive in nature, and last more than a few minutes are aerobically demanding, as in the case of unloading a number of boxes from pallets.

5.2 DESCRIPTION OF MILITARY MANUAL MATERIAL HANDLING TASKS

5.2.1 Recommended Limits or Standards Set for L-L&C Tasks

There are industrial load limits (Germany, Greece, Austria, Finland) or ergonomics guidelines (USA, UK, Netherlands) for many NATO countries [82]. The best known guideline in the United States is the National Institute for Occupational Safety and Health Work Practices Guideline [144]. The equation provided in the guideline can be used to evaluate the safety of a lifting task and takes numerous task variables into account (lift starting and ending height, load, frequency, reach, handles, task symmetry, etc.). It is a useful equation to determine the effect of changes in task variables. The NIOSH equation was evaluated and modified by Hidalgo et al., [41] to develop a comprehensive lifting model. Two new lifting indices were developed: The Relative Lifting Safety Index, which is used to evaluate a lifting task for a group of workers, and the Personal Lifting Safety Index, which is used to evaluate the relative safety of a lifting task for an individual worker [41]. These indices consider factors in addition to those considered by the NIOSH lifting index, particularly heat stress, body weight, gender and age. Some of the load modifiers were adjusted to include more recent data. The equations for calculating NIOSH or modified NIOSH recommended loads can be found in Appendix 5A-1.

The US Army sets limits on the loads to be lifted by soldiers during the design of new equipment in Military Standard 1472F [4]. The standard sets an absolute maximum load of 39.5 kg to be lifted by one male soldier using two hands from the floor to a waist high surface. This load is decreased if women will be handling the object (20 kg), if the object is to be lifted to a greater height (25.4 kg), if the object is lifted repetitively, or if the object is not compact or extends more than 30 cm away from the body. The limit for lifting from the floor, carrying an object 10 m or less, and replacing the object on the floor is 37.2 kg for men and 19 kg for women. Again, these allowable loads are decreased for repetitive tasks, loads lifted to greater than waist height, and unwieldy objects.

The UK Ministry of Defence has published design guidelines, with permissible loads located at various vertical and horizontal distances from the body for the 97^{th} and 3^{rd} percentile male and female for lifting rates of 1 lift•min^{-1} and 2 lifts•$hour^{-1}$ [3]. These limits are reduced for larger or bulkier loads, loads without handles, higher lifting frequencies, awkward body positions, etc. The goal of these limits and guidelines is to ensure that most soldiers will be able to handle the equipment that is being designed. Unfortunately, for most of these international and military standards, much of the equipment currently in use exceeds these standards, so there is a discrepancy between what is recommended by the standards and what is actually required of the soldier.

5.2.2 Physical Characteristics of Objects Handled by Military Personnel

Physical characteristics of the objects handled vary greatly in size, shape, existence or location of handles, and fluidity. Mital and Ayoub [80] recommended that objects lifted be compact, stable, not extend more than 50 cm away from the body, and that the distance between the hands be kept to a minimum. Handles have been shown to increase maximal lifting capacity by 4% – 30% [82]. US Army Military Standard 1472F [4] identifies the optimal object for lifting as *"an object with uniform mass distribution and a compact size not exceeding 46-cm high, 46-cm wide and 30-cm deep (away from the lifter)", pg 139.* It also assumes the object will have handles, and they will be located at half the object height and 15-cm deep. Not all objects lifted by military personnel meet these specifications. In their review of UK Army MMH tasks, Rayson [97, 101] report that while most objects had good hand coupling, *"A number of examples of large and variable shaped objects were measured which included various missiles, generators and scanners, camouflage nets, etc., which compelled unusual methods of handling. Other objects were* *either asymmetrical in load distribution (generators, missiles, drawbars, etc.) or had unstable loads (camouflage nets, fuel cans, food pots, etc.) thereby reducing performance" pg 396.*

Figure 5-1: Example of Soldiers Performing a Team Lift and Carry Task with an Asymmetrical Load.

Most of the research in the literature on L-L&C capabilities examined box lifting capacity. While it is convenient for research purposes to study box lifting performance, or Olympic weight bar lifting, it should be noted that these investigations represent an artificial environment and reflect the maximum performance possible. The measured L-L&C capabilities must be adjusted downward when handling sub-optimal configuration objects, such as sand bags, liquids [51], camouflage netting [91] or injured soldiers [106, 107].

5.2.3 Scope of Military Lifting and Lifting and Carrying Tasks

5.2.3.1 Loads Lifted and Carried

Rayson et al., [97, 101] and Sharp et al., [121, 122] have described the scope of L-L&C task demands for the United Kingdom (UK) and United States (US) Armies, respectively. Although the methodologies of the two studies differed, the results were similar. L-L&C were the most frequently performed physically demanding tasks. Figure 5-2 is a frequency diagram of the loads lifted and carried by US and UK Army soldiers. The US Army tasks were broken down into Lifting and Lifting and Carrying categories, while the UK Army tasks included both. Although the frequency distributions were similar, it appears British soldiers have a greater percentage of tasks in the highest load category. In the representative sample of tasks examined, the loads lifted and carried by US soldiers range from 4.5 to 85 kg/person as compared to 10 to 110 kg for UK soldiers.

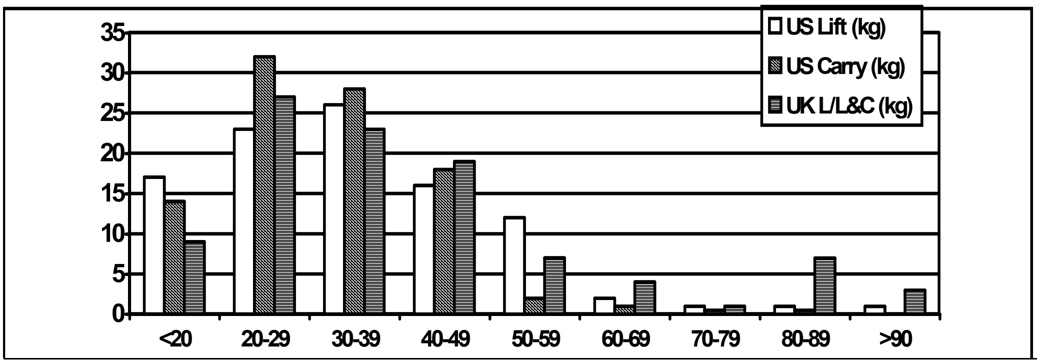

Figure 5-2: Frequency Distribution of Loads Handled by US and UK Soldiers.

5.2.3.2 Heights for Loads Lifted and Carried

Eighty-nine percent of the loads handled by US soldiers are lifted and carried from floor to waist height or below, 9.5% are lifted between waist and shoulder height, and only 1.7% are lifted and carried above shoulder height [121]. Not only do the loads for the British Army tasks tend to be heavier, the objects tend to be lifted higher. Seventy percent of British Army lifting tasks are initiated at floor level. The loads were lifted to waist height (0.8 – 1.3 m) in 57% of the tasks, to shoulder height (1.4 – 1.6 m) in 28% of the tasks and above shoulder height (>1.6 m) in 15% of the tasks [101].

5.2.3.3 Carry Distances for Loads Lifted and Carried

More than half the lift and carry tasks performed by both US and UK soldiers involve carries of 10 m or less, and the majority (>80%) are carries of 50 m or less (Figure 5-3). Loads in excess of 45 kg are carried an average distance of 11 m (range = 1 – 34 m), however, there is no relationship (r = –0.02, p = 0.74) between the weight of the load carried and the distance it is carried [97, 121].

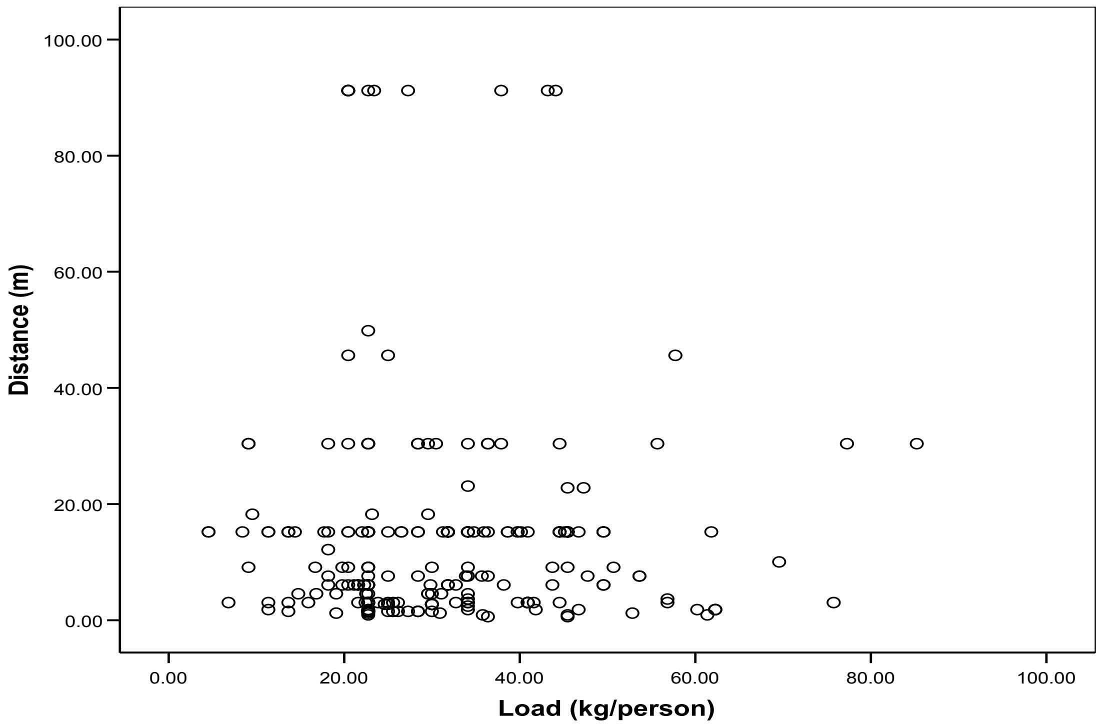

Figure 5-3: Relationship Between Load and Distance Carried for US Army Lifting and Carrying Tasks.

5.2.3.4 Scope of US Army Lifting/Lowering Tasks

The mean load for all US Army lifting/lowering tasks was 35.5 ± 17.0 kgs. The 25th, 50th, and 75th percentile loads calculated were 22.7 kgs, 34.1 kgs, and 48.9 kgs, respectively. The mean load lifted to each vertical lift height was: 44.1 ± 13.6 kgs to knuckle height (n = 27), 34.0 ± 19.0 kgs to waist height (n = 36), 28.2 ± 13.5 kgs to shoulder height (n = 25), and 35.5 ± 18.9 kgs above shoulder height (n = 4) [121].

5.2.4 Scope of Military Team Tasks

The mass or size of the load of many manual materials handling (MMH) tasks mandates the use of multiple-person teams. Examples of these tasks are moving bridge construction parts, carrying injured persons on stretchers and setting up camouflage. The majority of research on team lifting performance has concentrated on either a single maximum lift [48 – 50, 109, 123, 125] or the maximum acceptable weight of load (MAWL) for repetitive lifting [23, 45, 95, 113, 123]. The team-based task that has received the most scrutiny is patient handling [57, 59, 67, 73, 106 – 108, 138].

5.2.4.1 Military Team Lifting Limits

U.S. Military Standard 1472 F [4] provides recommendations to be used in the design of equipment for the U.S. Armed Forces and makes reference to team lifting. For two-person teams lifting from floor level to 91 cm, the standard recommends doubling the one-person load (79 kg for two men, 40 kg for two women), and a maximum of 75% of the one-person value can be added for each additional lifter beyond two. The Military Occupational Classification Structure [20] describes the physical demands of all U.S. Army jobs, and provides many instances where these standards are exceeded. One example is the medical specialist who treats injured soldiers and transports them on a hand-held stretcher in four person teams. Based on Military Standard 1472 F, four women should not lift patients weighing more than 70 kg. The fiftieth percentile male soldier weighs 78 kg, while the fiftieth percentile female soldier weighs 62 kg [36]. Based on this standard, four female soldiers could safely lift the average female soldier, but should not carry the average male soldier.

5.2.4.2 Assessment of Team Lifting

The one repetition maximum (1RM) isometric and isokinetic strength of teams of two and three men and two and three women [49, 50] and the 1RM dynamic lifting strength of two-, three- and four-person teams of men, women and mixed-gender teams has been studied [48, 125]. All these studies involved a simple lift/lower or isometric (simulated) lift under optimal conditions, using small samples of young healthy individuals. Table 5-1 presents a summary of the 1RM team lifting data from U.S. Army Soldiers [125]. The one person lift was a deadlift of an Olympic weight bar. A square shaped frame of four Olympic weight bars was used for two- and four-person lifting and a triangular shaped frame used for three-person lifts.

Table 5-1: Mean ± Standard Deviation for Maximum Team-Lifting Strength (kg) by Team Size and Gender (Numbers in Parentheses Indicates n of Sample or Number of Teams Included in Mean)

Team Size	Men	Women	Mixed-gender
Individual	137.0 ± 22.1 (23)	84.7 ± 14.2 (17)	
Two-person	252.9 ± 32.8[a](26)	155.8 ± 15.7[b](24)	183.5 ± 24.1[b,c](25)
Three-person	345.1 ± 39.5[d](18)	214.6 ± 17.6[c](18)	262.3 ± 33.5[a](36)
Four-person	493.2 ± 65.3[e](20)	307.7 ± 31.4[f](19)	397.3 ± 37.1[g](21)

[a-g] Letters indicate significant differences between means ($p<0.05$) for team lifting.

To examine the relationship between the sum of the individual lifting strengths of team members and team-lifting strength, the percentage of the sum of individual strength represented by the team strength (% sum) is calculated:

Equation 1: Percent of the sum of individual strengths in team lifting

$$\%sum = \left(\frac{team\ strength}{sum\ of\ individual\ strengths} \right) * 100$$

With the exception of isometric arm lift strength, the team 1RM lifting strength is less than the sum of the individual 1RM lifting strengths by 10% to 40%, or a % sum of 60% to 90%. The % sum varies with the team gender and the specific lifting task. During dynamic maximal lifting (isotonic lifting), the % sum was significantly greater for single gender teams (87% for men; 91% for women) than for mixed gender teams (80%) when lifting in teams of two, three or four [125]. Table 5-2 lists the % sum for three modes of lifting by gender and team size. Teams of men tend to lift heavier loads than mixed-gender teams, while teams of women tend to lift lighter loads than the other gender combinations [126]. The greater the combined strength of a multi-person team the greater the load that is lifted by the team. This has been shown to be true, regardless of differences in stature [95, 125]. Table 5-2 provides a range of several types of team lifting tasks to include deadlift of an Olympic weight bar [125], lifting a load mounted between two poles-similar to lifting a stretcher [95], box lifting [48], and isometric and isokinetic upward pulling on a bar [49, 50]. If norms are available for an individual lifting task, Table 5-2 can be used to estimate the load for various team sizes using the lifting task most similar to that in question.

Table 5-2: Percentage of the Sum of Individual Lifting Strengths Represented by the Team Lifting Strength (% Sum) by Lifting Mode, Team Gender and Size

	Team Size	Men	Women	Mixed-Gender
Dynamic	2-person	87.5 – 89.8 [1-3]	91.0 – 95.6 [1-3]	69.8 – 79.7 [2,3]
	3-person	85.0 [3]	90.9 [3]	78.5 [3]
	4-person	86.0 [3]	90.3 [3]	83.7 [3]
Isometric	2-person	94.1 [4]	79.1 [5]	
	3-person	88.6 [4]	87.0 [5]	
Isokinetic	2-person	66.5 [4]	70.5 [5]	
	3-person	60.3 [4]	72.8 [5]	

[1] Karwowski 1988, [2] Pinder, 1998, [3] Sharp et al., 1997, [4] Karwowski and Mital, 1986; and [5] Karwowski and Pongpantanasuegsa, 1988.

Litter carriage is a common military team task that has been studied, often with the focus on reducing the demands of the task [58, 59, 106, 107]. As in the study by Stevenson [132] a two person litter carriage task is often tested with the rear of the litter supported, and one person performing the task [58, 59, 106, 107]. The US Army uses a four person stretcher carry over an obstacle course during conduct of the Army Field Medic Training and for the Expert Field Medic Badge. As might be expected, handgrip strength has been cited as an important predictor of litter carriage performance, particularly for extended carrying [57, 108, 143]. Time in carrying a litter can be considerably extended by placing more of the load on the torso (as opposed to the hands) through a variety of straps and harnesses [57, 106, 107].

5.2.4.3 Maximum Acceptable Weight of Lift for Teams

In addition to maximum lifting strength, the load a team finds acceptable for prolonged periods of repetitive team lifting is important. The load acceptable to 95% of the working population has been used to set limits for safe materials handling in industrial settings. The MAWL is defined as the load a person is willing to work with under a given set of task conditions. For example, an individual may be asked to determine the MAWL for an 8-hour work day when lifting a box from the floor to a 70-cm high table at the rate of 3 times per minute. The person is given a box that is either too heavy or too light and asked to perform the defined task for a 20-min period. The individual then adds or subtracts weight from the box until it is judged acceptable. The load is adjusted by the individual so that he/she does not become overtired, overheated or out of breath. When working in teams, both team members must agree on the load adjustments and final load.

Unlike the 1RM for team lifting, the MAWL for material handling in teams tends to be equal to or greater than the sum of individual MAWLs (%sum = 98% – 140%) [23, 45]. In pairs of individuals with large strength differences, the lower strength person tends to have a slightly higher heart rate and works at a slightly greater percentage of their physical work capacity than the higher strength person, compared to when working alone. Because they tend to work harder, the weaker individual will fatigue faster over a prolonged exercise period and may be at an increased risk for injury during team MMH tasks [23]. This is reflected in the Rating of Perceived Exertion provided by the lower strength individual. Although individuals of fairly equal strength tend to lift as much or more than the sum of their individually selected loads, they tend to perceive the load as easier than when performing the same task alone [123]. This may be due to the different lifting technique used when working alone versus working in a team.

While the team MAWL is equal to or greater than the sum of the individual MAWLs, this is not true of 1RM team lifts. Task differences may be the source of these opposing results. The 1RM team lift is a one-time, maximum effort involving little decision making. The team is either physically able or unable to lift the load. In contrast, the MAWL is typically a repetitive, submaximal self-selected load, with the procedure allowing time for reflection and adjustment. The individual or team must estimate the load they are willing to handle for an extended period. Because there is a subjective element to MAWL selection, personality interactions may influence the team MAWL while not affecting the 1RM lift. Some studies have shown Type A individuals work at a higher percentage of their aerobic capacity, and are able to determine their MAWL in a shorter period of time than Type B individuals [112, 113]. The higher MAWL for teams than for the sum of individuals making up the team might be an expression of competitive behaviour or a higher level of arousal. Individuals may be more motivated to select heavier loads when working in teams than when working alone for social reasons. This may affect the risk of injury in team versus individual tasks.

Lifting frequency may also have an effect on the % sum obtained during a MAWL as compared to that obtained during a 1RM. Studies that used an infrequent lifting rate, one lift and lower per hour or less, reported % sums of less than 100% [48, 95]. Those studies using a more frequent lifting rate reported % sums approximately equal to or greater than 100% [23, 45, 123]. These low frequency MAWL studies seem to be more comparable to studies of 1RM team lifting, than to studies of team MAWL at higher lifting frequencies.

5.2.4.4 Military Team Task Loads and Gender Differences

In the U.S. and British Armies, the most commonly occurring team size is a two-person team, followed by four- and then three-person teams [97, 121]. In the absence of documentation, it is assumed two-person teams are the most common team size in industrial team tasks as well. The UK Army uses teamwork for 66% of the physically demanding L-L&C tasks [101]. Forty eight percent of the US Army L&C tasks and 53% of the lifting/lowering tasks involved teamwork. A survey of US Army MOS determined that the average load for a two-person L&C task was 59 kg. This is similar to the mean load of 60 kg selected by teams of two-soldiers during a study of the maximum acceptable weight load (MAWL) for repetitive lifting and carrying [123]. Teams of two men selected a load of 72 kg, teams of two women selected a load of 46 kg (22% less than the average US Army two-person lift and carry task), and mixed gender teams (one man and one woman) selected a load of 57 kg [123]. As these gender specific figures represent the mean of the soldiers studied, there are teams within all three gender groups that would experience difficulty with the average US Army two-person lift and carry task, but teams of two women and mixed-gender teams would have the most difficulty completing the team L&C tasks.

In Table 5-3 the median US Army loads for multi-person lifting tasks [121] are listed in column 1 (Task Requirement) as well as the 1-RM load lifted by individual women and teams of two to four women (column 2) [125]. The third column shows the task requirement as a percentage of the maximum load lifted by teams of women (% Women's Maximum). The percent maximum load was determined by:

Equation 2: Determining percent of maximum workload

$$\%\max = \left(\frac{Task\ Requirement}{Load\ Lifted\ by\ Women} \right) * 100$$

Table 5-3: US Army Lifting Task Requirements and Female Soldier Lifting Capability by Team Size

Team Size (persons)	Task Requirement (kg/person) [1]	1RM for Teams of Women (kg) [2]	% Women's Maximum
One	33	85	39
Two	77	156	50
Three	57	215	27
Four	62	308	20

[1] Sharp et al., [121].

[2] Sharp et al., [125].

The loads were lifted to knuckle height, under optimum conditions using a device similar to an Olympic weight lifting bar [125]. The loads were not carried, but rather lifted then immediately placed back on the ground. 1RM loads in Table 5-3 represent the maximum that could be lifted (not carried) by teams of healthy young female soldiers. As teams of all-women tended to have lower maximum lifting strength than mixed-gender or all-men teams, the percentage would be expected to be lower (easier to lift) for all-men and mixed-gender teams. Doolittle, et al., [21] recommends that an individual not lift more than 20% of his/her maximum for repetitive efforts, and not more than 75% for occasional efforts. Based on this, the typical loads encountered by teams of US Army soldiers do not appear to be too great to be lifted occasionally at least to knuckle height.

5.2.4.5 Prediction of Team Manual Materials Handling Performance

Several published regression equations can be used to predict team manual materials handling performance. Dependent variables have included measures of muscle strength (1RM lifting strength, and individual MAWL), anthropometric characteristics (flexed bicep, abdominal, and chest circumference), and gender (all-male, all-female, or mixed-gender teams) [23, 81, 95, 126]. These equations were able to account for between 35% – 98% of the variance in team MMH performance, but most reported a relatively large standard error of the estimate, making them of limited practical use.

5.3 PHYSIOLOGICAL REQUIREMENTS

A number of factors determine the physiological demands of a repetitive L-L&C task. These include the body position, lifting technique, physical characteristics of the load (most importantly the mass), starting height of the lift, vertical travel distance, frequency of lifting, and number of repetitions performed. In addition, environmental factors such as temperature and humidity, and clothing worn, can influence the physiological demands of a L-L&C task.

5.3.1 Technique

Lifting technique will greatly influence the energy expended, particularly during a prolonged repetitive lifting or lifting and carrying task [5, 27, 29, 38, 66, 139, 145]. Although a bent knee, straight back lifting technique is often recommended for safety, this technique is rarely used during repetitive lifting. This form may be maintained during an occasional heavy lift, and is particularly useful when the load fits between the knees [82]. However, squat lifting technique elicits a higher energy cost due to the work of moving one’s body mass up and down. For repetitive lifting, a freestyle or semi-stooped lift is typically self-selected as the most energy efficient.

5.3.2 Object/Task Variables

The heavier the load lifted, the greater the work done, and the greater the metabolic requirement to complete the task [5, 9, 28, 47, 70, 94, 117]. The starting height of the lift, in conjunction with the lifting technique will determine the degree to which the body center of mass must be displaced to complete the lift. If the same load is lifted a vertical distance of 0.5 m starting from the floor or from knuckle height, the knuckle height lift will involve less movement of the body center of mass, and will therefore incur a lower metabolic cost. All other factors being equal, the greater the vertical travel distance, the greater the work done, and the greater the metabolic cost of a L-L&C task. Increases in the frequency of lifting produce increases in the metabolic cost of repetitive lifting [43, 76, 94]. These increases tend to be linear at lower percentages of maximal oxygen uptake (<50%). As the object size increases, so does the energy cost for repetitive L-L&C [80].

Total energy cost is related to the rate of work, number of repetitions and total duration of L-L&C tasks. The longer the task duration, the lower the percent of maximal energy expenditure that can be maintained. The intensity and durations of most soldiering tasks are not well defined. For example, during a re-supply, soldiers move materials until the weapon or transport vehicle is full. This may take anywhere from a few minutes to several hours. If the vehicle has been recently re-supplied, fewer supplies will be needed and the task will be accomplished more rapidly. In peacetime, re-supply can be a self-paced activity. In some operationally hostile environments, Soldiers must accomplish the task as rapidly as possible. All these factors influence the metabolic requirements of the task. There are a number of predictive equations to determine the energy cost of L-L&C tasks and some are listed in Table 5-4 [10, 26, 28, 29, 79, 96, 135, 136].

Table 5-4: Prediction Equations for Energy Expenditure During Lifting Exercise

Type	Height	Energy Expenditure Equation (kcal/min)	Reference
Stoop Lift		E = 0.0109 BW + (0.0012 BW + 0.0052 L + 0.0028 S x L) f	Garg (1976)*
Squat Lift		E = 0.0109 BW + (0.0019 BW + 0.0081 L + 0.0023 S x L) f	Garg (1976)*
Arm Lift		E = 0.0109 BW + (0.0002 BW + 0.0103 L – 0.0017 S x L) f	Garg (1976)*
Stoop Lift	$h_1<h_2\leq.81$	$E = 10^{-2}[0.325\ BW\ (0.81- h_1) + (1.41L + 0.76S \times L)\ (h_2- h_1)]$	Garg et al., (1978)*
Squat Lift	$h_1<h_2\leq.81$	$E = 10^{-2}\ [0.514\ BW\ (0.81- h_1) + (2.19L + 0.62S \times L)\ (h_2- h_1)]$	Garg et al., (1978)*
One Hand Lift	$h_1< h_2\leq.81$	$E = 10^{-2}\ [0.352\ BW\ (0.81- h_1) + 3.03L\ (h_2- h_1)]$	Garg et al., (1978)*
Arm Lift	$.81<h_1< h_2$	$E = 10^{-2}\ [0.062\ BW\ (h_2-0.81) + (3.19L + 0.52S \times L)\ (h_2- h_1)]$	Garg et al., (1978)*
Stoop Lower	$h_1<h_2<0.81$	$E = 10^{-2}\ [0.268\ BW\ (0.81- h_1) + 0.675L\ (h_2-h_1) + 5.22S\ (0.81- h_1)]$	Garg et al., (1978)*
Squat Lower	$h_1<h_2\leq.81$	$E = 10^{-2}\ [0.511\ BW\ (0.81- h_1) + 0.701L\ (h_2- h_1)]$	Garg et al., (1978)*
Arm Lower	$.81<h_1< h_2$	$E = 10^{-2}\ [0.093\ BW\ (h_2-0.81) + (1.02L + 0.37S \times L)\ (h_2- h_1)]$	Garg et al., (1978)*
Carry	At arms length at sides	$E = 10^{-2}\ [80 + 2.43\ BW \times V^2 + 4.63L \times V^2 + 4.62L + 0.379\ (L + BW)\ G \times V]t$	Garg et al., (1978)*
Carry	Held against thighs or waist	$E = 10^{-2}\ [68 + 2.54\ BW \times V^2 + 4.08L \times V^2 + 11.4L + 0.379\ (L + BW)\ G \times V]t$	Garg et al., (1978)*
Lifting and/or Carrying	From 75 cm – 150 cm	$VO_2 = 0.1809 + [(BW + L) \times (2.6112 \times (BW + L)92.594 \times D \times H) + F \times (318.16 \times L + 7.9185 \times BW \times D + 49.1565 \times L \times D)] \times 10^{-5} + 2.2956 \times WID/L$	Taboun and Dutta (1989)**
Lifting and/or Carrying	From floor – 150 cm	$VO_2 = 0.0738 + [(BW + L) \times (3.9918 \times (BW + L) + 61.226 \times D \times H) + L \times F \times (424.131 + 81.926 \times D)] \times 10^{-5} + 3.851 \times WID/L$	Taboun and Dutta (1989)**
Intermittent Carry	Waist Height	$VO_2 = 36.3 – (1.74W) – (1.76D) – (7.17F) + (0.027W^2) + (0.014WD) + (0.196WF) + (0.783DF)$	Randle et al., (1989) ***

* E = energy expenditure (kcal/min), BW = body weight (lbs), L = load weight (lbs), S = Sex (female = 0, male = 1), f = frequency (lifts/min), h_1 = Vertical height from floor (m) at the lower end of the lift or lower, h_2 = vertical height from floor (m) at the upper end of the lift or lower.

** VO_2 = oxygen uptake (l/min), BW = body weight (kg), L = load (kg), F = frequency (lifts/min), D = carrying distance (m), H = height range of lift (m) and WID = box width along the sagittal plane (m).

*** VO_2 = oxygen uptake (mL/kg/min), W = load weight (kg), D = carrying distance (m), and F = frequency (carrys/min).

There are a number of reports in the literature indicating the energy cost of soldiers performing various simulated L-L&C tasks [15, 70, 85, 92, 97, 106, 118, 119, 124]. A summary of energy cost of soldier tasks measured in a laboratory setting are found in Table 5-5 for women and Table 5-6 for men. Rayson [97] measured the cardiovascular requirements of UK soldiers performing actual L-L&C tasks (not simulated tasks) of longer duration. Soldiers worked at 55 to 88% of their maximum heart rate, with 59% of the tasks in the 70 to 79% maximum heart rate range. The rate of oxygen uptake ranged between 1.16 and 2.92 $l \bullet min^{-1}$, with 80% of the tasks falling within the 1.5 to 2.5 $l \bullet min^{-1}$ range. Due to the difficulty of identifying the required lifting rate, the aerobically demanding L-L&C tasks were self-paced during the metabolic measurements. As mentioned above, the intensity of MMH task performance of soldiers is often determined by the situation. For this reason, it is difficult to accurately characterize the typical cardiovascular strain of soldiers during MMH tasks because an acceptable level of intensity and duration of task performance has not been operationally defined.

Table 5-5: Energy Cost of Soldier MMH Tasks Performed by Women [92]

Task	Load (kg)	Frequency (lifts/min)	Height or Distance (m)	VO_2 (L/min)	VO_2 (ml/kg)	VO_2 max (%)	VE (L/min)	HR (b/min)
Lift	22.7	1	1.32	0.46	7.8	17.8	15.1	100
	22.7	2	1.32	0.67	11.5	26.2	20.8	120
	22.7	4	1.32	1.02	18	41	29.3	146
Lift/Lower	25	0.25	1.32	0.39	6.2	13.8	13.4	87
	25	1	1.32	0.63	12.3	26.4	20	120
	22.7	6	1.32	1.14	18.2	41.1	32.1	127
Lift and Carry	25	0.5	15	0.42	8.2	17.7	14.3	103
	25	1	15	0.6	11.5	24.6	19.7	115
	18	1	6.1	0.57	9.9	22.7	18.1	108
	27.3	1	4	0.66	10.7	23.9	22.7	113
	6.8	0.5	15	0.43	6.8	15.6	16	94
	25	2	15	0.85	13.7	30.6	28.4	124
	18.2	1	9	0.87	14	31.5	26.2	114
	27.2	3	30	2.03	33.1	74.1	71.3	170
	25	3	15	1.25	20.8	48	40.2	157

Table 5-6: Energy Cost of Soldier MMH Tasks Performed by Men

Task	Load (kg)	Freq (/min)	Height or Distance (m)	VO_2 (L/min)	VO_2 (ml/kg/min)	VO_2 max (%)	VE (L/min)	HR (b/min)	Workrate (W)
Lift[1]	22.7	4	1.32	1.14	15.4	28.8	29.6	119	394
	22.7	2	1.32	0.74	9.8	19.2	20.9	106	256
	22.7	1	1.32	0.58	7.5	14.9	18.1	95	201
Lift/Lower[1]	22.7	6	1.32	1.33	16.5	30.3	33.9	119	460
	25	0.25	1.32	0.54	6.7	12.2	16.1	87	187
	25	1	1.32	0.7	9.5	17.9	20.4	100	246
Lift and Carry[1]	25	0.5	15	0.49	6.7	12.7	15.3	88	170
	25	1	15	0.63	8.5	16	18.3	97	242
	36	1	6.1	0.86	11	21.4	24.4	104	298
	18	1	6.1	0.71	9.1	18	20.5	98	247
	27.3	1	4	0.78	9.6	17.7	23	98	270
	6.8	0.5	15	0.6	7.4	13.7	19.3	89	208
	45	2	5	0.82	11	21.1	22.7	104	284
	45	4	5	1.29	17.4	33.5	37.1	130	446
	45	3	5	1.07	14	26.8	31.3	115	370
	25	2	15	1.01	12.4	23	27.5	104	349
	18.2	1	9	1.11	13.7	25.1	29	109	384
	27.2	4	30	3.36	41.4	76.2	104.8	167	1162
	25	4	15	1.76	22.9	44.8	46.4	135	609
Lift, Control[2]		8.2	1.4		38.4	86.9		169.6	
Lift, Trained[2]		9.2	1.4		38.1	88		182.8	
Lift/Lower[3]	26.4	4	40% Subject Height	0.75			17.3	101.5	
	26.4	5.3	40% Subject Height	0.75			17.4	102.9	
	24.1	4.8	40% Subject Height	0.71			16	98.4	
Lifting[4]	22.4	8	40% Subject Height	1.55	20.5	41.4	42.8	131	1.24
	22.4	10	40% Subject Height	1.79	23.9	47.7	51.2	143	1.54
	22.4	12	40% Subject Height	1.86	25	49.5	57	150	1.86
	44.8	4	40% Subject Height	1.41	18.6	37.6	38.1	123	1.24
	44.8	6	40% Subject Height	1.79	23.7	47.6	54	147	1.86
	44.8	8	40% Subject Height	1.98	27.1	53.9	61.7	160	2.48
	67.2	2	40% Subject Height	1.17	15.3	31	36.5	122	0.93
	67.2	3	40% Subject Height	1.52	20	40.3	45.8	141	1.4
	67.2	4	40% Subject Height	1.91	25.1	50.9	60.5	153	1.86

* 1: Patton, 1995; 2: Sharp et al, 1993; 3: Nicholson and Legg, 1986; 4: Legg, 1984.

5.3.3 Physiological Limits for Repetitive L-L&C Tasks

The recommended upper limits for prolonged performance of aerobically-demanding, repetitive L-L&C tasks typically ranges from 28% up to 35% cycle ergometer VO_2max for an 8 hour day [6, 46, 70, 72, 93].

Garg [28] recommends that the exercise intensity of repetitive L-L&C tasks not exceed 50% VO_2max (treadmill or cycle ergometer) for one hour, 40% VO_2max for 2 hours or 30% VO_2max for 8 hours to avoid fatigue.

5.4 EVALUATION OF L-L&C PERFORMANCE

There are several approaches for evaluating L-L&C performance. The maximum performance capability of the individual, such as a 1RM can be examined, or a minimal performance standard can be set and soldiers tested to determine if they are capable of meeting that standard. Several of the NATO allies have conducted job analyses of physically demanding soldiering occupations and have developed CMTs representing the most common lifting or lifting and carrying tasks. Many of these tests were designed as the first step to develop pre-assignment screening tests to place service members into physically appropriate jobs. Knapik et al., [62] has recently published a thorough review of the pre-assignment screening tests used by many of the NATO Forces. The types of tests pertaining to L-L&C used in the literature, as well as the tests used by the NATO Forces will be briefly reviewed here.

5.4.1 One-Repetition Maximum (1RM) Lift

Tests of lifting strength are typically a one-repetition maximum lift (1RM) of a box to a given height. In most military applications, it is the height of the standard supply transport vehicle [40, 103, 114, 114]. Alternatively, the lift height can be based on body landmarks, such as floor to knuckle height or floor to shoulder height [12]. Physical fitness measurements found to be predictive of 1RM lifting strength include fat free mass [12, 98, 114, 137], isometric 38-cm upright pull [114, 137], isometric back extension strength [98], incremental lift machine [12, 98, 137], vertical jump, broad jump and push-ups [12, 42].

5.4.2 Repetitive Lifting

Tests designed to measure repetitive lifting capacity include tests of repetitive lifting maximal oxygen uptake [47, 71, 117, 149], timed maximal effort tests [14, 40, 115, 118], tests of maximum acceptable load [19, 69, 70, 85, 120, 131], timed completion of a set amount of work [146] or a set work rate to exhaustion [148]. Most repetitive lifting tests are labor intensive, as the boxes that are lifted need to be lowered, either using an automated system (automated shelf or rollers) or manually.

5.4.3 Repetitive Lifting Maximal Oxygen Uptake

Tests of repetitive lifting maximal oxygen uptake are progressive in nature, either increasing the load lifted, the rate of lifting, or both, until the maximum rate of oxygen consumption has been reached [52, 71, 88, 94, 117, 149]. Metabolic measurement equipment is needed to conduct the tests, and they are not commonly used to evaluate L-L&C performance. Table 5-7 lists the VO_2peak for men and women for several modes of exercise.

Table 5-7: VO_2peak for Various Testing Modalities in Men and Women

	Men [117]	**Women [86]**
	VO_2peak (L/min)	*VO_2peak (L/min)*
Treadmill	4.12 (0.53)	2.78 (0.38)
Leg Cycle	3.63 (0.56)	NA
Upper Arm Cycle	2.57 (0.46)	NA
Repetitive Lifting	3.20 (0.42)	2.32 (0.27)

5.4.4 Maximal Effort Timed Repetitive Lifting Test

A maximal-effort, timed repetitive lifting test was used to simulate the re-supply of a 155 mm self-propelled howitzer [118]. The final test score was the maximum number of 21 to 41 kg boxes lifted to a 132-cm high shelf in a 10 min period. Similar protocols with varying weights (20.9 – 41.0 kg) and varying lengths of time (5 – 10 min) have been used to examine the repetitive lifting capacity of men and women before and after physical training programs [40, 54, 55, 64, 116]. These tests have been shown to have high test-retest reliability with a stable score obtained after two trials [54, 90, 118].

5.4.5 Maximum Acceptable Weight of Lift (MAWL)

As mentioned earlier (Section 5.2.4.3), tests of the maximum acceptable load or lifting rate involve a subjective measure of the exercise intensity an individual is willing to work at under a defined set of conditions. Snook and colleagues have developed an extensive data set for a wide variety of L-L&C tasks with loads determined to be acceptable to various percentages of the population of US workers [19, 129 – 131]. While these tests provide useful information for setting limits and equipment design guidelines, they can also be used to measure performance before and after a training program [120].

5.4.6 Completion of a Set Amount of Work

The Canadian Army repetitive lifting task involves lifting 20.9-kg boxes from the floor onto a 1.3-m truck bed 48 times in 5 min (9.6 lifts/min). As with all the Canadian common task requirements, the scoring is pass/fail, and does not discriminate well between skill levels [68].

5.4.7 Timed Work Rate to Exhaustion

The Dutch Army repetitive lifting test involves lifting loaded boxes from the floor to 145 cm at the rate of 6 lifts/min for 90-second periods. The initial box load is 12 kg. The load is increased by 4 kg during a 30 sec rest period at the end of each 90 sec lifting period. The maximum load is 56 kg. This load is administered two times if the volunteer is successful. The maximum number of lifts completed, while maintaining the lifting pace is the final score (possible range = 0 – 117 lifts). The average man (n = 137) lifted the 52-kg box five times for a total of 95 lifts. The average woman (n = 59) lifted the 32-kg box two times for a total of 47 lifts [140].

5.4.8 Continuous and Repetitive Carrying

Carrying and repetitive carrying tests incorporate walking while holding an object. These tasks are the most commonly performed physically demanding tasks conducted by the US Navy [111], and the Armies of both the US [121] and the UK [97]. Reported tests include maximal effort timed tests [12, 12, 40], continuous carrying tests [35, 106] and maximum acceptable load determinations [123]. The reported loads for bi-manual carrying (one object in each hand) ranged from two 10-kg jerry cans to two 35-kg cans (total load 20 to 70 kg). Twenty kg sandbags and 34-kg boxes have been used for carrying one object with both hands. The U.S. Navy utilized a box carry with distance carried as the measure of performance. Sailors carried a 34-kg box with handles along a 51.4 m up-and-back course for two five-minute periods. The box was placed on a table, and Sailors walked the distance without a box. The final score was the distance covered during the two-five minute exercise periods [42].

The British Army developed a set of representative military tasks that included a single maximum lift, a repetitive lift and carry test and a continuous carry to exhaustion [97]. The single lift task was a lift from the ground to 1.45 or 1.70 m of an ammunition box with handles. The initial load was 10 kg. Load increments were 5 kg for men and 2.5 kg for women until a load of 40 kg was reached. After 40 kg was lifted, the load increments were 4 kg for men and 2 kg for women. For the repetitive lift and carry test, 3 box loads, either 10, 22 or 44 kg, were lifted, carried 10 m, and lifted onto a platform at rates of 6, 3 or 1 shuttles per min, respectively. The load and rate standard was based on the requirements of the Soldier's assigned job. All Soldiers tested were able to complete the required lift and carry task for their assigned job. This test was later dropped from the test battery. For the continuous carry, Soldiers walk up and down a 30-m course at a rate of 1.5 m/sec while carrying a 20-kg jerry can in each hand. The test is over when the Soldier can no longer maintain the pace, or when the jerry cans are placed on the ground. The final score is the distance (m) covered [103]. There are five levels of acceptable performance, with the passing standard based on the physical demands of the soldiers' job (PSSR Pamphlet).

The Dutch Army repetitive carrying task is the only progressive test. Two 15-kg cans are carried 90 meters twice (180 m total) at a speed of 5.3 km/hr (3.3 mph). The cans are then replaced with cans that are 4 kg heavier until the Soldier cannot maintain the pace, or until the maximum load of 35 kg is reached. The average male Soldier (n = 135) completed the segment with the 27-kg cans and failed during the 31-kg cans. The average female Soldier completed the 19-kg load and failed during the 23 kg load. The final score is the total distance walked. Performance on this carrying task (total distance completed) was best predicted by measures of upper body aerobic capacity, strength and body size [142].

5.5 NATO FORCES PREDICTION OF MMH PERFORMANCE

5.5.1 British Army Program

One of the most comprehensive and well documented efforts to predict common military manual material handling capability was undertaken by the British Army [97 – 100, 102 – 105]. They conducted a detailed job analysis of all entry-level Army occupations and identified four Representative Military Tasks (RMTs) that were common to most military occupations and critical to soldier performance [97]. Three of the tasks involved L-L&C. These were a 1RM lift of an ammunition box, a continuous carry of 2 – 20 kg water jugs (jerry cans), and a repetitive lift and carry of an ammunition box (see Table 5-8). The repetitive lift and carry test was later dropped. Based on the actual array of job demands, all Army jobs were assigned to one of five levels of difficulty within each task [2]. The difficulty of the task was altered using different loads and carry distances. Each employment group, or job specialty, was assigned to the appropriate difficulty level for each task. Soldiers from various specialties were then tested on the RMTs and on a comprehensive battery of physical fitness and anthropometric measurements [98]. These data were used to develop a series of models to predict the RMTs [102]. The predictive models were cross-validated in a separate study using a group of initial-entry trainees [99]. 1RM box lifting was best predicted by fat-free mass and muscle strength measures. The continuous carrying models used muscular endurance and anthropometric measures. The repetitive L&C models included muscular strength, muscular endurance, and anthropometric measures. The 1RM lifting models worked well, but the continuous carry and repetitive lift and carry models did not accurately predict success on the criterion tasks.

Table 5-8: Performance Standards for Representative Military MMH Tasks

Task Level	Single Lift of Ammunition Box (Measure: Max load)	Carry (Measure: Time to exhaustion in min)	Repetitive Lift and 10 m Carry of Ammunition Box (Measure: Time to exhaustion up to 60 min)
1	Lift 45 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	44 kg, ground to 1.45 m, 1/min
2	Lift 40 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 150 m in 1:40	22 kg, ground to 1.45 m, 3/min
3	Lift 35 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 120 m in 1:20	10 kg, ground to 1.45 m, 6/min
4	Lift 30 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	NA
5	Lift 25 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	NA

5.5.2 U.S. Air Force Program

The US Air Force designed an initial entry screening test to assign recruits to jobs for which they were physically qualified [11, 75]. A job analysis was conducted for all of the Air Force specialties. The physically demanding tasks were identified and quantified. A series of predictor tests were used to model performance on 13 representative lifting and lifting and carrying tasks. Incremental Lift Machine (ILM) strength to 183 cm was found to be the best predictor in 11 of the 13 tasks and the second best predictor in the other 2 tasks. The ILM test was selected for pre-assignment screening. The lifting height on the ILM is a common lifting height for loading aircraft. All job descriptions were assigned a rating for the ILM load that must be lifted for an individual to qualify. The load was based on the average demands of the job, rather than the maximum demands, because it was assumed an Airman could request help in lifting during the heaviest lifts. A report by the US General Accounting Office was critical of the accuracy of the system [1], but Dr. McDaniel reports that this placement system is working well (personal communication, Dr. Joseph McDaniel, December 2004).

5.5.3 U.S. Army Program

The ILM weight stack machine lifting test was also used by the US Army. A three phase study was conducted [137] in which a group of new recruits was tested on entry to Basic Combat Training (BCT) (Phase 1), during the last week of BCT (Phase 2), and near the end of Advanced Individual Training (AIT) (Phase 3). The only CMT was a 1RM box lift to 132 cm. The physical fitness measures selected to predict 1RM box lift included isometric hand grip, isometric 38-cm upright pull, an ILM to 2 heights (152 cm and 183 cm), a bicycle test of predicted VO_2max (Astrand-Rhyming test) or a step test of predicted VO_2max, and a skinfold estimate of body composition. While the Air Force ILM test was to 183 cm, the Army used a lifting height of 152 cm. This was because the 152-cm height represented lifting a box with handles (handles 20 cm from the bottom of the box) to the height of a 2-1/2 ton truck [137]. The 1RM box lift was measured at the end of BCT and a multiple regression analysis was conducted to predict the CMT from the measures of physical fitness. Fat-free mass and ILM produced multiple regression correlation coefficients (R^2) of 0.33, 0.11 and 0.47 for men, women, and combined genders, respectively. The standard error of the estimate was too large for the gender combined equation to be recommended for further use.

Figure 5-4: Incremental Lift Machine (Starting and Ending Position).

Using the physical fitness data collected by Teves et al., [137], and the same Phase 3 volunteers, a modelling study was conducted concurrently by Myers et al., [84]. The following additional criterion measures were made: 1RM box lift, a prolonged carry, pushing, and applying torque (turning a wrench). The criterion tasks and the physical fitness predictors were measured at the end of AIT. A combined score was calculated to represent performance on the four criterion tasks. The ILM was found to be the best predictor of the combined score [84]. Pre-assignment ILM standards were set for Soldiers. In a two year follow on study, the US Army was unable to establish the efficacy of the program and dropped the screening test in the early 1990s [141].

5.5.4 Canadian Forces Program

The Canadian Forces have identified three L-L&C common military tasks: Land casualty evacuation, sea casualty evacuation and a sandbag carry [132]. These tasks were standardized for evaluation purposes to develop tasks that could be tested on one soldier. The land evacuation involves one person carrying the front end of a litter, with wheels on the back for .75 km. The litter was loaded to 40 kg (representing ½ of an 80-kg man). The sea evacuation task was conducted in fire fighting protective clothing and consisted of three parts. An 80-kg litter was moved 12.5 m, then a 40-kg litter was pushed up and down a ship staircase and finally, the 80-kg litter was carried back to the starting position. The sandbag carry task required the movement of 20-kg sandbags a distance of 50 m as many times as possible in 10 min. The passing score for these CMTs was the 75th percentile, or the score at which 75% of the tested population would pass the test. The distribution was corrected for differences in the number of men and women. The EXPRES physical fitness test (sit-ups, push-ups, combined maximal grip strength and step test prediction of VO_2max) was used to predict performance on the criterion tasks. While the EXPRES tests were significantly correlated with the CMTs, they were not strong predictors. The 5th percentile on each fitness test for the population of subjects who achieved the 75th percentile on all criterion tasks became the passing score. These standards for the EXPRES test are considered to be the minimal level of physical fitness needed to successfully perform the CMTs. The soldier readiness tests, fitness checks and training procedures are all age and gender free [68, 132 – 134].

The Canadian Land Forces Command Army Fitness Manual [146] lists two L-L&C CMTs. The casualty evacuation task is a fireman lift and carry of an equally sized soldier for 100 m in less than 60 sec. The ammunition box lift requires the soldier to lift 20.9-kg boxes from the floor to 1.3 m, 48 times in under 5 minutes. Canadian soldiers are tested on the casualty evacuation task annually. The Army Fitness Manual provides a Fitness Check to assess an individual's fitness level and ability to perform the CMTs. The standards include four levels of performance on measures of aerobic capacity (2400-m run, 5-km run), strength (bench press, squat, sit-ups) and power and speed (long jump, two jump and 40-m sprint). Detailed training instructions are provided to assist the soldier in achieving the standard.

5.5.5 Royal Netherlands Army Program

The Royal Netherlands Army designed two L-L&C CMT tests: a repetitive lift [140] and a carry [142]. Each test is progressive in nature with the goal of obtaining a maximum measure of performance. The Repetitive Lifting Task involved lifting a box from the floor to 145 cm one time / 10 sec for 9 repetitions. The initial weight in the box was 12 kg and the weight was increased in 4 kg increments. Thirty seconds of rest were given between each load increase. This sequence was repeated until the soldier could not keep up with the pace. The performance measure was the number of repetitions. The Carry Task involved a progressive, interrupted jerry can carry of 90 m at a pace of 5.4 km/h. The initial load was 15 kg was increased by 4 kg each trip with 1 min rest between trips. The task ended when the soldier could not maintain the pace and the performance measure was the distance covered. The tests were performed by a group of Soldiers who also performed a series of laboratory and field measures of physical capacity. The more traditional physical capacity tests were used to predict performance on the occupational tasks, and these traditional tests were used to place Royal Netherlands Army recruits into jobs compatible with their physical ability.

5.6 TRAINING FOR MANUAL MATERIALS HANDLING

Increasing physical fitness in Soldiers is an important part of protecting them from injury [55], while improving their occupational performance. Ninety percent of physically limiting tasks of Army MOSs include lifting or lifting and carrying [114, 122], and all manual materials handling tasks rely on muscular strength and endurance. By increasing muscular strength and endurance of soldiers, they can perform the same MMH tasks at a lower percentage of their capacity, reducing fatigue and reducing the risk of injury [54, 55]. Cardiorespiratory endurance training can also be beneficial for materials handling tasks that are done for longer periods, such as manually lifting boxes for several minutes or hours [63]. The benefits of proper physical training for Soldiers also include improved health, longevity, and lower medical costs [13, 16, 83, 89], benefiting both the soldier and improving military readiness.

Physical training is defined as muscular activity designed to enhance the physical capacity of the individual by improving one or more of the components of physical fitness [63]. The three most important fitness components include muscular strength, muscular endurance and cardiorespiratory endurance (aerobic capacity). Muscular strength is the ability of a muscle group to exert maximal force in a single voluntary contraction. Muscular endurance is the ability of a muscle group to perform short-term, high-power physical activity. Cardiorespiratory endurance depends on the functioning of the circulatory and respiratory systems.

5.6.1 Training Types

Performance gains in manual materials handling depend on three physical improvements through training: psychomotor learning, improved muscle strength, and cardiovascular changes [63]. Psychomotor learning will result from improved neural coordination. Improved strength results from increased muscle activation and hypertrophy. Cardiovascular changes are the result of adaptations of the circulatory and respiratory systems through endurance training.

Training to improve manual materials handling performance can be grouped by the type of training, either task-specific or general (traditional). Task specific training includes training by performing movements similar to the actual task, but organized as progressive resistance training. General or traditional training includes doing aerobic and weight training for general fitness. Where task-specific training utilizes equipment similar to military situations, such as ammunition boxes and truck beds, traditional training would use weight training equipment found in most gymnasiums. In order to be effective, both training protocols must include progressive resistance training (PRT). PRT is accepted as the most effective way to improve performance in sports [118]. Progression is achieved through the concept of progressive overload which involves small, systematic increases in the frequency, intensity and/or duration of the exercise as fitness improves [74].

5.6.1.1 Task Specific Training

Progression in task-specific training is an important way to increase occupational performance. Progression can be accomplished in manual materials handling by increasing the load (weight lifted), the rate (times per minute) of lift, duration (time per training session), or the frequency (training days per week). Increasing the rate or duration can increase aerobic gains, increasing the load will increase strength, and increasing the total number of repetitions can improve muscular endurance. Task-specific training has the advantage of a shorter training period for improving specific operational tasks because specific physiological adaptations, especially neural adaptations are rapidly acquired. The downside is that the gains are largely restricted to the muscle groups and movements trained, and there may be limited improvements for other types of tasks. Task-specific training is usually difficult for large groups of soldiers to perform because it requires a specialized training environment and equipment. The need for specialized equipment and non-traditional exercises could result in a more dangerous or less controlled training environment compared to more traditional training. Task-specific training is best used for soldiers who have a repetitive and predictable task where loads and movements can be defined. This type of training is also useful for any materials handling tasks that require a higher skill level because strength and skills can be achieved through specificity of training.

Psychophysical training is a form of task-specific training, where the individual sets the exercise intensity and makes adjustments based on their perception of discomfort. It has been shown to improve job performance of inexperienced lifters (1 hr repetitive lifting capacity test), but may result in limited improvements in general physical fitness [120]. Psychophysical training may result in increased muscular endurance, which is important for highly repetitive lifting tasks [120].

A summary of the improvements that have been found through task specific training is summarized in Table 5-9. The improvements noted by Genaidy et al., [30 – 35] in endurance time appear to be much larger than for any other form of training. It is likely that some portion of the increases in endurance time were due to learning effects, as the tasks were extremely complex. Asfour et al., [8] reported large increases in a 1RM box lifting task to three different heights, and noted that most of the increases occurred after the first two weeks of training. These authors concluded that a two week training program was sufficient to improve box lifting strength. It is likely, however, that most of these increases were due to psychomotor learning, especially improved technique and familiarity with the task.

Table 5-9: Summary of Task-Specific Training and Improvements in Materials Handling

Author	Year	N	Sex[a]	Population	Weeks	Testing	Description	% Improvement
Asfour et al.	1984	10	M	Students	6	1RM box lift	0 – 76 cm	41%
							76 – 127 cm	99%
							0 – 127 cm	55%
						VO_2max	Cycle Ergometer	24%
Sharp and Legg	1988	8	M	Soldiers	4	Box Lift	1RM 0 – 132 cm	7%
							Psychophysical Mass	26%
							VO_2max (direct)	6%
Genaidy et al.	1989	11	M	Civilians	2.5	Lift and Carry	Endurance time to fatigue	102%
Genaidy et al.	1990b	15	M	Civilians	6	Lift, carry, push and pull Group A: 6 RM[d] Load Group B: 10 RM Load	1RM	a. & b. 32%
							20 kg, 8 lifts/min endurance	Time/Heart Rate A. 57% / 10% B. 172% / 7%
Genaidy et al.	1990a	27	M	Students	4	Lift and Lower	Endurance time to fatigue	Sym[b]: 248%, Asym[c]: 46%
							Frequency of handling	Sym: 44%, Asym: 34%
Genaidy et al.	1991	20	M	Students	6	Lift, carry, push/pull: Group A: 15 kg both hands Group B: 8 kg separate hands	Endurance time to fatigue	A. 557%, B. 1350%
							Heart rate	A. 18%, B. 9%
Genaidy et al.	1994	23/5	M/W	Industrial Workers	6	Lift, carry, push and pull	1RM	58 – 84%
							Endurance time to fatigue	117 – 127%
							Total Cycles	107 – 183%

[a]M = men, W = women
[b] Sym = symmetrical lift
[c] Asym = asymmetrical lift
[d] RM = Repetitions Maximum, i.e. only 6 or 10 repetitions could be completed with that load

5.6.1.2 General Training

General training takes a longer training period to produce improvements in materials handling, because the increase in performance is attributed to neural adaptations, muscle hypertrophy and some improvement in cardiorespiratory endurance. General training is not limited to the specific tasks trained, and therefore has the potential to improve performance on a wider variety of tasks than task-specific training. General training is usually safer than task-specific training and most military training facilities have traditional training equipment, designed with safety in mind. General training can improve whole body fitness and should be used in situations where occupational tasks vary. The increase in overall fitness associated with more traditional training may also be effective in preventing muscular imbalances and overuse injuries. Generalized training is better for military, police, and fire fighting where there are varied occupational tasks requiring heavy physical labour [63]. Twelve weeks of general training can significantly improve performance, however task performance improvements have been seen in as little as 4 [116] to 8 weeks [24, 39].

When a "carefully structured progressive resistance training element" was added to British Army Basic Training, the increase in materials handling was much greater (12.4%) than the original basic training regimen (1 to 4%). Most of this training was general, but there were some specific skills training sessions as well [147]. For women, general training can improve materials handling performance, especially when the training includes exercises are designed to increase upper body strength [87]. Table 5-10 show a comparison of several different training programs. Maximal lifting capacity was not affected by aerobic endurance training, but improved with every type of general PRT. Additional studies of general physical training and improvements in manual material handling, including studies of new recruits can be seen in Table 5-11.

Table 5-10: Comparison of Upper vs. Total Body Progressive Resistance Training Programs in Women

Study	N	Weeks	Sessions	Program	Maximal Lift	Repetitive Lift
Nindl (1998)	46	12	36	Total body PRT	15%	24%
				Upper body PRT	14%	22%
Kraemer et al., (2001)	93	24	72	Total body strength/power PRT	27%	33%
				Total body strength/hypertrophy PRT	24%	33%
				Upper body strength/power PRT	12%	30%
				Upper body strength/hypertrophy PRT	19%	41%
				Plyometric/Partner PRT	17%	29%
				Aerobic Training	0%	29%

Table 5-11: General Training Programs and Percent Improvement in Materials Handling Tasks

Author	Year	N	Sex	Population	Weeks	Testing	Description	% Improvement
Sharp et al.	1993	18	M	Soldiers	12	1RM Box Lift	1RM, floor to chest	23%
						Repetitive Lift	10 min, 41 kg, floor to chest	18%
						VO_2max	Direct	2%
Knapik and Gerber	1996, 1997	13	F	Soldiers	12	1RM Box Lift	Floor to knuckle	19%
							Floor to chest	16%
						Repetitive Lift	15 kg, floor to chest	17%
						Maximal Run	3.2 km	9%*
Harman et al.	1996	41	F	Civilians	14	1RM Box lift	Floor – 76 cm	19%
							Floor – 132 cm	23%
							76 – 132 cm	32%
						Repetitive Lift	18 kg, floor – 132 cm	28%
						Lift and Carry	18 kg, 8 m, lift 132 cm	11%
						VO_2max	Direct	12%

* In addition to PRT, program included 2 days/wk of running.

Table 5-11 (Cont'd): General Training Programs and Percent Improvement in Materials Handling Tasks

Author	Year	N	Sex	Population	Weeks	Testing	Description	% Improvement
Williams et al.	2002	43/9	M/F	Soldiers	10	Maximal Box Lift	145 cm	12%
							170 cm	8%
						Repetitive Lift and Carry	10 kg, 10 m, 145 cm	15%
							22 kg, 10 m, 145 cm	19%
Williams et al.	1999	47/10	M/F	Soldiers	10	Maximal Box Lift	145 cm	2%
							170 cm	4%
						Repetitive Lift and Carry	10 kg, 10 m, 145 cm	7%
							22 kg, 10 m, 145 cm	30%
Brock and Legg	1997	73	F	Soldiers	6	Incremental Dynamic Lift (USAF)	Increasing resistance to max 152 cm	10%

5.6.2 Applications

There is ample evidence that PRT can improve performance in manual materials handling [7, 39, 40, 56, 63, 87, 120, 147]. Task specific training is best for jobs where there little variability in the day to day work, whereas general training is better for jobs where the materials handling tasks vary from day to day [63]. An ideal training regimen for soldiers would include both traditional and task specific training. Most soldiering jobs require the basic fitness associated with general training because their tasks vary by situation, but the nature of their individual jobs may also require skills and specific fitness that can only be learned through task-specific training. This combination of training programs may be effective in reducing injuries and increasing the effectiveness of soldiers who are new to the job. One example of a training program already in place is the US Army Physical Fitness School's Physical Readiness Training [60, 61, 110]. This training program proscribes the exact exercise to be used, based on a task analysis of common soldiering tasks. The Physical Readiness Training Program includes interval running to improve aerobic fitness and limits the distance run to reduce overuse injuries [53, 60]. British Army Basic Training produced greater improvements in materials handling than the original basic training program by adding progressive resistance training and skill specific training to the syllabus [147].

5.7 CONCLUSIONS/RECOMMENDATIONS

5.7.1 Military Lifting Requirements

1) L-L&C tasks are the most common physically demanding tasks performed by the Armed Forces of many of the various NATO nations.

2) L-L&C tasks (and MMH tasks in general) appear to contribute to overexertion injuries, particularly low back pain, and disability in the military and the civilian sector.

3) Low back pain and injury complaints account for the 2nd largest number of outpatient medical visits for US Army Servicemembers.

5.7.2 Recommended L-L&C Limits

1) There are published safe load recommendations for military and civilian populations.

2) When considering the safety of an object to be L-L&C, the limits should be adjusted downward if the load is not optimally configured, or if the conditions are outside the range of those described in the recommendation.

3) Loads L-L&C by servicemembers often exceed the recommended safe limits and vary from country to country.

5.7.3 Team Lifting

1) Team work can be used to effectively decrease the load handled on a per-person basis, and some MMH tasks are specified to be multi-person tasks.

2) The one-repetition maximum (1RM) for dynamic two-person team lifting is 10 – 20% lower than the sum of individual 1RM lifts, but little further decrease is found with the addition of one or two more people. If a recommended load for an individual performing a task has been determined, the % sums from Table 5-1 can be used to estimate the load for two to four persons lifting as a team. It is essential that there is adequate team coordination, space, handholds, and an equal distribution of the load when performing infrequent heavy team lifting tasks.

3) Repetitive team lifting and carrying maximum acceptable weight of lift (MAWL) tends to be equal to or greater than the sum of the individual MAWL for the same task. Therefore, doubling the individual MAWL provides a reasonable estimate of the load two-person teams will find acceptable for a repetitive MMH task if the individual MAWL is known. This is most appropriate for tasks that are symmetrical. It is essential that there is adequate team coordination, space, handholds, and an equal distribution of the load when performing infrequent heavy team lifting tasks.

4) Where possible, individuals should be roughly matched for strength. When a large strength discrepancy exits between two persons performing a repetitive team lifting task, the weaker individual works at a higher relative intensity, predisposing that person to early fatigue and possible injury. For 1RM lifting, the lower strength individual limits the maximum load that can be lifted.

5) A number of prediction equations have been published to estimate team lifting strength based on the characteristics of the individuals lifting.

6) Litter carriage is an important team L&C task. The time to exhaustion for carrying long distances can be greatly extended with the use of shoulder straps or specialized harnesses that have been described in the literature.

5.7.4 Physiological Requirements

1) The energy cost of a repetitive L-L&C task is influenced by technique, object characteristics and task variables. A number of published equations to estimate energy expenditure of L-L&C tasks are included in this report (Table 5-4).

2) It is generally recommended that the exercise intensity of a L-L&C task not exceed 28 – 35% if it must be maintained for an 8-hour day. The intensity can be increased with decreasing durations of exercise.

5.7.5 Evaluation of L-L&C Task Performance

1) L-L&C task performance of an individual or team can be evaluated using one time maximum test, maximum performance of a repetitive task, with time, work or exercise intensity as the end point, maximum acceptable weight of lift determinations, or tests to exhaustion.

2) A number of NATO countries have implemented some form of physical performance testing to directly or indirectly measure L-L&C performance. Typically this testing is in addition to testing for physical fitness.

5.7.6 Training

1) Progressive resistance training will improve manual materials handling ability and is likely to reduce injury in soldiers because so many soldiering tasks require manual materials handling. For lower strength soldiers it is particularly important to include upper body progressive resistance training exercises.

2) Task-specific training should be designed for jobs that are the same from day-to-day or require specialized movement skills. The gains from task-specific training, will be realized more quickly than with general training, presumably because of increased neural coordination.

3) General training can improve whole body fitness and should be used when occupational tasks change from day-to-day or where increased physical demands can be sudden or unexpected. General training

is not limited to the specific tasks trained, and therefore has the potential to improve performance on a wider variety of tasks than task-specific training.

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Appendix 5A-1 – LOAD LIMIT RECOMMENDATIONS

Table 5A-1-1: Load Limit Calculations for Various MMH Tasks

Type	Equation	Reference
Lowering	LOC = W_B*H*V*F*AG*BW*TD	Shoaf et al., 1997 [127]
Carrying	CC = W_B *V*T*AG*BW*TD	Shoaf et al., 1997 [127]
Lifting	RWL = LC*HM*VM*DM*AM*FM*CM	Waters et al., 1993 [144]
Lifting	LC = WB*H*V*D*F*TD*T*C*HS*AG*BW	Hidalgo et al., 1997 [41]

* See Appendix 5A-1.1 for variable definitions and values.

5A-1.1 VARIABLE DEFINITIONS

Table 5A-1-2: Variables for Load Limit Equations for Shoaf et al., (1997)

Variable	Source	Definition	Notes
LOC	From eqn	Lowering capacity	
W_B	From table	Base weight	
H	From table	Horizontal distance multiplier *	Distance from body with respect to the mid-point between the ankles
V	From table	Vertical distance multiplier	
F	From table	Frequency multiplier	
AG	From figure	Age group multiplier	
BW	From figure	Body weight multiplier	
CC	From eqn	Carrying capacity	
T	From table	Travelled distance multiplier	
TD	From figure	Task duration multiplier	

* Figures and tables are not included here, but can be found in the original reference.

Table 5A-1-3: Variables for Load Limit Equations for Waters et al., (1993)

Variable	Source	Definition	Notes
LC	= 23	Load constant (kgs)	
HM	= 25/H	Horizontal multiplier	H = horizontal distance of hands from midpoint between the ankles (cm)
VM	= (1-(0.003|V-75|))	Vertical multiplier	V = vertical distance of hands to the floor (cm)
DM	= (0.82+(4.5/D))	Distance multiplier	D = vertical travel distance between the origin and the destination of the lift (cm)
AM	= (1-(0.0032A))	Asymmetric multiplier	A = angle of asymmetry(degrees)
FM	From table	Frequency multiplier	F = average frequency rate of lifting measured in lifts/min
CM	From table	Coupling multiplier	

* Figures and tables are not included here, but can be found in the original reference

Table 5A-1-4: Variables for Load Limit Equations for Hidalgo et al., (1997)

Variable	Source	Definition	Notes
LC	From equation	Lifting Capacity (kg)	
WB	From figure	Base Weight (kg)	
H	From figure	Horizontal distance factor (cm)	Distance away from the body with respect to the mid-point between the ankles
V	From figure	Vertical distance factor (cm)	Distance from the floor to the hands at the origin of lift
D	From figure	Vertical travel distance factor (cm)	Distance of the hands between the origin and the destination of lift
F	From figure	Lifting frequency factor (times/min)	
TD	From figure	Task duration factor (h)	
T	From figure	Twisting angle factor (°)	
C	From figure	Coupling factor	
HS	From figure	Heat stress factor (°C wet bulb globe temperature)	
AG	From figure	Age factor (years)	
BW	From figure	Body weight factor (kg)	

Chapter 6 – EVIDENCED-BASED JOB ANALYSIS AND METHODOLOGY TO DETERMINE PHYSICAL REQUIREMENTS OF SPECIAL MILITARY OCCUPATIONS

by

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Diagnostic analysis of the individual physical performance and statistical group analysis of Austrian Special Forces soldiers (Jagdkommandosoldaten). Derivation of a model identifying the optimal weighted sports motor components with regard to the physical demands of the military missions

ABSTRACT

Minimal requirements, selection procedures and training recommendations concerning Special Forces (Jagdkommando) are to be in accordance with mission demands. This is especially true for the physiological performance of the soldiers: Therefore sports motor profiles are the basis for all physiological military assessments, minimal requirements and all specific training recommendations.

With this current study for the first time we were able to identify the relevant sports motor components for Special Forces operators and describe their influence on a soldier's mission performance. A comprehensive quantitative test battery was applied to 26 Austrian Special Forces soldiers and actual sports motor profiles

were established from the results. Furthermore a qualitative investigation (experts rating) enabled to develop task specific target profiles.

*Finally, a synopsis of all results led to sports motor key-qualifications for Special Forces soldiers: **coordinative abilities**, **reaction speed**, **aerobic endurance**, **strength endurance** and **anaerobic endurance**. This knowledge enabled:*

1) *The development and accordingly;*
2) *The evaluation of precise and valid selection procedures;*
3) *The derivation of minimal requirements;*
4) *The development of task specific;*
5) *Individual; and*
6) *Group training recommendations.*

Besides the high practical significance of this knowledge the authors have herewith also invented and empirically tested a methodology that proved to be highly useful for establishing comprehensive (target and current-status) sports motor profiles for (Special Forces) soldiers.

6.1 INTRODUCTION[1]

Specially trained and equipped soldiers are required for special military operations. Those soldiers are characterized by special tactical and psychological skills as well as above-average physical capacity. In describing those physical skills by means of sports motor components, characteristic sports motor profiles for Special Forces operators can be derived.

Evidence-based physical sports motor profiles for Special Forces soldiers have not been established yet. However, the availability of profiles of sports motor requirements is of great importance. Valid selection criteria and procedures can only be established through the knowledge of the physical requirements of Special Forces operations. Furthermore sports motor requirement profiles serve as substructures for the development of precise individual and group training recommendations.

The Austrian Special Forces (Jagdkommando) are formed of rather small but specially trained, equipped and organized units to undertake military operations of high strategic and political significance. These units are in a permanent state of readiness and can be engaged on short notice. Austrian Special Forces missions are usually limited in time and space but provide the Austrian government a flexible and precise option for conducting sensitive missions across the entire spectrum of conflict.

Austrian Special Forces conduct special reconnaissance to gain information of high relevance; conduct direct action operations (hostile liberation operations, neutralizing enemy personnel of strategic importance, destroying military infrastructure, etc.); provide VIP-protection; conduct combat search and rescue operations; evacuate Austrian citizens from foreign hostile areas; fight subversives and terrorism; and support the conventional Austrian Armed Forces on international and exceptionally dangerous missions [1].

[1] This article is the outcome of a joint research project of the Research Group on Physical Performance of the Army Hospital Vienna, the Army Sports Science Service, the Austrian Special Operation Command, the Austrian Special Forces (all Departments of the Austrian Armed Forces) and the University of Vienna. The project was initiated by the leading author who investigated the outlined area as a doctoral candidate of the named University. Therefore the results presented in this article are descended from the doctoral thesis which was approved by the respective committee of the University of Vienna in October 2006. As this is true for the complete paper and as it is stated here we do not quote each passage of the article. However, for detailed information and a comprehensive view we suggest studying the original literature (EISINGER, 2006).

In order to be able to accomplish these comprehensive military tasks all Austrian Special Forces soldiers are trained in:

i) Shooting with all relevant weapons;

ii) Close combat;

iii) Using explosives;

iv) Amphibious fighting;

v) Cooperating with other military forces (especially the Air Force);

vi) Parachuting;

vii) Mountaineering (winter and summertime);

viii) Paramedic;

ix) Orienteering;

x) Close quarter battle; and

xi) Survival techniques [2].

Based upon the wide variety of Special Forces operations, it is unrealistic to describe such complex Special Forces scenarios by single military activities (like marching or digging). For this reason we have chosen a totally different approach. Instead of looking at single military activities, we identified relevant sports motor components (such as endurance, muscular strength, etc.). In earlier work of RSG 4 and 17 *muscular strength*, *muscular endurance* and *aerobic endurance* were already identified as relevant components of fitness in military task performance. We investigated parameters of the physical performance in Special Forces soldiers who were declared as ready for mission by their Commanding Officers. This methodology enabled us to describe the key-sports motor components of complex mission demands in Special Forces operations.

Objectives of the present paper are to analyse the physical requirements of the military tasks of Special Forces; to examine whether the current physical selection procedures and assessment criteria agree with the physical mission demands; and to establish a model of optimal weighted sports motor components as a basis for the development of task specific individual and group training recommendations. Besides the high practical significance of this knowledge the applied and now empirically tested methodology has proved to be highly useful for establishing comprehensive (target and current-status) sports motor profiles. The method furthermore seems applicable not only for Special Forces soldiers but for any group of soldiers regardless of nationality.

6.2 METHODS

In order to be able to produce complete sports motor profiles we invented a threefold (hermeneutical and empirical [qualitative and quantitative]) methodical approach.

Although a comprehensive literature review was conducted limited information could be obtained since most investigations dealing with Special Forces are held confidentially or are simply not for public release. However, basic information on the physical performance of soldiers was available.

Besides the literature review we developed a qualitative and a quantitative approach.

Objectives of the qualitative approach were to identify the **relevant sports motor components** for Special Forces soldiers by means of guided expert interviews and to derive sports motor **target profiles** by having experts weight the relevant components by means of questionnaires.

In the quantitative approach we tested 26 Austrian Special Forces soldiers on a complete test battery. A group analysis of the physical performance of the tested soldiers with other soldier populations led to **actual sports motor profiles**. The 10th percentile was considered to be a suitable cut-off value for **minimal requirements** for combat ready Special Forces soldiers.

Finally, a synopsis of all results enabled us to identify sports motor **key qualifications** for Special Forces operators.

An overview is given by the following picture:

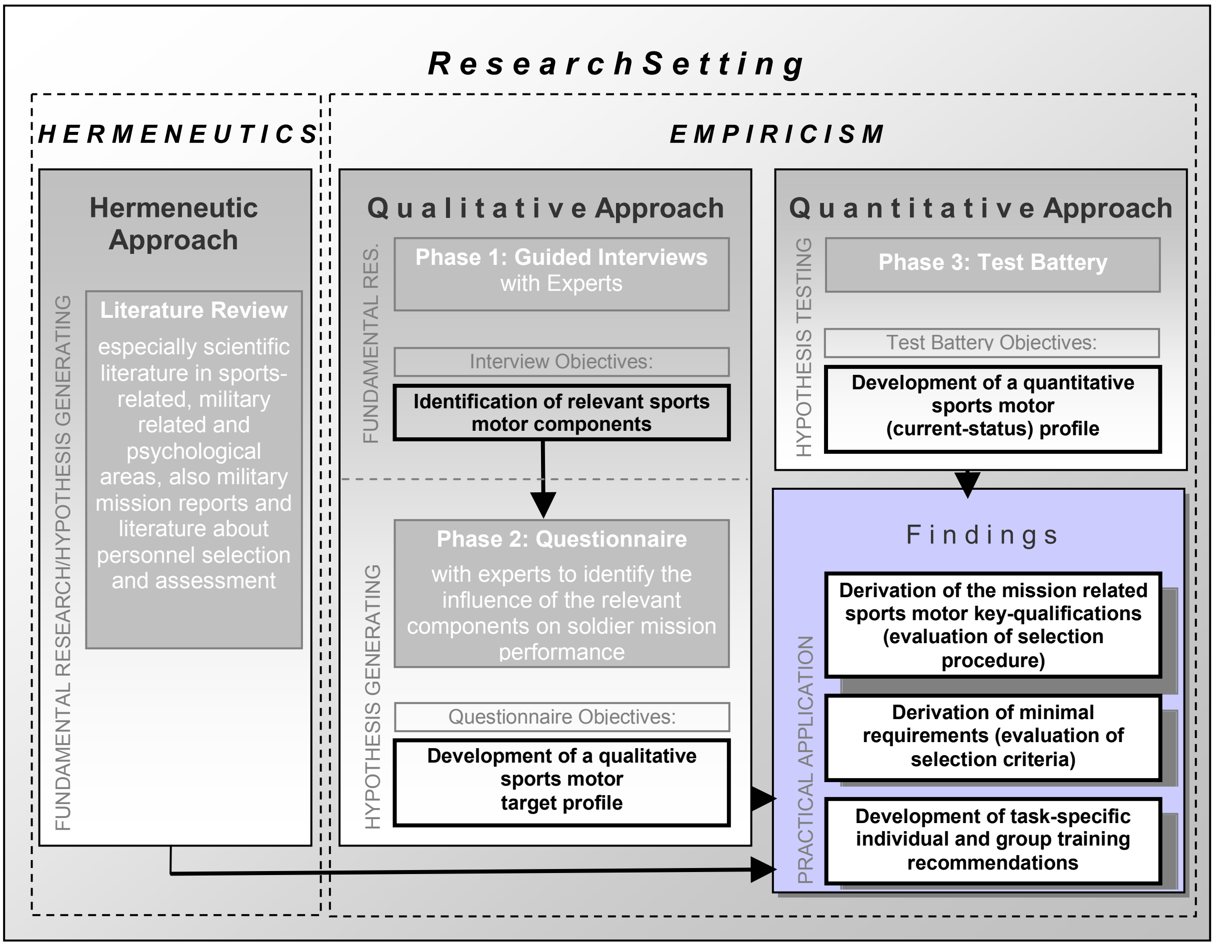

Figure 6-1: Overview of the Applied Research Setting (Source: According to Eisinger et al., 2007).

6.2.1 Qualitative Approach

There were three main reasons for using a qualitative approach: First of all we intended to find not only a current-status profile but also target profiles. Second we aimed to investigate whether there were differences in Special Forces internal specifications (like Direct Action [DA], Close Combat [CC], Combat Diving [CD], Alpinism [Alp] and Sky Diving [SD]). Third, only by the use of qualitative methods could hidden structures and unknown potentials be discovered.

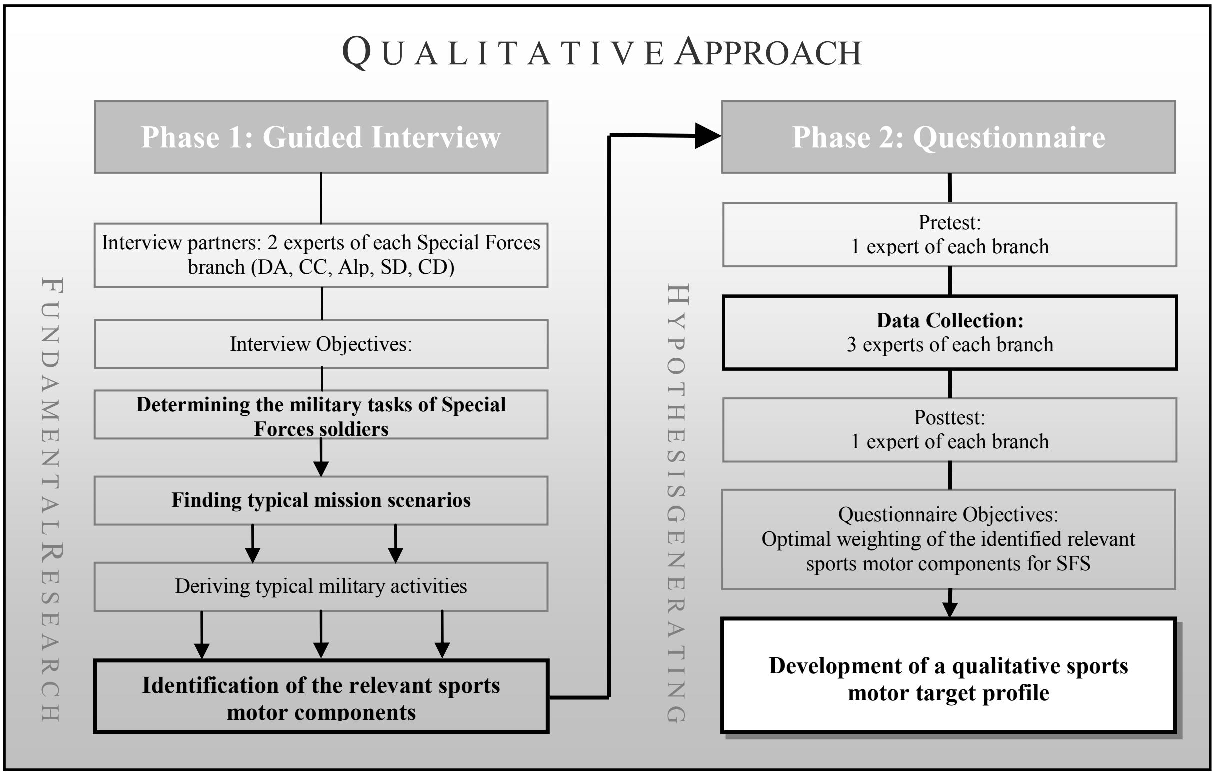

Figure 6-2: Detailed Description of the Qualitative Approach (Source: According to Eisinger, 2006).

As can be seen from the above picture, the qualitative investigation can be divided into two phases. In a phase one, the relevancy of different sports motor components for Special Forces specialities (DA, CD, CC, Alp. and SD.) was assessed. By means of guided interviews[2] with two military experts from each branch, we determined the *military tasks*, *typical military mission scenarios* and *task specific activities*. By identifying the sports motor components which were dominantly influencing the performance of those task specific activities, we were able to mark the relevant sports motor components. In other words we were looking which sports motor components actually influenced the military performance of the soldiers. This seems worth emphasizing since the main interest is not the physical performance alone but the military performance of the soldiers.

Once the relevant sports motor components were identified we produced a structured questionnaire for use in stage two. After having pre-tested the questionnaire, we had three experts from each branch weight the relevant components regarding their influence on the military performance of soldiers. From that ranking we developed precise sports motor target profiles (see Section 3.2).

6.2.1.1 Questionnaire

As was mentioned above, the questionnaire[3] was set-up with the knowledge of the guided interviews. In order to examine construct validity we subdivided the questionnaire into two sections (LIKERT [19] like scale/pair comparison [4]). If the experts weighted the relevant components similarly in both approaches, we assumed valid constructs.

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[2] The complete guided interview can be found in Appendix 6A-2.

[3] Find the applied questionnaire in Appendix 6A-3.

In the first section the experts were instructed to weight the sports motor components as either "not necessary at all", "not important", "important" or "very important" regarding their influence on the military performance of the soldiers. We assumed that the scale complies approximately with a LIKERT scale [19] (which means that the intercepts between the items are equal).

In the second section of the questionnaire we arranged pair comparison. Every questionnaire item was confronted with every other questionnaire item. The experts were asked to decide which of the two items had a higher impact on the military performance of a soldier in their branch.

From that we obtained a clear ranking which enabled the derivation of precise task specific target profiles.

Objectivity was addressed by comparing the expert's estimations of each branch, and reliability was examined via pre- and post-tests.

Due to the fact, that the military experts were not experts in sports sciences, the questions were presented in a non-scientific style, and did not contain terms of sport scientific nomenclature. Therefore we used the task specific activities, which predominantly represented the sports motor components in question.

The arithmetic mean of the answers provided by the three experts in their respective military fields were computed and used as a baseline for the target profiles.

6.2.1.2 Experts

The military experts who participated in this research were Officers and Non-Commissioned Officers with long time experience in their speciality. Examples of experts are given as follows: Mountain guides with over 20 years of active alpine experience; skydiving instructors with more than 3000 thousand jumps in all types of terrain, in full battle gear, under extreme weather conditions and at night; diving instructors with up to 1000 hours under-water-experience, and so on.

6.2.1.3 Used Terminology/Sports Motor Components

As sport scientific terminology is not understood uniformly we give brief definitions of the used sports motor components:

Aerobic endurance is defined as the ability to conduct low intensity physical work over a long period of time [30] (over 30 min, usually over hours or in extraordinary situations even over days) and the ability to recover quickly after physical exhaustion [11].

Anaerobic endurance is the ability to undertake high intensity work for a short period of time (not more than 2 min) [11].

Strength endurance is a subcategory of muscular power. It is understood as being resistant against exhaustion in long time power performance (more then 15 repetitions) [26].

Maximum strength is also a subcategory of muscular strength. It is the ability to contract muscles once against a very high resistance [30].

Rapidity is defined as the ability to conduct body movements within the shortest period of time [3].

The term ***reaction speed*** (synonym: reaction) stands for being able to react as quickly as possibly upon a signal [21].

Coordinative ability (synonym: coordination) is a collective term for spatiotemporal adjustments of different muscular activities [25], the ability to work efficiently and to learn new techniques quickly [10].

The term ***constitution*** (synonym: physique) is used for the description of a candidate's body composition (by means of body measurements like body height, body weight, body circumferences, body width, etc.).

6.2.2 Quantitative Approach

In a third phase a test battery was established to derive a current-status profile of the Austrian Special Forces soldiers to identify key-qualifications by comparing the physical performance of the Special Forces soldiers with other groups of soldiers, and to establish minimal requirements.

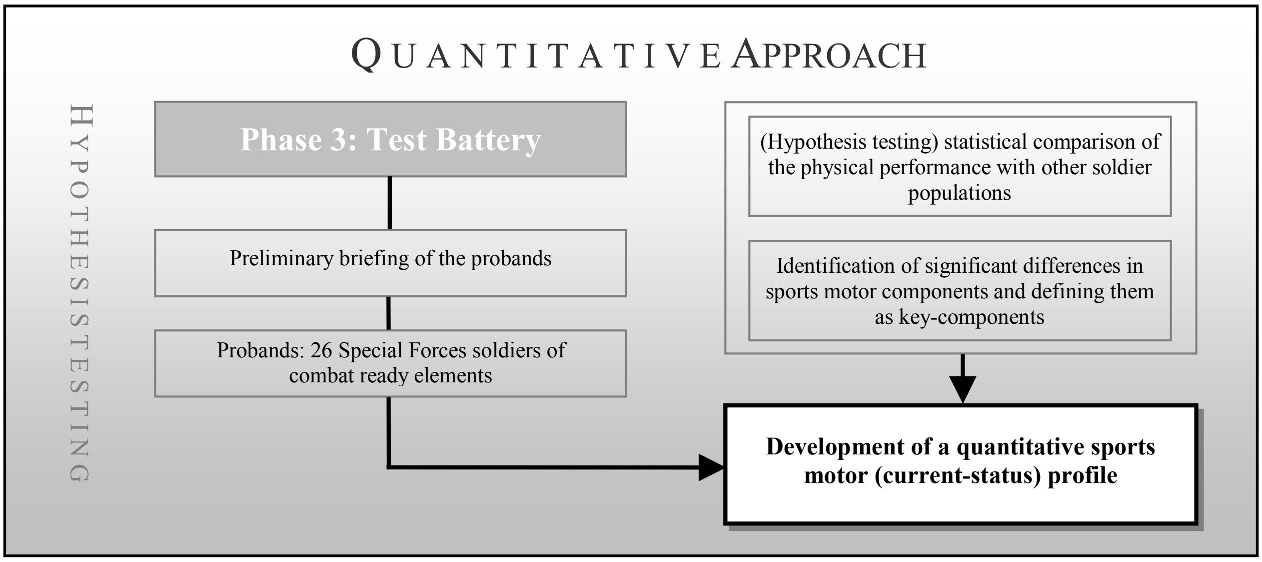


Figure 6-3: Detailed Description of the Quantitative Approach (Source: According to Eisinger et al., 2007).

The applied test battery need not necessarily be used in exactly the same way in future investigations. All standardized test methods which are suitable for examining the relevant sports motor components seem applicable. The following test battery therefore is given as an example, and the complete test standards can be found in Appendix 6A-1.

6.2.2.1 Test Battery

The test battery was performed on two different occasions (13th, 14th and 15th July 2004 and on the 19th, 22nd and 23rd November 2004). All tests were conducted in standardized training areas on military bases and were supervised by educated sport science personnel.

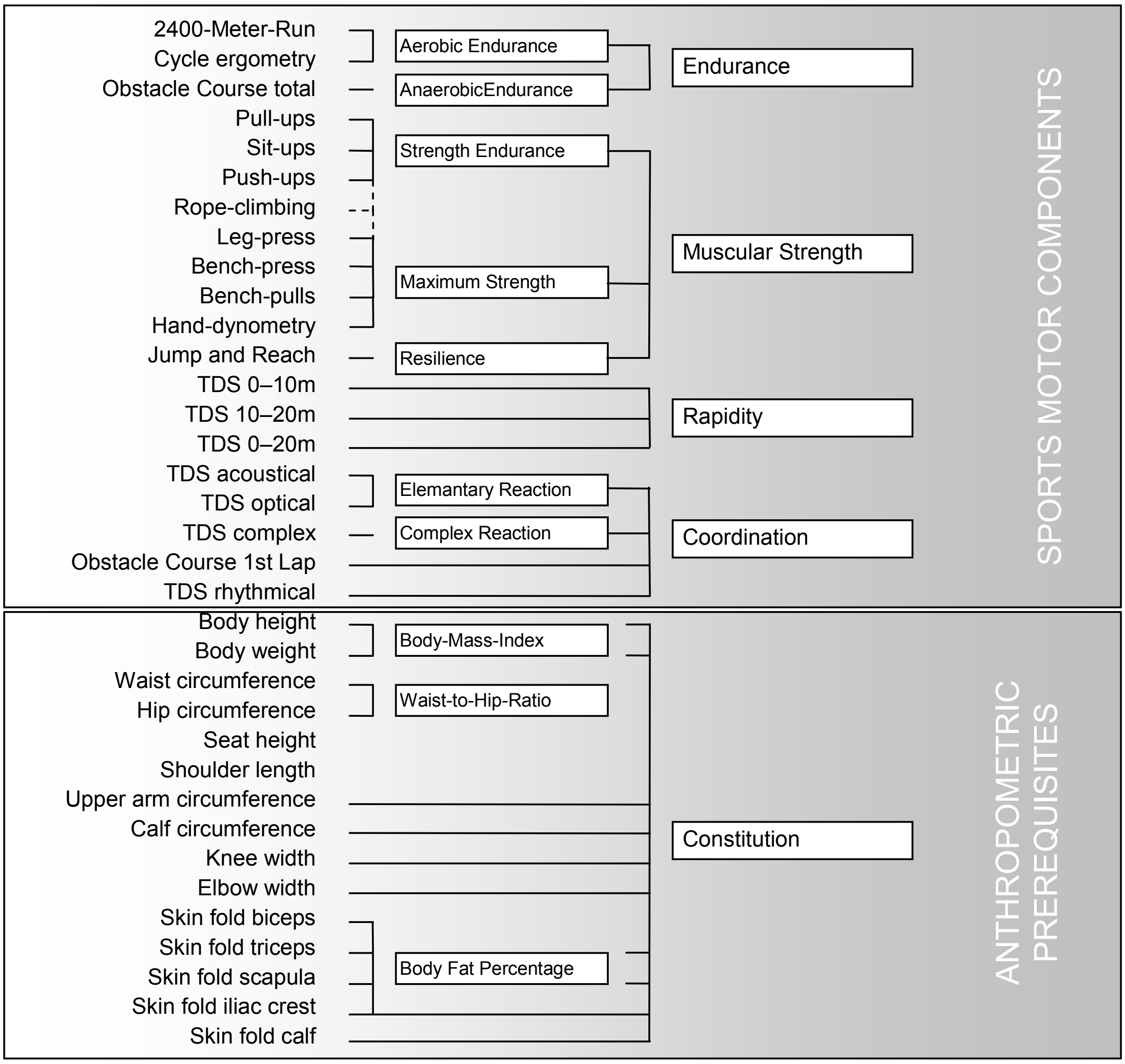


Figure 6-4: Quantitative Test Battery (Source: According to Eisinger, 2006).

6.2.2.2 Probands

The examinations were performed exclusively among 26 Austrian Special Forces soldiers of combat ready elements. These soldiers stand in a permanent training process and are ready for immediate response. Consequently, all soldiers tested are able to accomplish the military tasks successfully. On average the soldiers were 26.8 (SD = 4.9) years old. The distribution of ranks was as follows: 6 Privates, 18 Non-Commissioned Officers and 2 Officers. The probands were selected by the Commanding Officers of the elements. The number of soldiers who just came back from missions and those who were in training for missions was equal. The probands were included after full information and after their voluntary consent was obtained. The probands were all highly motivated to participate in the course.

6.2.2.3 Data Processing

The recorded data were digitalized. All statistics were computed via *SPSS 11.5 for Windows*. For descriptive analyses the arithmetic mean and the standard deviation (SD) were computed. For the comparison between the Special Forces soldiers and the other groups of soldiers the *T-test for one sample* was performed, as only mean values of the other soldier collectives were available. An alpha level of $p<0.05$ was considered to be significant.

The 10th percentile was computed and declared as the minimal requirements for Special Forces soldiers of combat ready elements (detailed information on that rationale can be found in Section 3.3.6).

6.3 RESULTS

The following presentation of the results is subdivided into qualitative and quantitative outcomes.

6.3.1 Qualitative Results

6.3.1.1 Sports Motor Target Profile for Direct Action Operators

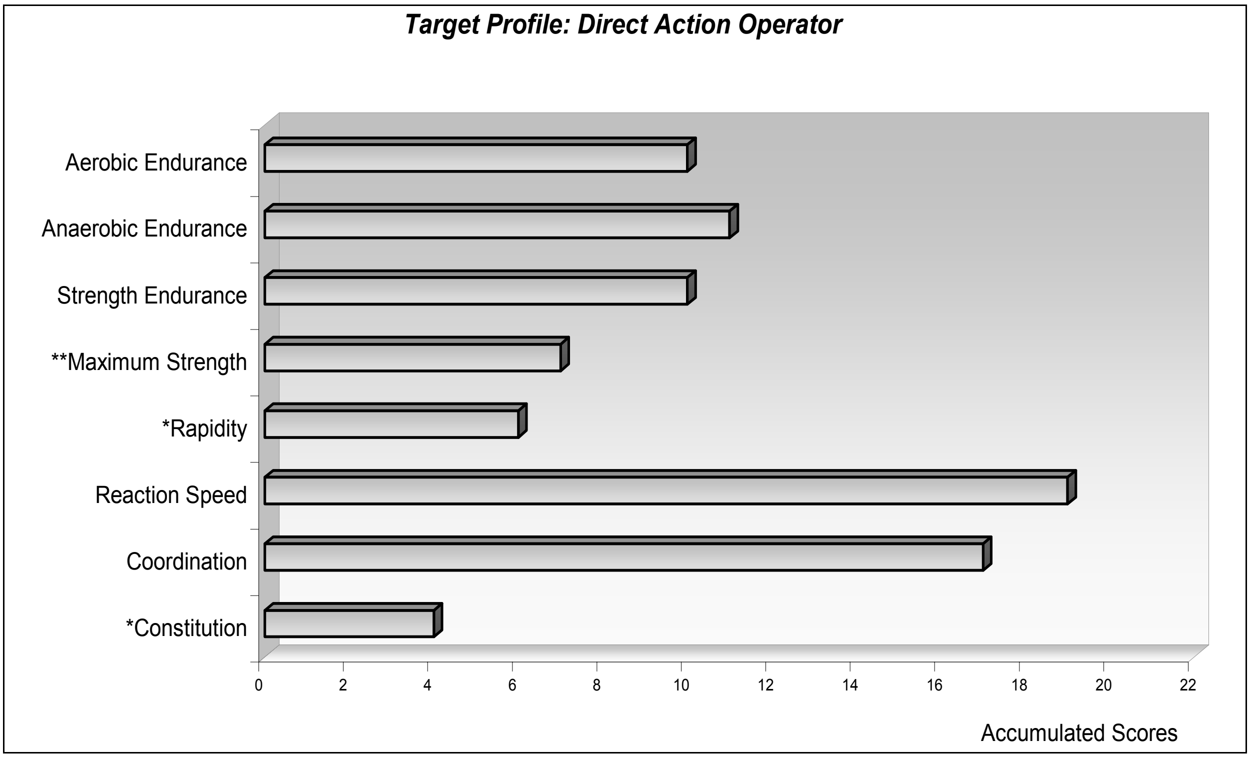


Figure 6-5: Relevancy of Sports Motor Components for Direct Action Operators (Source: According to Eisinger, 2006).

Direct Action specialists weighted reaction speed (19 scores out of 21) and coordinative abilities (17 scores) as the components that have the highest impact on the military performance of Direct Action operators. It is interesting to note that those nervous dominated components seem to be more important than the conditional dominated components.

In addition, experts rated aerobic (10), anaerobic endurance (11) and strength endurance (10) as important components that influence the performance of the operators in that speciality, whereas maximum strength (7), rapidity (6) and constitutional prerequisites (4) were rated as being less important.

6.3.1.2 Sports Motor Target Profile for Close Combat Specialists

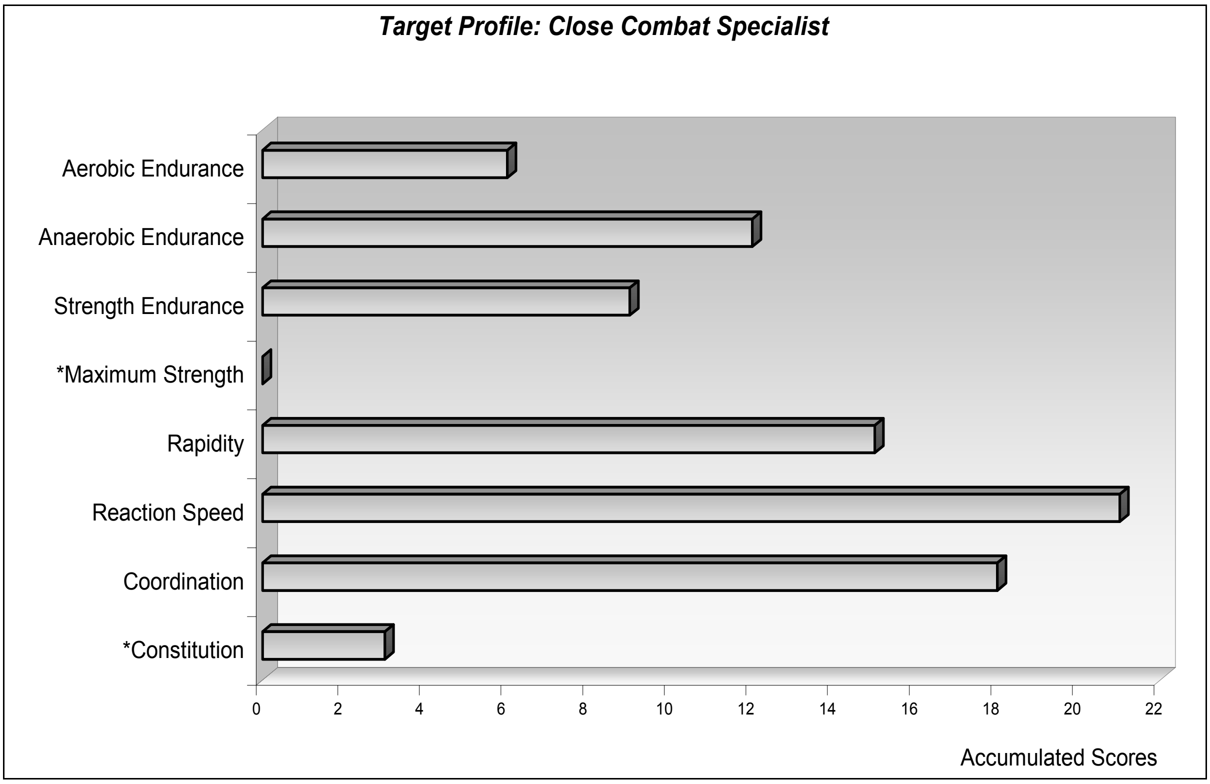


Figure 6-6: Influence of the Relevant Sports Motor Components on the Military Performance of Close Combat Specialists (Source: According to Eisinger, 2006).

According to close combat instructors, reaction speed and coordinative abilities dominantly influence the close combat performance of the soldiers. Rapidity also seems to be very important. The conditional dominated components of aerobic endurance and maximum strength, as well as the physique of a soldier were interestingly enough not of great relevancy. This finding is not supported in the literature [5, 18], where certain correlations between the constitution and the military performance has been reported.

Due to the fact that close combat scenarios generally are limited in time but of high physiological intensity, anaerobic and strength endurance were weighted important as well.

6.3.1.3 Sports Motor Target Profile for Alpine Specialists

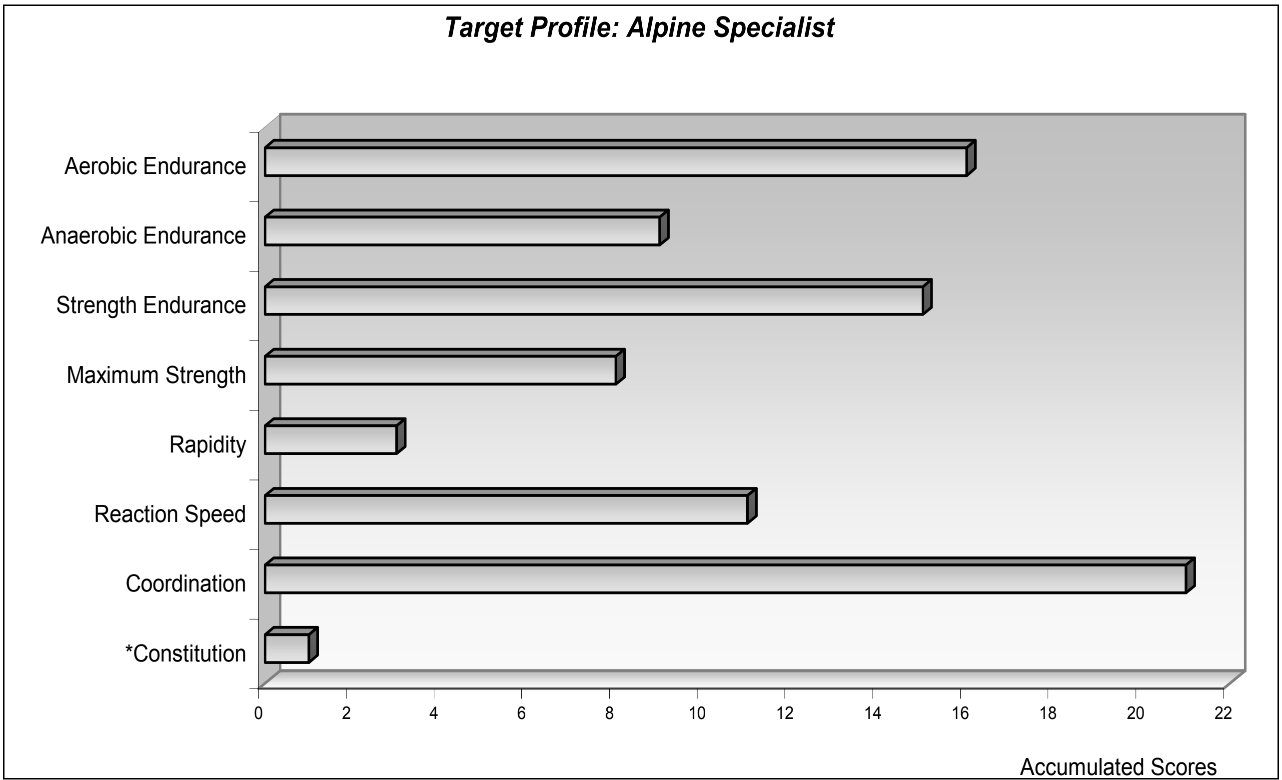


Figure 6-7: Relevancy of Sports Motor Components for Alpine Specialists (Source: According to Eisinger, 2006).

Experts identified coordinative abilities (21 scores), aerobic endurance (16) and strength endurance (15) as the key-components for alpine specialized soldiers. All experts identified coordination as the most important sport motor skill. This might be due to high technical skills necessary for typical activities (skiing or climbing in alpine terrain) in that branch.

Anaerobic endurance (9), maximum strength (8) and reaction speed (11) were identified as being of medium significance, whereas rapidity (3) and constitutional prerequisites (1) were identified as being less important for alpine specialised soldiers.

6.3.1.4 Sports Motor Target Profile for Combat Diving Specialists

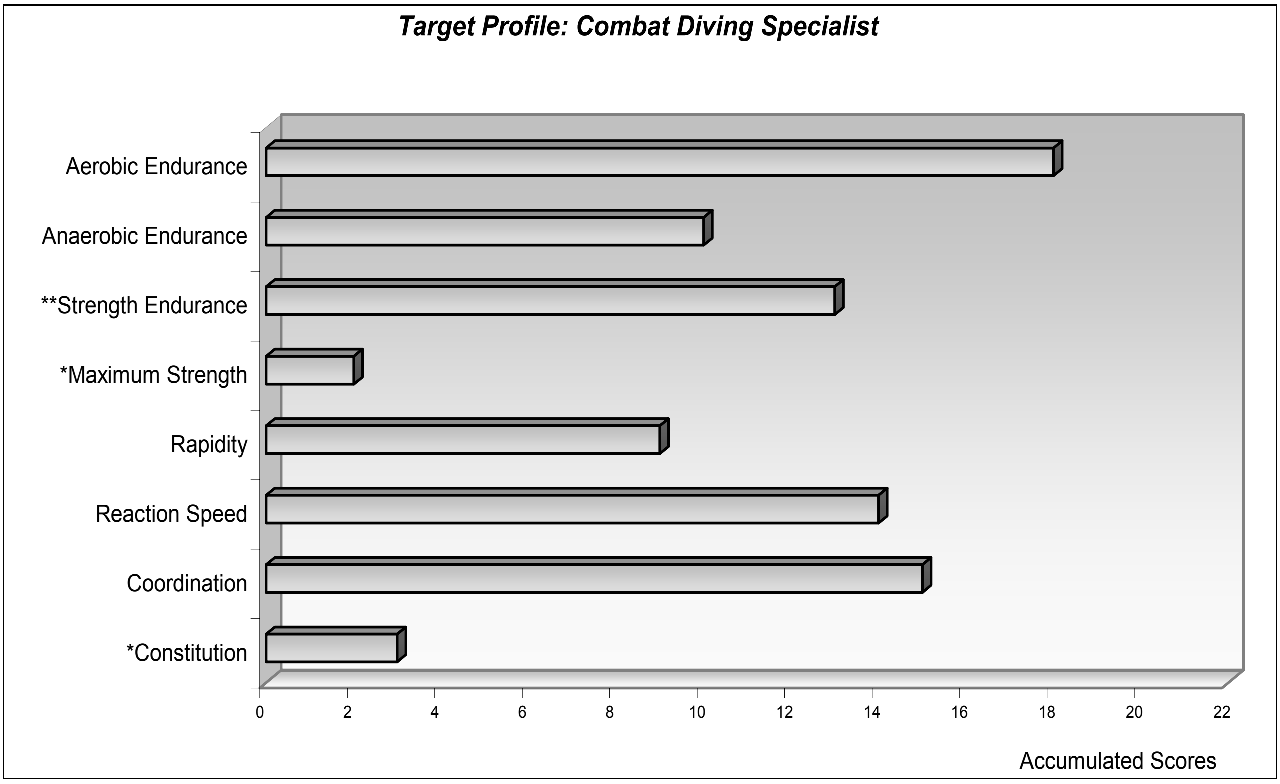


Figure 6-8: Relevancy of Sports Motor Components for Combat Diving Specialists (Source: According to Eisinger, 2006).

It was reported by the experts that aerobic endurance (18), coordinative abilities (15), reaction speed (14) and strength endurance (13) strongly influence the military performance of combat divers. Furthermore it is interesting that in the combat diving section, the conditional dominated aerobic endurance was assessed as being most important, which was not the case in any other area.

Anaerobic endurance (11) as well as rapidity (9) seems to have a medium impact on the combat diving performance. Constitutional prerequisites (3) and maximum strength (2) are of low relevancy.

6.3.1.5 Sports Motor Target Profile for Sky Diving Specialists

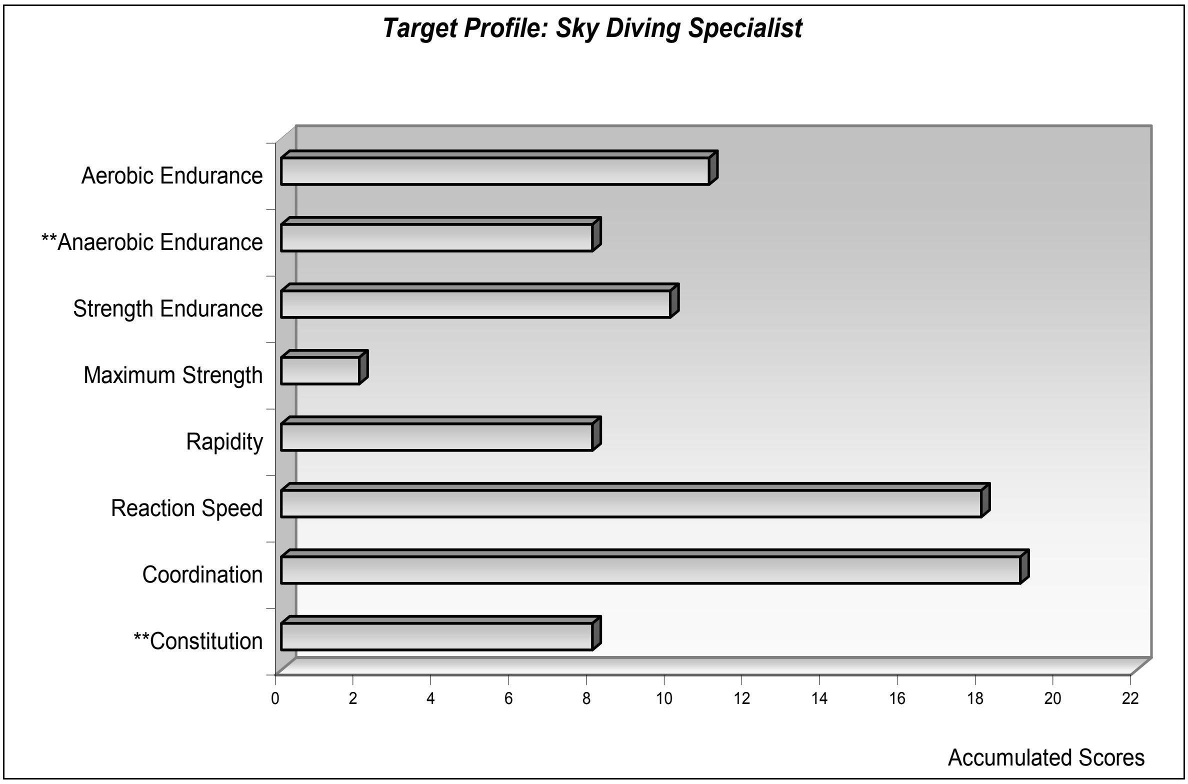


Figure 6-9: Relevancy of Sports Motor Components for Sky Diving Specialists (Source: According to Eisinger, 2006).

As can be seen from Figure 6-9 the performance of military sky divers is dominantly determined by coordinative abilities (19) and certainly by being able to react quickly (18). This finding is not surprising since both components are obviously needed in sky diving specialist. Apart from this finding, the sky diver profile is somewhat balanced. Aerobic, strength, anaerobic endurance, rapidity and physique (all scores between 8 and 11) are of medium significance. It is remarkable that the body measurements are weighted relatively high in this speciality; however, this might be due to aerodynamic reasons. Maximum strength (2) is of less importance in this specialty.

6.3.1.6 Overview of the Derived Sports Motor Target Profiles

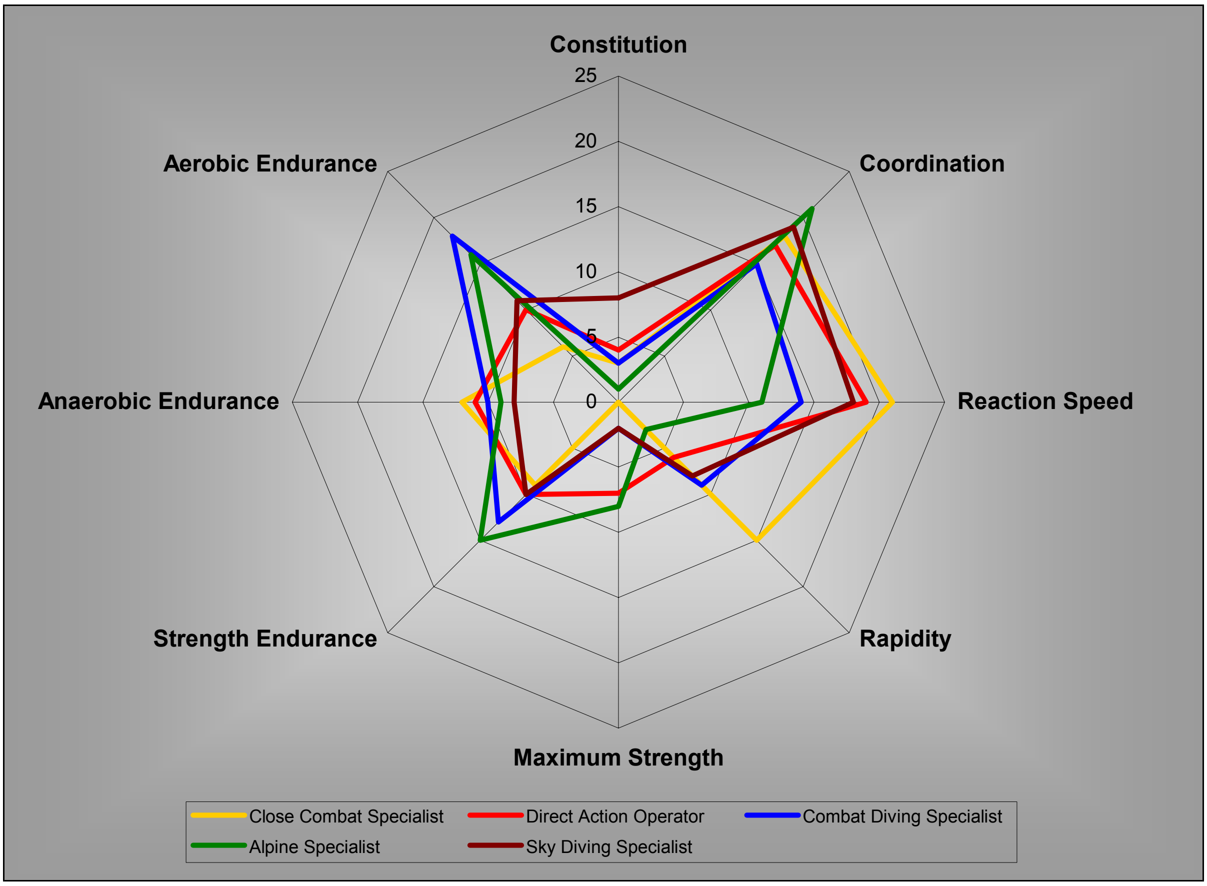


Figure 6-10: Net Diagrams of the Derived Sports Motor Components (Source: According to Eisinger, 2006).

The presented overview (in Figure 6-10) clearly depicts the differences of the target profiles in the investigated specialities. These findings are of great practical significance as selection procedures and training recommendations may be optimized by understanding the derived profiles.

6.3.1.7 Sports Motor Target Profile for Special Forces Soldiers

Under the premise that all Austrian Special Forces soldiers have at least basic skills in all investigated areas, we assumed that the accumulation of all profiles must lead to a general profile for the Special Forces soldier [9].

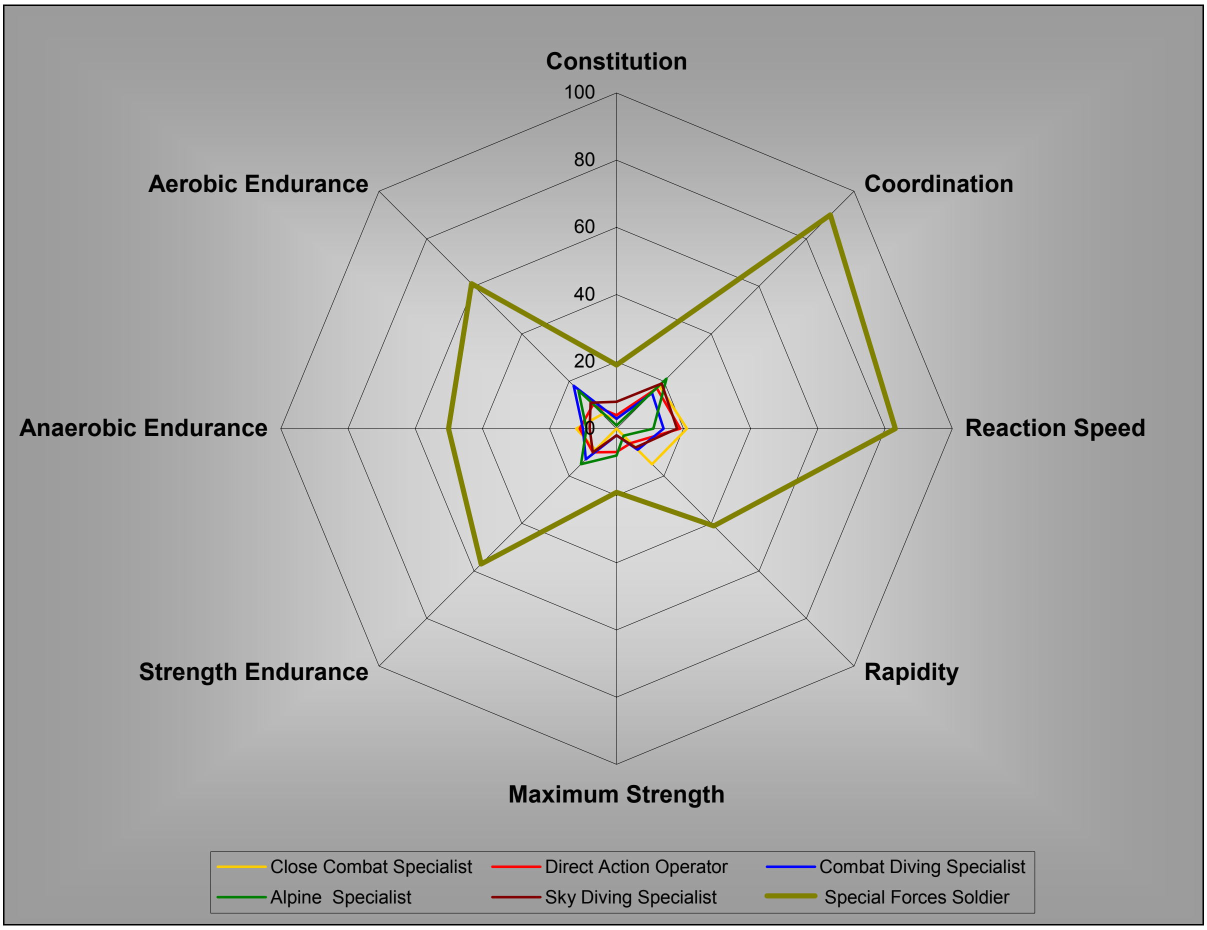


Figure 6-11: Accumulation of the Task Specific Sports Motor Profiles to a General Profile for the Special Forces Soldier (Source: According to Eisinger, 2006).

The summation of the profiles is indicated by the green line in Figure 6-11 respectively in the following figure:

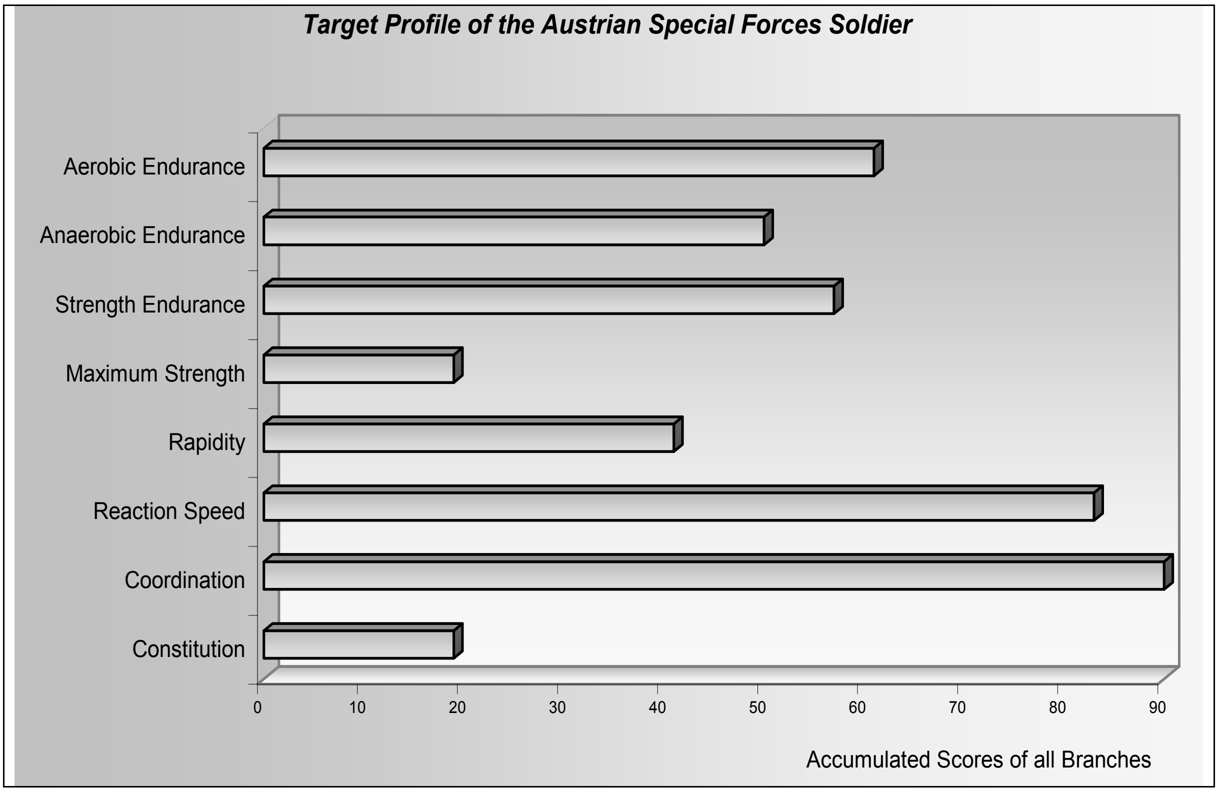


Figure 6-12: Influence of the Relevant Sports Motor Components on the Military Performance of the Special Forces Soldier (Source: According to Eisinger, 2006).

Figure 6-12 presents the general sports motor profile of Special Forces soldiers. Coordinative abilities (90 scores out of 105) and reaction speed (81) have the highest influence on the military performance of the operators. Remarkably those nervous system dominated components seem to have a higher impact than the conditionally dominated components. However, aerobic endurance (61), strength endurance (50) and anaerobic endurance (57) must also be developed very well in Special Forces soldiers.

According to the experts, rapidity (41) is of medium significance whereas maximum strength (19) and constitutional prerequisites (19) are of less importance.

6.3.1.8 Summary of the Qualitative Approach

In a first phase through identifying the military tasks, typical mission scenarios and typical military activities in the investigated areas via guided interviews, we were able to exclude those sports motor components which had a certain influence on the military performance of the Special Forces operators. Those relevant components are: aerobic endurance, anaerobic endurance, strength endurance, maximum strength, rapidity, reaction speed, coordinative abilities and constitutional prerequisites.

Based upon this information, we developed a questionnaire in phase two, and had military experts weight the relevant components regarding their impact on the military performance of the soldiers. By doing so, we obtained a clear ranking and the key-components identified were: coordination, reaction speed, aerobic endurance, strength endurance and anaerobic endurance.

These findings enabled the researchers to evaluate current selection procedures and to establish task specific training recommendations. The qualitative approach also enabled the researchers to discover hidden correlations. It therefore has hypothesis generating character (see the following chapter). However, to test these hypotheses and to produce quantitative information (e.g. minimal requirements) we applied quantitative methods. These methods will be summarized in the following pages.

6.3.2 Generation of Hypotheses Based on the Findings of the Qualitative Approach

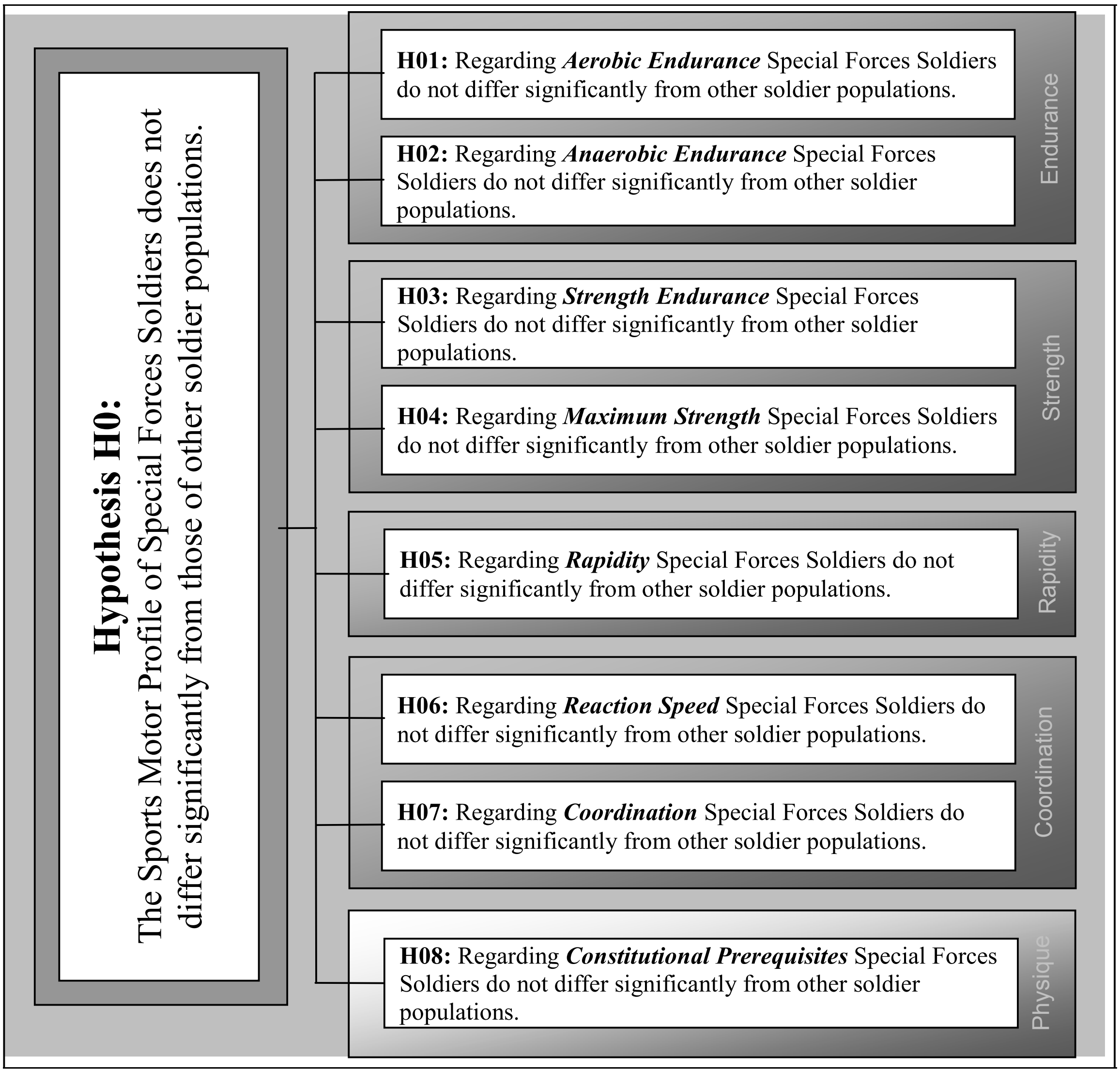


Figure 6-13: Framework for Identifying Key-Qualifications (Source: According to Eisinger, 2006).

6.3.3 Quantitative Results

Examination of Reliability, Validity and Objectivity of the Test Battery

Due to the fact that the applied test battery was established by the Austrian Army Sports Science Service in the past few years, the repeated determination of reliability and validity were not explicitly examined again. However, reliability was indirectly addressed since the tests were performed on two different occasions, and construct validity was indirectly examined via statistical correlation and factor analyses.

Objectivity was ascertained since only scientifically educated personnel were drawn on performing the tests and personnel rotation did not cause any differences whatsoever in the results.

6.3.3.1 Results of the Test Battery

Table 6-1: Average Mean Value and Standard Deviation of the Quantitative Testing of 26 Austrian Special Forces Soldiers (Source: According to Eisinger, 2006)

Results of the Test Battery

Test Procedures and Test Parameters	Short Cuts	Results [Mean Average Value]	Standard Deviation	Measurements	Number of Probands	Tested Sports Motor Components
Cycle Ergometry absolute	Cycle Ergo abs	**337.2**	(54.4)	[W]	26	**Aerobic Endurance**
Cycle Ergometry relative	Cycle Ergo rel	**4.26**	(0.58)	[W/kg]	26	
Cycle Ergometry: Oxygen consumption (computed according to HABER, 2001)	Cycle Ergo VO_2 abs	**3938.1**	(588.5)	[ml/min]	26	
Cycle Ergometry: Oxygen consumption per kg body weight (computed according to HABER, 2001)	Cycle Ergo VO_2 rel	**49.8**	(5.9)	[ml/kg/min]	26	
2400-Meter-Run	2400 m-Run	**9.20**	(29.9)	[min,sec]	25	
2400-Meter-Run: Oxygen consumption per kg body weight (computed according to NELSON, 1995)	2400 m-Run VO_2 rel	**52.8**	(2.0)	[ml/kg/min]	25	
Obstacle Course 2nd Lap	Obst. C. 2nd Lap	**35.2**	(3.8)	[min,sec]	25	**Anaerobic Endurance**
Obstacle Course total	Obst. C. total	**69.6**	(6.5)	[min,sec]	25	
Pull-ups	Pull-ups	**26**	(6.4)	[repetitions]	26	**Strength Endurance**
Push-ups	Push-ups	**50**	(12.5)	[repetitions]	26	
Sit-ups	Sit-ups	**49**	(18.2)	[repetitions]	26	
Rope-climbing	Rope-climbing	**10**	(5.7)	[sec]	26	**Strength Endurance/ Resilience/ Maximum Strength**

Results of the Test Battery

Test Procedures and Test Parameters	Short Cuts	Results [Mean Average Value]	Standard Deviation	Measurements	Number of Probands	Tested Sports Motor Components
Bench-press absolute	Bench-press abs	**93.4**	(16.6)	[kg]	26	**Maximum Strength**
Bench-press relative	Bench-press rel	**1.18**	(0.15)	[kg/kg]	26	
Bench-pulls absolute	Bench-pulls abs	**97.9**	(14.6)	[kg]	26	
Bench-pulls relative	Bench-pulls rel	**1.24**	(0.15)	[kg/kg]	26	
Leg-press absolute	Leg-press abs	**224.5**	(41.3)	[kg]	26	
Leg-press relative	Leg-press rel	**2.83**	(0.47)	[kg/kg]	26	
Hand Dynometry absolute	Hand Force abs	**178.8**	(17.4)	[kg]	14	
Hand Dynometry relative	Hand Force rel	**2.35**	(0.23)	[kg/kg]	14	
Jump and Reach	J&R	**56.3**	(7.0)	[cm]	26	**Resilience**
Talent-Diagnosis-System 0 – 10 Meter Sprint	TDS 0 – 10 m	**1.77**	(0.08)	[sec]	26	**Rapidity**
Talent-Diagnosis-System 10 – 20 Meter Sprint	TDS 10 – 20 m	**1.31**	(0.06)	[sec]	26	
Talent-Diagnosis-System 0 – 20 Meter Sprint	TDS 0 – 20 m	**3.08**	(0.12)	[sec]	26	
Talent-Diagnosis-System Elementary Reaction acoustical	TDS acoustical	**199.7**	(17.9)	[ms]	14	**Elementary Reaction**
Talent-Diagnosis-System Elementary Reaction optical	TDS optical	**230.7**	(22.4)	[ms]	26	
Talent-Diagnosis-System Complex Reaction	TDS complex	**18.4**	(2.1)	[sec]	26	**Complex Reaction/ Co-ordination**
Obstacle Course 1st Lap	Obst. C. 1st Lap	**32.2**	(3.5)	[min,sec]	25	**Coordination**
Talent-Diagnosis-System Rhythmical Sprint	TDS rhythmical	**2.1**	(0.22)	[sec]	26	

Results of the Test Battery

Test Procedures and Test Parameters	Short Cuts	Results [Mean Average Value]	Standard Deviation	Measurements	Number of Probands	Tested Sports Motor Components
Body Height	Height	**178.9**	(6.0)	[cm]	26	Anthropometric Measures
Body Weight	Weight	**79.2**	(8.7)	[kg]	26	
Hip Circumference	Hip Circum.	**95.2**	(7)	[cm]	26	
Waist Circumference	Waist Circum.	**83**	(5)	[cm]	26	
Upper Arm Circumference	Upper Arm Circum.	**32.9**	(3.2)	[cm]	26	
Calf Circumference	Calf Circum.	**39.2**	(2.1)	[cm]	26	
Seat Height	Seat Height	**92.6**	(3.5)	[cm]	26	
Shoulder Length	Shoulder Length	**39.8**	(2.7)	[cm]	12	
Elbow Width	Elbow Width	**7.4**	(0.4)	[cm]	26	
Knee Width	Knee Width	**9.6**	(0.5)	[cm]	26	
Body Mass Index	BMI	**24.8**	(1.9)	[kg/m^2]	26	Anthropometric Parameters
Waist-to-Hip-Ratio	WHR	**0.87**	(0.04)	[Ratio]	26	
Body Fat Percentage (computed according to DURNIN/WOMERSLEY, 1974)	Body Fat Percentage	**12**	(4.7)	[%]	26	
Endomorphy (computed according to HEATH/CARTER, 1967)	Endo	**2.5**	(1.1)	[Index]	26	Body Composition
Mesomorphy (computed according to HEATH/CARTER, 1967)	Meso	**5.6**	(1.1)	[Index]	26	
Ectomorphy (computed according to HEATH/CARTER, 1967)	Ecto	**1.9**	(0.9)	[Index]	26	

6.3.3.2 Identification of Key-Qualifications

The purpose of this section was to investigate whether significant differences exist in sports motor components between Special Forces Soldiers and other groups of soldiers. It was discovered that differences existed, and were due to military training and to the military performance of the Special Forces soldiers. Based upon this information, we assumed that those differences are a strong indication for the component in question to be a key-qualification.

6.3.3.3 Characteristic of the Other Soldier Population

Table 6-2: Overview of the Other Groups of Soldiers (Source: According to Eisinger, 2006)

Overview of the other groups of soldiers drawn form the literature						
Groups of Soldiers: categorised in –		**Literature**	**Number of Probands**	**Age**	**BMI**	**VO_2** [ml/kg/min] according to NELSON (1995)
Rank	**Privates**	MAYER (2002)	102	21.2	20.8	50.6
	Non-commissioned officers (NCO)	MAYER (2002)	259	27.5	21.6	51.6
	Non-commissioned officers	HÖLZL (2005)	75	29.5	25.7	–
	Officer cadets	HÖLZL (2005)	80	21.1	23.9	–
	Officers	MAYER (2002)	102	26.1	21.2	52.7
Branch	**Recruits**	MUCHA (2002)	397	20.2	23	–
	Paratroopers	WITTELS et al., (2005)[4]	36	23.7	23.7	53
	Force for International Missions	WITTELS et al., (2005)[5]	132	23.5	24.6	49.3
Function	**NCOs (office duty)**	HÖLZL (2005)	33	29.9	26.2	–
	NCOs (field duty)	HÖLZL (2005)	40	29	25.3	–
Other Criteria	**Male Soldiers**	HÖLZL (2005)	72 – 167	–	–	–
	20 – 40-years aged soldiers	RAUSCH (2004)	305	20 – 40	25.2	–

With the table above an overview is given of the other groups of soldiers, which are used as the reference group for statistical comparisons. The samples used are representative for their home units.

[4] Source of the Data: Austrian Army Sports Science Service.

[5] Source of the Data: Austrian Army Sports Science Service.

6.3.3.4 Hypotheses Testing

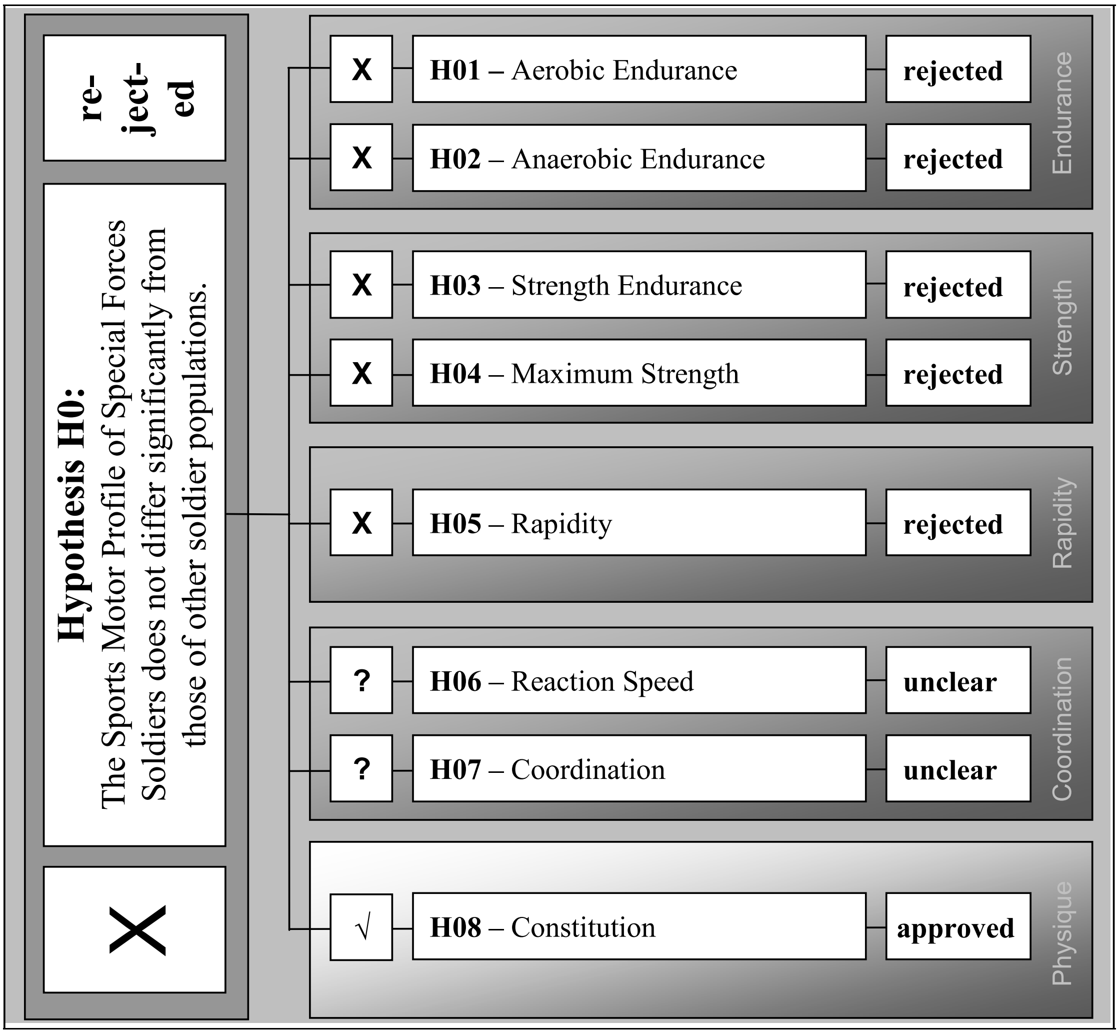


Figure 6-14: Results of the Statistical Comparison (Source: According to Eisinger, 2006).

As summarized in Figure 6-14 the formulated hypothesis that there would be a difference in the sports motor profile between Special Forces soldiers and other groups of soldiers is rejected. Specifically, the physiological performance of the Special Forces soldiers was significant higher than the other groups of soldiers tested with respect to aerobic endurance, anaerobic endurance, strength endurance, maximum strength and rapidity.

Hypotheses 6 (reaction speed) and 7 (coordination) could for several reasons not be explicitly clarified and is therefore a matter for further investigation.

Regarding the physique of Special Forces operators and other soldier collectives we could not find any differences. Consequently hypothesis 8 is approved.

A graphical synopsis of the physiological performance of all soldier populations is presented in the following figure. In order to be able to display all measurements in one graph it was necessary to *standardise* them. Therefore the sets of data were transformed so that the mean value of the distributions was 0 and the standard deviation was 1. Furthermore, the algebraic sign of the data were manipulated so that scales on the periphery of the graph mean better performance (except anthropometric data and age).

6.3.3.5 Current-Status Profiles of Special Forces Soldiers Compared to Other Soldier Collectives

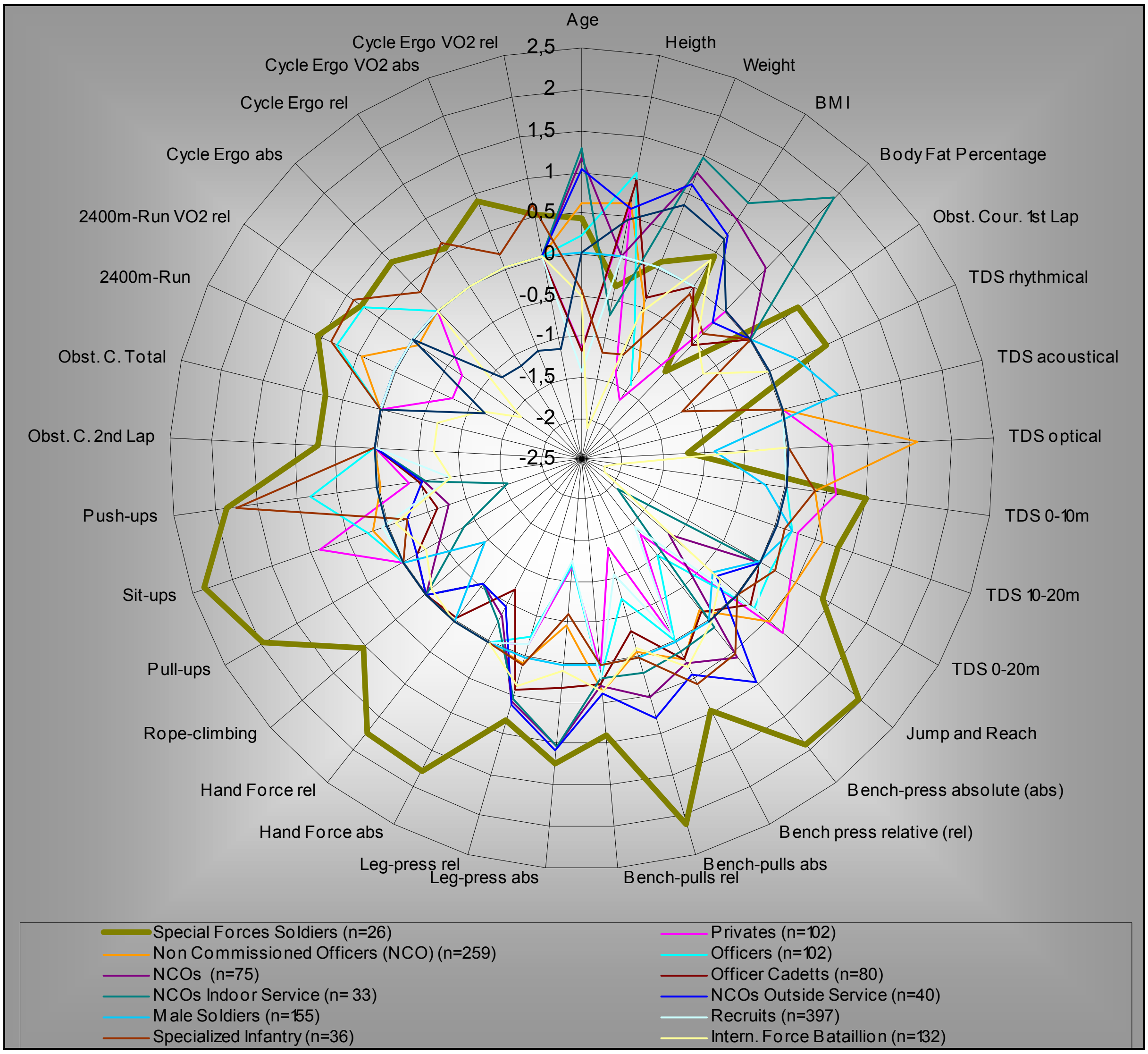


Figure 6-15: Current-Status Sports Motor Profiles of the Special Forces Soldier (Source: According to Eisinger, 2006).

This data indicates the above average performance of the tested Special Forces soldiers compared to other groups of soldiers. Furthermore, the results clearly outline that Special Forces operators perform better almost throughout the whole spectrum of physiological performance.

Only the soldiers of a specialised infantry battalion demonstrated as good achievements as the Special Forces soldiers in some areas. This might be due to the fact that those soldiers are also in a permanent state of readiness and are part of very well trained infantry units.

It was interesting to note that the Special Forces soldiers showed poor reaction speed abilities, which is of special interest as this findings does not conform with what was observed via the qualitative approach. A detailed analysis of this result showed that the applied reaction tests (TDS acoustical and optical) are not valid if we want to examine the influence of reaction on the military performance of a soldier.

The signified tests were established to measure *elementary reaction*[6] speed whereas *complex reaction*[7] speed is dominantly needed in Special Forces scenarios respective operators. We also know from literature sources that there is no correlation between these two kinds of reaction abilities [17, 28, 30].

Also, slightly different standards in the conduction of the tests for the different populations might have led to the poor reaction abilities of the Special Forces collectively. As this statement is speculative and as only little referential material was available, hypothesis 6 could neither be rejected or approved. For similar reasons the coordinative area must also be left unanswered. Both components are certainly important for successful mission accomplishment but must be further investigated in the future.

6.3.3.6 Development of Minimal Requirements

Minimal requirements like selection procedures and training recommendations must be reflective of mission demands. Nevertheless, even when minimal requirements are derived from the actual mission demands criticism exists. This criticism is often rooted in the fact that at a certain point even when on a scientific basis the cut-off level must be set somehow arbitrarily.

Under that premise and after long debating with military and scientific experts we have chosen the 10th percentile as a suitable selection criterion for Special Forces soldiers of the combat ready elements. The idea was that the tested operators were declared to be able to accomplish all requested military task successfully. Consequently even the very lowest measured physiological performance could be defined as minimal requirement. Since we aimed to exclude outliers and since individual weaknesses can be compensated we found the 10th percentile to be adequate.

6.3.3.7 Summary of the Quantitative Findings

As was shown in Figure 6-14 (results h0-testing) the formulated hypothesis, according to which the sports motor profile from Special Forces soldiers alters from other groups of soldiers, had to be rejected. The tested Special Forces operators performed significantly better in the sports motor dimensions of aerobic endurance, anaerobic endurance, strength endurance, maximum strength and rapidity. However, we could not clarify whether there are differences with respect to reaction speed and coordinative abilities. We did not find clear differences concerning the physique of the soldier collectives; hence hypothesis 8 had to be approved.

The quantitative approach also enabled us to derive plausible minimal requirements (see Table 6-3) for Special Forces soldiers of combat ready elements.

[6] The term *elementary reaction* stands for a reaction which is started by a known signal and performed by a known movement.

[7] Under the term *complex reaction* a reaction is understood which is initiated by an unknown signal and followed by an unknown action. In this case the subject has to make a decision which alternative amongst a number of alternatives is the best answer in a specific situation. Quite obviously complex reaction abilities are very much needed in Special Forces scenarios rather than pure elementary reaction abilities.

Table 6-3: Minimal Requirements for Special Forces Soldiers of the Combat Ready Elements (Source: According to Eisinger, 2006)

10th Percentile as Minimal Requirement					
Test Procedures and Test Parameters	**Short Cuts**	**10th Percentile**	**Measurements**	**Number of Probands**	**Tested Sports Motor Components**
Cycle Ergometry absolute	Cycle Ergo abs	**256**	[W]	26	**Aerobic Endurance**
Cycle Ergometry relative	Cycle Ergo rel	**3.56**	[W/kg]	26	
2400-Meter-Run	2400 m-Run	**10.4**	[min,sec]	25	
2400-Meter-Run: Oxygen consumption per kg body weight (computed according to NELSON, 1995)	2400 m-Run VO_2 rel	**49.92**	[ml/kg/min]	25	
Obstacle Course 2nd Lap	Obst. C. 2nd Lap	**40.4**	[min,sec]	25	**Anaerobic Endurance**
Obstacle Course total	Obst. C. total	**79.7**	[min,sec]	25	
Pull-ups	Pull-ups	**19.1**	[repetitions]	26	**Strength Endurance**
Push-ups	Push-ups	**35.7**	[repetitions]	26	
Sit-ups	Sit-ups	**22.1**	[repetitions]	26	
Rope-climbing	Rope-climbing	**11.7**	[sec]	26	**Strength Endurance/Resilience/ Maximum Strength**
Bench-press absolute	Bench-press abs	**68.7**	[kg]	26	**Maximum Strength**
Bench-press relative	Bench-press rel	**0.96**	[kg/kg]	26	
Bench-pulls absolute	Bench-pulls abs	**77.7**	[kg]	26	
Bench-pulls relative	Bench-pulls rel	**1.05**	[kg/kg]	26	
Leg-press absolute	Leg-press abs	**172.0**	[kg]	26	
Leg-press relative	Leg-press rel	**2.15**	[kg/kg]	26	

10th Percentile as Minimal Requirement

Test Procedures and Test Parameters	Short Cuts	10th Percentile	Measurements	Number of Probands	Tested Sports Motor Components
Hand Dynometry absolute	Hand Force abs	**152.5**	[kg]	14	
Hand Dynometry relative	Hand Force rel	**2.05**	[kg/kg]	14	
Jump and Reach	J&R	**43.0**	[cm]	26	**Resilience**
Talent-Diagnosis-System 0 – 10 Meter Sprint	TDS 0 – 10 m	**1.9**	[sec]	26	**Rapidity**
Talent-Diagnosis-System 10 – 20 Meter Sprint	TDS 10 – 20 m	**1.38**	[sec]	26	
Talent-Diagnosis-System 0 – 20 Meter Sprint	TDS 0 – 20 m	**3.26**	[sec]	26	
Talent-Diagnosis-System Elementary Reaction acoustical	TDS acoustical	234.5	[ms]	14	**Elementary Reaction**
Talent-Diagnosis-System Elementary Reaction optical	TDS optical	255.1	[ms]	26	
Talent-Diagnosis-System Complex Reaction	TDS complex	21.15	[sec]	26	**Complex Reaction/ Co-ordination**
Obstacle Course 1st Lap	Obst. C. 1st Lap	37.56	[min,sec]	25	**Coordination**
Talent-Diagnosis-System Rhythmical Sprint	TDS rhythmical	2.37	[sec]	26	
Body Mass Index	BMI	**26.94**	[kg/m^2]	26	**Anthropometric Parameters**
Body Fat Percentage (computed according to DURNIN/WOMERSLEY, 1974)	Body Fat Percentage	**18.27**	[%]	26	

6.3.4 Declaration of Key-Qualification for Special Forces Operators

In order to finally identify sports motor key-qualifications for Special Forces operators both the qualitative and quantitative findings are confronted and a conclusion is drawn as outlined in the following picture:

Key-Qualification

Methodical Approach	Qualitative Approach		Quantitative Approach	Conclusion
Instruments	Guided Interview	Questionnaire	Test Battery	
Importance of the Results	Relevant (sports motor) Components	Key-Components		Key-Qualifications
	Aerobic Endurance	+	+	+
	Anaerobic Endurance	+	+	+
	Strength Endurance	+	+	+
	Maximum Strength		+	
	Rapidity		+	
	Reaction Speed	+		+
	Coordination	+		+
	Constitution			

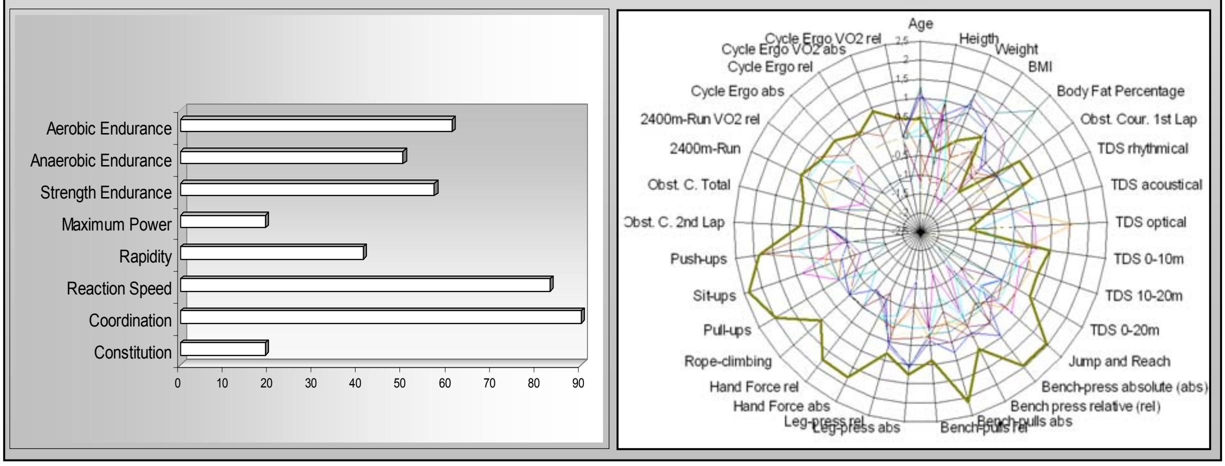


Figure 6-16: Identification of Sports Motor Key-Qualification for Special Forces Soldiers (Source: According to Eisinger, 2006).

By means of qualitative instruments, coordinative abilities, reaction speed, aerobic, strength and anaerobic endurance were identified as having the highest impact on the military performance of the soldiers. In contrast the quantitative approach revealed significant differences in aerobic, anaerobic, strength endurance as well as rapidity and maximum strength. From these findings aerobic endurance, anaerobic endurance and strength endurance can explicitly be declared as key-qualifications.

The found differences in maximum strength and rapidity are possibly due to the training habits of the tested soldiers. In the authors opinion these differences are not caused by military demands and are therefore classified relevant but not key-qualification. At this point it seems worth highlighting the importance of the qualitative approach, which worked well as corrective for the quantitative methods and findings.

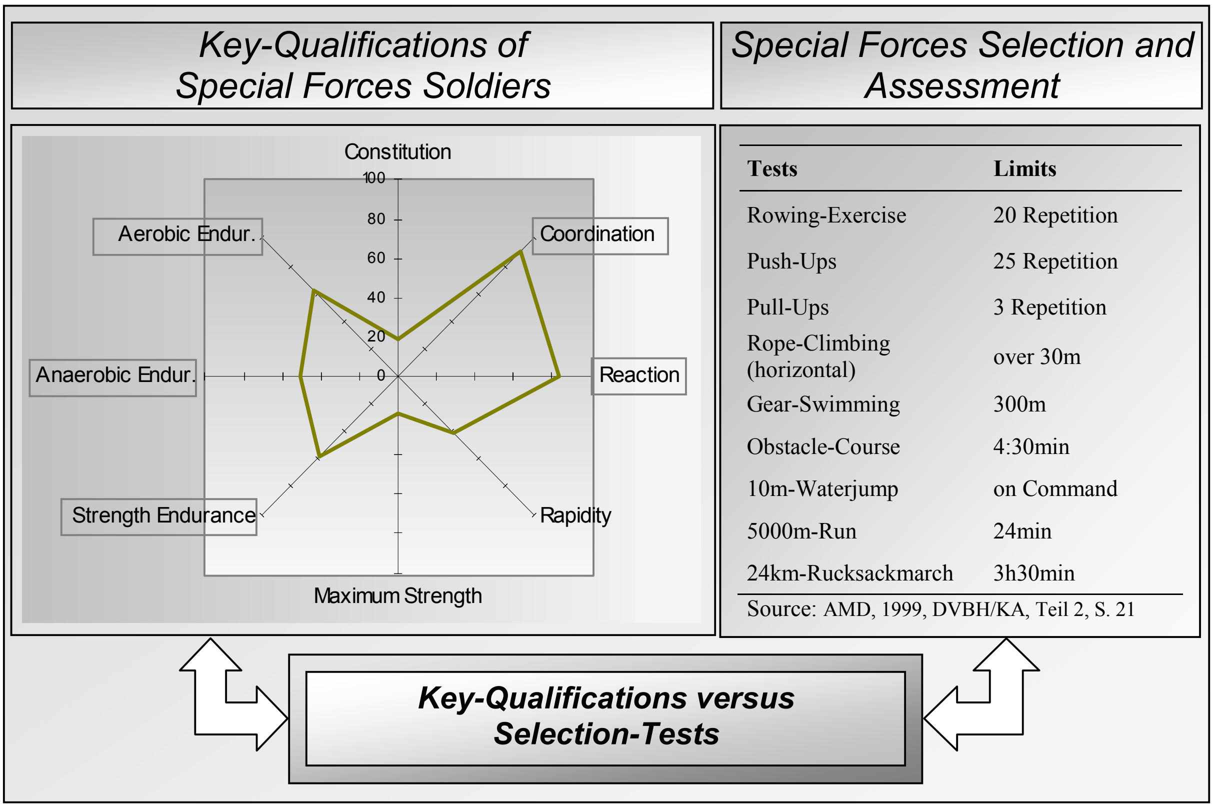
Although the results of the quantitative testing do not support the qualitative findings regarding reaction speed and coordinative abilities we defined them to be key-qualifications too. The decision was based on the fact that all military experts of all branches weighted the respective components as highly important.

6.4 PRACTICAL APPLICATIONS OF THE GENERATED KNOWLEDGE

6.4.1 Evaluating or Establishing Military Selection Procedures

Earlier in this chapter, the key-qualifications for Special Forces operators were identified. We now know which components must be developed in a Special Forces candidate. That knowledge associated with the computed minimal requirements brings us to a position where we can precisely investigate whether the currently applied selection procedures are valid[8] and whether they are complete[9].

Figure 6-17 exemplifies this framework. The confrontation of the derived key-qualifications with the selection tests revealed that aerobic, anaerobic and strength endurance is examined during the process. However, we cannot find reaction or coordination tests. Consequently the selection procedures are incomplete. From a scientific point of view it is recommended that tests to evaluate reaction speed and coordinative abilities be implemented. This is especially true since we know from the literature that the dimensions in question are to a high degree genetically determined and trainability is limited [11, 15, 27, 29, 30].



Tests	Limits
Rowing-Exercise	20 Repetition
Push-Ups	25 Repetition
Pull-Ups	3 Repetition
Rope-Climbing (horizontal)	over 30m
Gear-Swimming	300m
Obstacle-Course	4:30min
10m-Waterjump	on Command
5000m-Run	24min
24km-Rucksackmarch	3h30min

Source: AMD, 1999, DVBH/KA, Teil 2, S. 21

Figure 6-17: Framework for Analysing Selection Procedures and Assessment (Source: According to Eisinger, 2006).

8 Do the selection procedures actually test those (key-) components which are influencing the military performance of soldiers?

9 Are all relevant sports motor components examined?

6.4.2 Development of Individual Training Recommendations

Amongst other reasons the quantitative investigation was also conducted in order to gain referential material for performance diagnostic and training recommendation purposes. As stated earlier, the soldiers tested were able to accomplish the requested military tasks successfully. Therefore it is plausible to use the mean average value as reference and compare this collective performance with the individual performance of soldiers. By doing so physiological performance deficits can be identified and precise training recommendations given.

In Figure 6-18 two probands are exemplified: Proband j20 (blue line) is relatively poorly trained. In order to fit the Special Forces profile training across almost the whole spectrum is indicated (except rapidity and reaction). An average BMI associated with a high body fat percentage shows additionally low skeletal muscle mass. The graph also shows extremely poor abdominal force which makes the proband prone to back injuries.

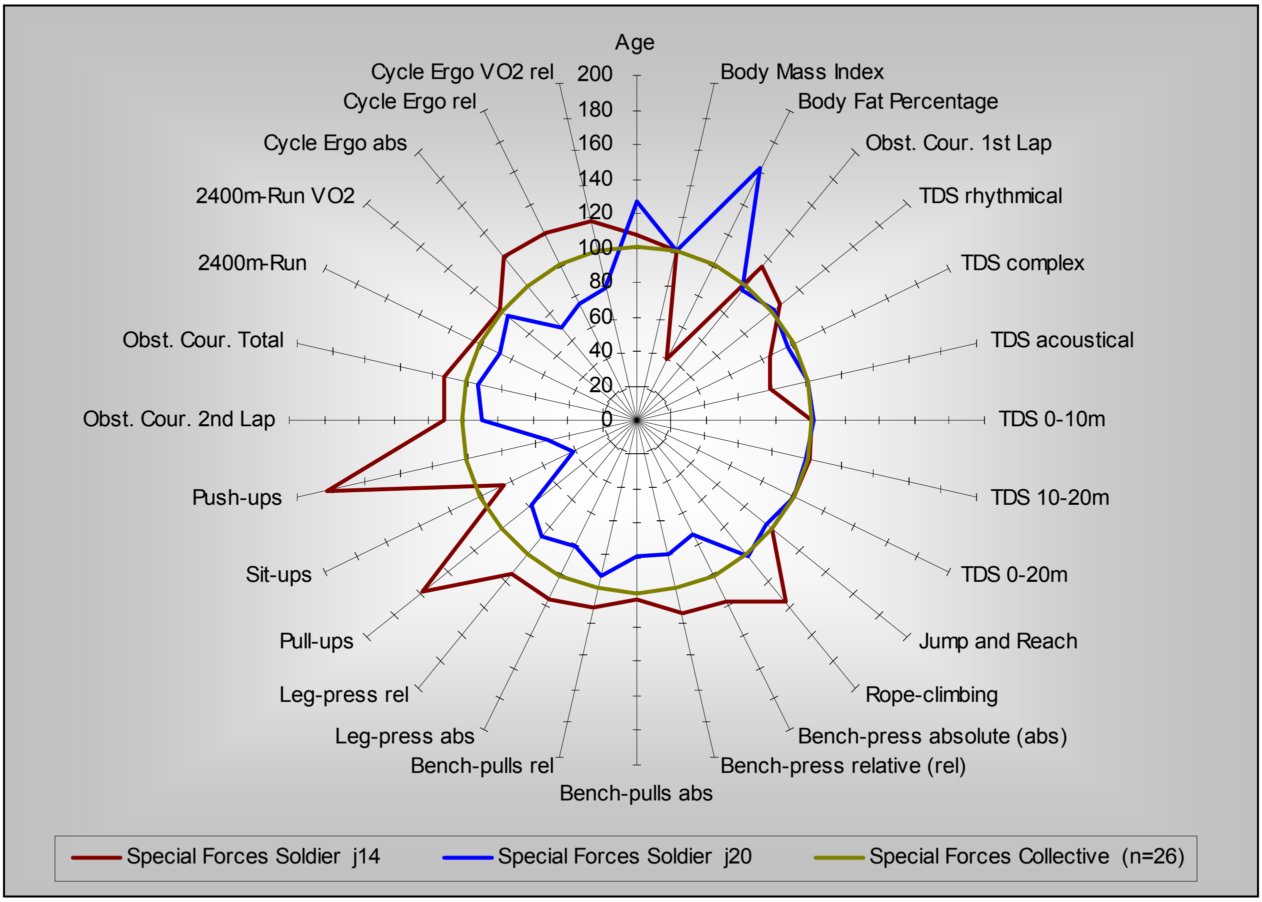


Figure 6-18: Framework for Identifying Individual Training Deficits (Source: According to Eisinger, 2006).

In contrast proband j14 (red line) is in a good shape. The graph clearly demonstrates an average BMI and a low body fat percentage, which is due to high lean skeletal muscle mass. However, we also found weak abdominal force. Again the abdominal region must be trained and should be a matter of muscle function testing in order to clarify whether muscular disbalances are profound.

6.4.3 Development of Special Forces Specific Individual and Group Training Recommendations

If we extend the model exhibited in Figure 6-18 by the sports motor target profile for Special Forces operators and compare the actual performance of a soldier (proband j20) with that profile respectively with the marked key-qualification we are in a position to give Special Forces specific training recommendations. In the shown case we would have to suggest the candidate to focus on improving aerobic, anaerobic, strength endurance as well as reaction and coordination whereas maximum strength and rapidity can be neglected.

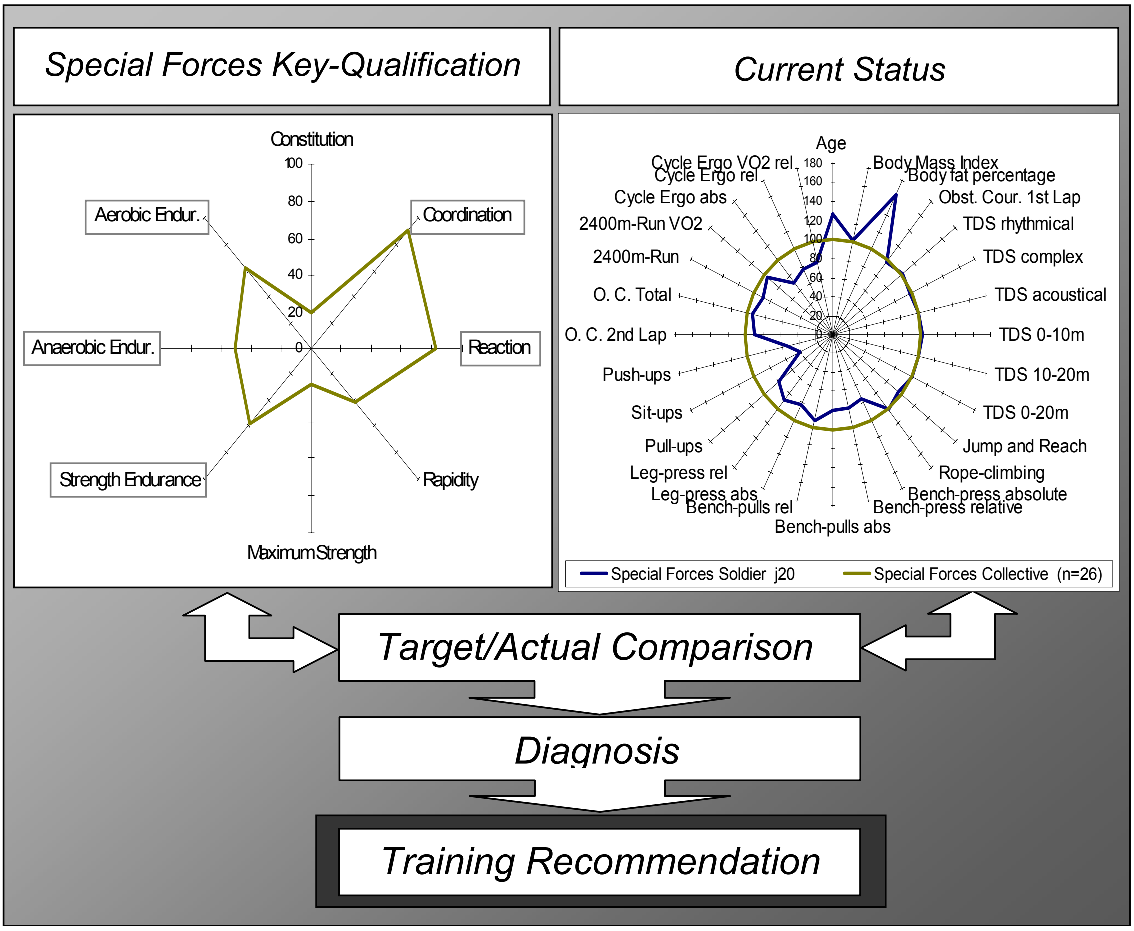


Figure 6-19: Model for Special Forces Specific Training Recommendations (Source: According to Eisinger, 2006).

Additionally this model enables us to not only give general Special Forces training recommendations but also precise task specific training recommendations. Therefore we replace the profile for Special Forces operators with a task specific qualitative sports motor target profile – as exemplified in Figure 6-20. In this case we would not recommend to emphasis anaerobic training as it seems not to have a great influence on the military performance of combat divers. Instead, it would be recommended that the candidate concentrate on aerobic training, strength endurance, reaction speed and coordination as such. Again maximum strength and rapidity need not to be developed further if the candidate plans to specialise in combat diving.

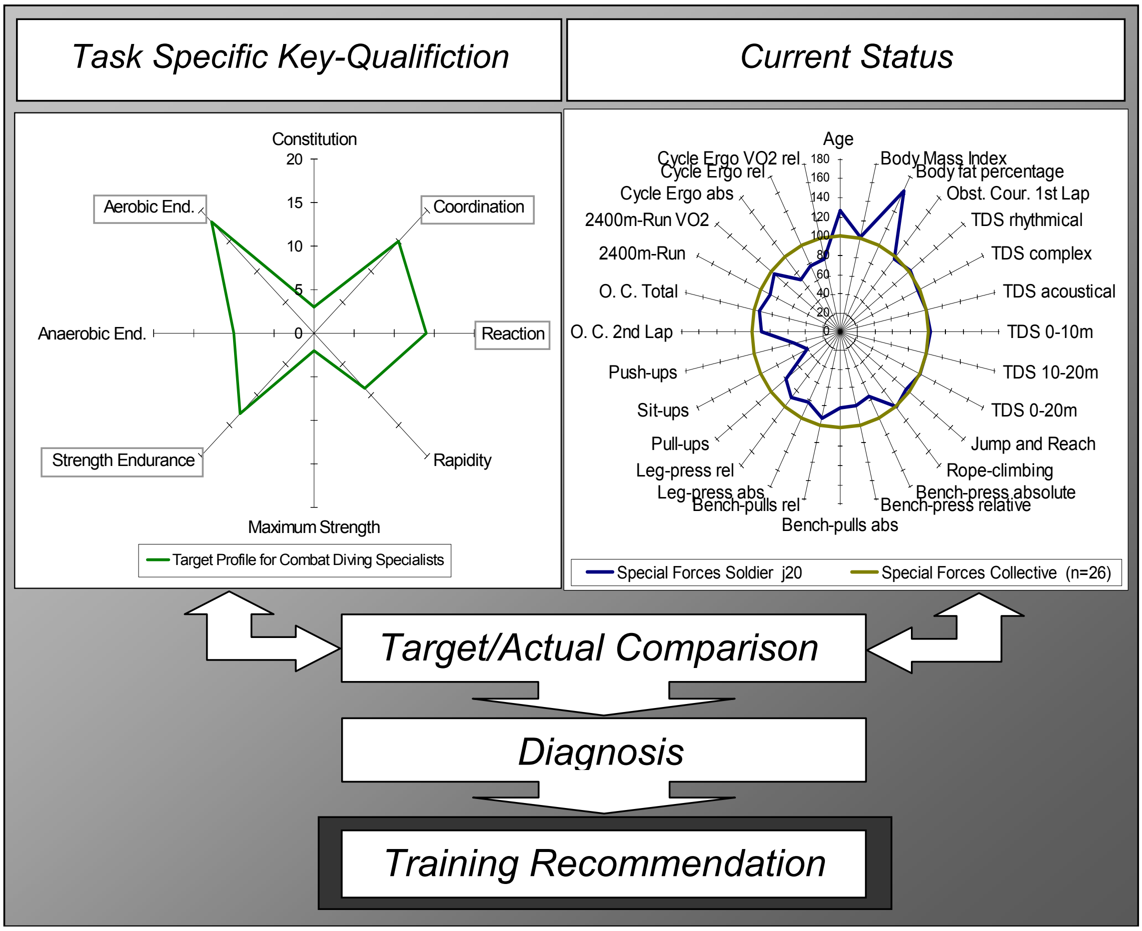


Figure 6-20: Model for Task Specific (Combat Diver) Training Recommendations (Source: According to Eisinger, 2006).

6.5 DISCUSSION

Complex military mission demands like those of Special Forces operators cannot be described conclusively via single military activities (marching, digging, etc.). In order to get a comprehensive view we invented a different methodology. Instead of looking at single military activities we identified relevant sports motor components (as endurance, muscular strength, etc.) and investigated data of the physical performance of Special Forces soldiers who were declared as ready for mission by the commanding officers. This methodology enabled the description of complex Special Forces mission demands.

Coordinative abilities, **reaction speed**, **aerobic endurance**, **strength endurance** and **anaerobic endurance** were identified as key qualification for Special Forces soldiers. Whereby, the conditional dominate components (aerobic, strength and anaerobic endurance) were found to be key qualifications both by the qualitative and the quantitative approach. However, coordination and reaction were declared to be key qualifications based on qualitative findings only. Although our argumentation is conclusive and the qualitative reports are very strong this conclusion can be criticised; therefore coordination and reaction are certainly an issue of further research.

Furthermore, our findings have to be seen in context with the premises made and the Austrian conditions of the investigated field. Whether the results of the Austrian Special Forces operators are applicable to other foreign Special Forces units could not be clarified in this paper and therefore is also a matter of further investigation.

In this context the small number of subjects involved in this study should be considered. In fact, the sample is, in respect of the small main unit, representative of Austrian Special Forces. However, international statements based on this study have to be interpreted carefully.

A further point of criticism is that currently no international standards or definitions of the studied operational areas exist. The term Special Forces as well as the operational areas of direct action, close combat, mountaineering, combat diving and parachuting are on the international scene not understood uniformly. From a scientific point of view this is highly problematic and should be resolved at least within NATO.

Knowing that there is no linear correlation between the physiological performance and the military performance of a soldier the definition of minimal requirements is essential. The 10th percentile was found to be a suitable cut-off level for Special Forces operators to be declared combat ready. These computed minimal requirements (e.g. 49.9 ml/kg^{-1}/min^{-1} [2400 m-run]; 3.6 Watt/kg [cycle ergometry]; Pull-ups 19; Push-ups 36; Sit-ups 22)[10] have again to be associated with the stated premises. The level is only accurate if the drawn sample satisfies the given prerequisites. Whether respective cut-off values match with Special Forces operational demands must be evaluated in practice.

In general, the authors indicated that in order to accomplish the applied methodical approaches successfully the given premises must be met by the investigated population. We furthermore remarked that the applied methods are not exclusive. However, the solely developed and herewith presented research setting was empirically tested and was proven to work exceptionally well for establishing sports motor profiles for (Special Forces) soldiers.

6.6 ACKNOWLEDGEMENT

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The views, opinions, and/or findings contained in the report are those of the authors and should not be construed as an official position of the Austrian Ministry of Defence, unless so designated by other official documentation. The study was conducted in accordance with current laws in Austria regarding research with human subjects.

We would like to thank the participating Special Forces soldiers. Additionally we would like to thank the staff of the Research Group on Physical Performance Medicine and the staff of the Army Sports Science Service for performing the test battery.

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10 The test standards can be looked up in Appendix 6A-1.

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Appendix 6A-1 – Test Standards

The 2400-meter run was performed outdoor. Cycle ergometry, indoor obstacle course, the 20-meter sprint and the tests for strength endurance as well as maximum strength were performed indoor, in a gym.

6A-1.1 TESTS FOR AEROBIC ENDURANCE

To examine aerobic endurance a 2400-meter run (reversed Cooper test) and a cycle ergometry were conducted.

6A-1.2 2400 M RUN

For the 2400 m-run a standardized 400-meter outdoor runway with sand surface was used. When testing the Special Forces soldiers, the temperature during the test was 20° C on the first recording date and 9° C on the second. The weather was similar at both dates: cloudy with drizzle. Wind speed was 1 m/s and 4 m/s at the respective dates. The strength and the direction of the wind were constant at both dates.

The soldiers were instructed and motivated to run 6 rounds with their individual highest speed possible. Time was recorded with standard stop watches by educated sports trainers.

From the results of the 2400-meter run the absolute and relative VO_2max was computed via the following regressions equations after NELSON [23]:

$$VO_2max(L/min) = 2.683+(0.2812*sex)+(0.035*BW)–(0.1749*t)$$

$$VO_2max(ml/kg/min) = 88.02+(3.716*sex)–(0.1656*BW)–(2.767*t);$$

whereas:	sex:	1 for men
		0 for women
	BW	body weight in kg
	t	time in min

6A-1.3 CYCLE ERGOMETRY

For the cycle ergometry standardized ergometers (Schiller Medizintechnik Ergoline Ergometrics 800 S) were used. The ergometers were equipped with an eddy current break; the hinge moment was measured independently from the rotation speed. The operating range for the ergoline was from 25 to 990 watt, the accuracy of measurement was about 3 watt. After the heart rate monitor was checked for full functionality, the subjects were advised to start the warm-up phase. The seat of the cycle ergometry was adjusted to the subject's height. The probands were advised to perform the ergometry until exhaustion to get adequate results. For the warm-up phase the ergometer was set 3 minutes at 50 watt. The test was started with 100 watt for 3 minutes. Every 3 minutes the strain was raised by 50 watt, the subjects were advised to keep the rotation speed by 60 – 70 revolutions per minute. The rotation speed was monitored on a display, when the subject was not able to keep the given rotation speed, the test was broken off.

The heart rate was measured via commercial acquirable heart rate monitors (Polar Vantage NT/Polar Electro, Kempele, Finland). The device consists of a chest belt with a sensor and a watch with an integrated microcomputer. The sensor is sending the data telemetrically to the microcomputer from where the data can be uploaded to a personnel computer for further processing.

From the results of the cycle ergometry the absolute and the relative VO_2max was computed via the formula by HABER [12]:

$$VO_2max(ml/min) = BW*6.3 + 10.2*watt$$

$$VO_2max(ml/kg/min) = (BW*6.3 + 10.2*watt)/BW$$

whereas: BW body weight in kg

6A-1.4 ANAEROBIC ENDURANCE AND COORDINATIVE ABILITIES

For assessment of anaerobic endurance and coordination under time-pressure we used a standardized indoor obstacle-course. The obstacle course consisted of 9 obstacles: start-four-leg-stand, rhythm sprint, network of wires, pull-bar, slalom, balance beam, double beam, grid ladder and beam wave. Every subject had to pass the course twice. The subjects were advised to overcome the obstacle course as fast as possible with correct performance of the given obstacles. If an obstacle was not overcome correctly, penalty seconds were added. Every obstacle was introduced to the soldiers and everyone had the possibility to test the course by himself. The equipment used for the obstacle course is shown in Table 6A-1-1 and the arrangement of the obstacles is outlined in Figure 6A-1-1. Figures 6A-1-2 – 6A-1-10 are showing the obstacles 1 – 9.

Table 6A-1-1: Description of the Obstacles of the Indoor Obstacle Course

Order	Description	Equipment
Obstacle 1	Start-four-leg-stand	2 long benches 1 gym mat (1 m x 2 m) 1 hurdle (7 parts)
Obstacle 2	Rhythm sprint	4 long benches
Obstacle 3	Network of wires	3 mats 3 hurdles
Obstacle 4	Pull-bar	1 long bench
Obstacle 5	Slalom	4 slalom rods
Obstacle 6	Balance beam	1 balance beam 1 slalom-rod
Obstacle 7	Double beam	2 gym boxes 1 mat 1 slalom rod
Obstacle 8	Grid ladder	1 grid ladder (2 m) 1 low jump mat
Obstacle 9	Beam wave	2 gym boxes 2 mats 2 hurdles 1 slalom rod

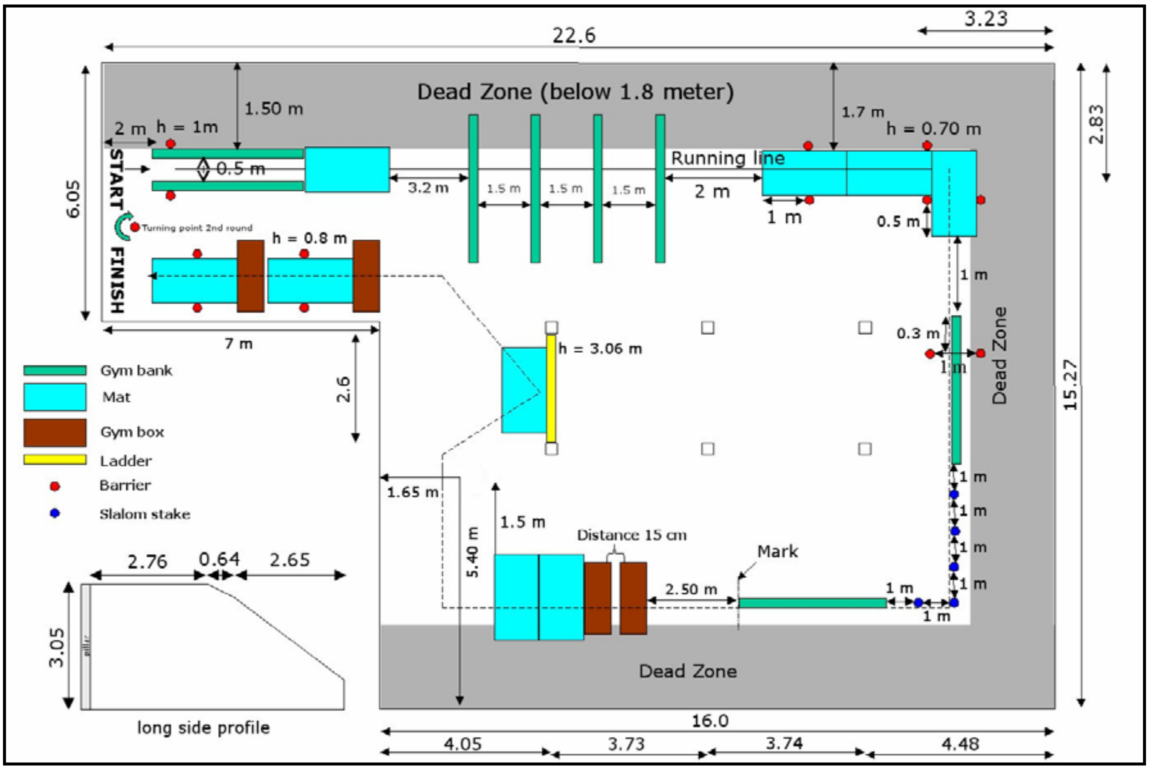

Figure 6A-1-1: Arrangement of the Obstacles of the Indoor Obstacle Course.

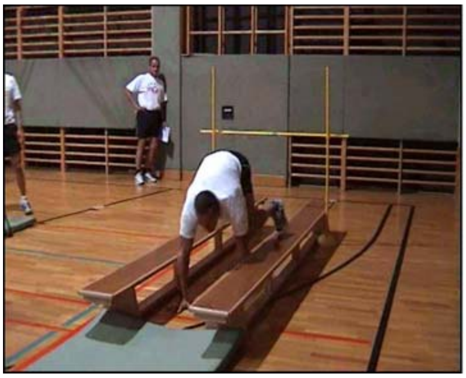

Figure 6A-1-2: Obstacle 1 – Start-Four-Leg-Stand.

Figure 6A-1-3: Obstacle 2 – Rhythm Sprint.

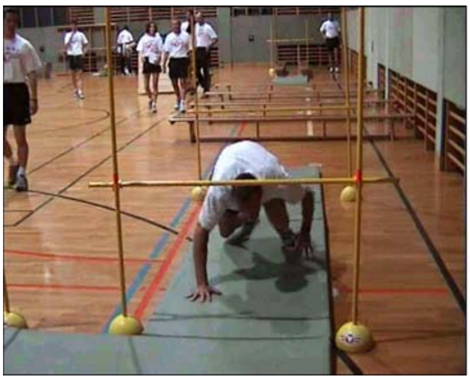

Figure 6A-1-4: Obstacle 3 – Network of Wires.

Figure 6A-1-5: Obstacle 4 – Pull-Bar.

Figure 6A-1-6: Obstacle 5 – Slalom.

Figure 6A-1-7: Obstacle 6 – Balance Beam.

Figure 6A-1-8: Obstacle 7 – Double Beam.

Figure 6A-1-9: Obstacle 8 – Grid Ladder.

Figure 6A-1-10: Obstacle 9 – Beam Wave.

6A-1.5 COORDINATIVE ABILITIES/REACTION SPEED

6A-1.5.1 Rhythm Sprint

Five long benches (height 31.5 cm) were placed across the running direction between the second and third light barrier. The space between the first, second and third light barriers were 10 m. The position of the first long bench was one meter after the second light barrier, the second to fifth long bench were placed 2 m after each (light bars are at 1 m, 3 m, 5 m, 7 m, 9 m).

With 11 m run-up the five long benches had to be overcome as fast as possible with the following movement presetting: The probands were asked to touch the floor twice in between the long benches. Consequently one leg was used as “free” and the other leg as “trail leg”. The test had to be done twice. The fastest run was recorded. Time was measured electronically by a light barrier. A run was not counted if the proband could not meet the rhythm-task (2 contacts in between the benches, see Figure 6A-1-11).

Figure 6A-1-11: Rhythm Sprint.

6A-1.5.2 Velocity

Velocity was measured by a 20-m sprint. The test was performed in a straight course of the gym. Light barriers were placed 1 m, 11 m and 21 m after the starting line. So, the measured course was 20 m. The subjects were advised to run as fast as possible through this course. Every subject had the possibility to complete the course twice. The best result was recorded.

6A-1.5.3 Strength Endurance

Strength endurance was tested by means of push-ups, chin-ups with inclined body, sit-ups and a three meter rope-climbing test.

6A-1.5.4 Push-ups

For push-ups the subjects were advised to pose in the press up position, legs extended, and arms supporting upper body. The arms were to be brought shoulder-wide and the legs hip-wide outstretched put on the ground. The body had to be fully stretched; head, shoulders, hips and heels had to build an imaginary straight line (no dip of the hip); fingers should be pointing forward, thumbs had to be on the height of the acromion; the elbow joint had to be stretched; the look should be on the ground (see Figures 6A-1-12 and 6A-1-13).

Figure 6A-1-12: Start Position of Push-ups, en Face.

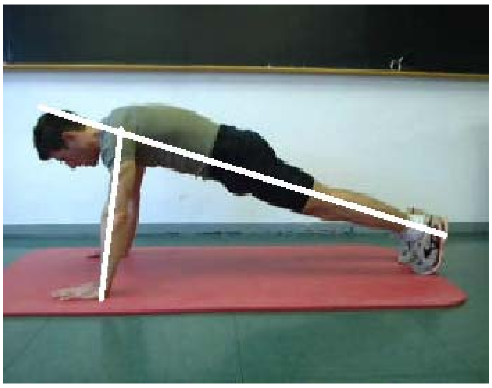

Figure 6A-1-13: Start Position of Push-ups, en Profile.

The subjects were now instructed to bend the arms in the elbow joint until chin and chest almost touched the floor (body and arms built an imaginary straight line); the body tension had to be kept all the time; then the subjects were asked to stretch their arms to get into the starting position. The movement had to be dynamically done – movement breaks were not allowed. Every correctly performed push-up was counted. Breaking off criteria were a not fully stretched elbow joint, not enough flexion in the elbow joint (body and arms not in a straight line), loss of body tension (head, shoulders, hip, heels not in a straight line) and a stop of the movement fluency.

6A-1.5.5 Inclined Chin-ups

For setting of the height of the bar the subject had to sit down under the bar with extended legs, his arms stretched out vertically (straight back, hip directly vertical under the bar). The height of the bar was adjusted, so that the wrist of the subject was a few centimetres higher than the bar. At the height of the plantar pedis a tight resistor (e.g. a part of a cupboard) was placed to brace the feet. The subjects had to grab the bar shoulder broad with the wrist grip. Then they had to take the inclined position, the feet were supported, arms were stretched, from the inclined position the subjects had to bend the elbow till they reached the bar with the chest or the chin. After touching the bar the starting position had to be taken in. The body tension had not to be lost. A short break was allowed in the starting position, but the body tension had to be kept. Every correctly performed chin-up was counted. Break off criteria were loss of body tension, a movement upwards initiated by the hips and not from the arms and inability to pull the chin up to the height of the bar. The inclined chin-ups are shown in Figures 6A-1-14 and 6A-1-15.

Figure 6A-1-14: Start Position of Inclined Chin-ups.

Figure 6A-1-15: Inclined Chin-ups.

6A-1.5.6 Sit-ups

To allocate the starting position the test person had to lie down in dorsal position on the floor. The legs had to be bent, heels on the ground, knee angle was 90 degrees; the arms were stretched diagonally in front of the body, the stanchions are located in hip height of the lying test person. To setup the reaching height individually, the test person had to erect the body until the distance between floor and the inferior scapula angle was 15 cm. A string was stretched at the end of the fingertips. The test person was instructed to lift the scapulas slowly off the floor and to erect the body to touch the string with the fingertips. The body had not to be completely dropped onto the mat afterwards – the base tension in the frontal abdominal muscles had to be kept. The whole movement had to be dynamically (without breaks) and to be repeated as often as possible. The heels had to be kept on the floor all the time. The arms had to be stretched diagonally straight front upwards. Every correctly performed sit-up was recorded. Break-off criteria were heels lifted off the floor, no fluent movement, when the test person could not keep the arms stretched to the front, when the upper back of the test person touched the floor and a stop of the movement fluency. Starting position and performance of sit ups are shown in Figures 6A-1-16 – 6A-1-18.

Figure 6A-1-16: Start Position of Sit-ups.

Figure 6A-1-17: Sit-ups.

Figure 6A-1-18: Sit-ups.

6A-1.5.7 Rope Climbing

For the rope climbing test a marker was set on the rope at a height of 2 m and another one at 6 m. A mat was placed under the rope. The subjects were advised to climb the course of 4 meters as fast as possible. On the command, “On your mark”, the subjects had to go into the starting position: hands had to be placed on the first mark, both arms had to be stretched and the legs must not touch the mat. On the command "Go" the subjects were asked to start climbing. Break-off criteria was a wrong start position and a duration of the test longer than 20 seconds.

6A-1.5.8 Maximum Strength (Jumping Power)

Maximum strength was assessed via the CONCEPT2 DYNO power measure device, using seated bench press, leg press and bench pull. Maximal jumping power was assessed by the jump and reach-test.

6A-1.5.9 Seated Bench Press

With the exercise "seated bench press" the maximum strength of the upper extremity was measured. The resistance was adjusted with six open dampers. Started was in a seating position, whereas the bench press device was fixed for the upper body directly under the sternum. Hands were placed in a broad wrist grip, the feet had to be put flat on the floor, the legs ha to brought wide enough so that the skid could slide between them. At the beginning the subjects had to warm-up by doing three movements with any desired power. Then the starting position had to be taken in; the probands must not begin until the resistance wheel stopped (display at Rep-Timer approximately 6 sec). Then the bench press device had to be pressed away from the chest until the arms were fully stretched. The test procedure was repeated three times. The best result was recorded. The exercise is shown in Figure 6A-1-19.

Figure 6A-1-19: Seated Bench Press.

6A-1.5.10 Leg Press

The exercise "leg press" was used to measure maximum strength of the lower extremities. The resistance was adjusted with six open dampers. The footplate was adjusted. The hands grabbed the hand grip under the seat. The subjects had to sit in the starting position, the angle between femoral and lower leg had to be 90°. At the beginning the subjects had to warm-up by doing three movements with any desired power. Then the starting position had to be taken in; the probands must not begin until the resistance wheel stopped (display at Rep-Timer approximately 6 sec). Then the leg press device had to be pressed away until the legs were fully stretched. The test procedure was repeated three times. The best result was recorded. The exercise is shown in Figure 6A-1-20.

Figure 6A-1-20: Leg Press.

6A-1.5.11 Bench Pull

The exercise "bench pull" was applied to measure maximum strength of the upper extremities. The resistance was adjusted with six open dampers. Started was in a seating position, whereas the bench pull device has to be fixed one track lower then the bench press device. Hands were placed in a broad wrist grip, and the feet had to be positioned flat on the floor, legs wide enough that the skid could slide between them. From the starting position were the arms were stretched the subjects had to pull the device to their chest. At the beginning the subjects had to warm-up by doing three movements with any desired power. Then the starting position had to be taken in; the probands must not begin until the resistance wheel stopped (display at Rep-Timer approximately 6 sec). Then the bench pull device had to be pulled to the chest and back until the arms are fully stretched. The test procedure was repeated three times. The best result was recorded. The exercise is shown in Figure 6A-1-21.

Figure 6A-1-21: Bench Pull.

6A-1.5.12 Jump and Reach

Here the subjects were advised to stand in front of the wall; the toes had to contact the wall, the arms had to be elevated parallel as indicated in Figure 6A-1-22. The subjects had to stand sideways in a distance of 20 – 30 cm to the wall. Then the soldiers were instructed to jump as high as possible and to place a mark (sticky tape) with their middle finger of the arm nearer to the wall on the highest position they could reach. The jump had to be done with both legs and the arms could be used to have a better drive (see Figures 6A-1-22 – 6A-1-24). The subjects had three attempts; the best one was recorded. The difference between jumping height and reaching height was measured. Break-off criteria were jumping with only one leg, jumping out of the striding position, rotation of the body in the air and floundering before the jump.

Figure 6A-1-22: Jump and Reach 1.

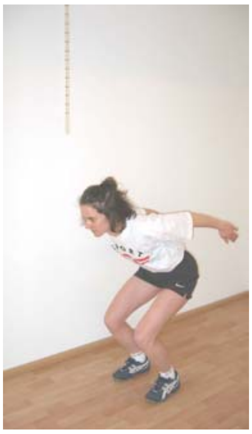

Figure 6A-1-23: Jump and Reach 2.

Figure 6A-1-24: Jump and Reach 3.

6A-1.5.13 Anthropometric Parameters

Finally we recorded the anthropometric parameters body height and body weight. The body-mass-index was computed as kg/m².

For computing the total body fat, the Caliper method according to DURNIN and WORMERSLEY [6], using skin fold measurements was applied. The measurements were recorded at four points (inferior angle of the scapula, biceps brachii, triceps brachii and iliac bone). The skin fold in the region of the inferior scapula angle was measured on the crease one fingerbreadth under the lower scapula angle. The skin fold of the biceps was measured centrally, between the acromion and the cubita, per building a vertical fold. Skin fold of the triceps was measured centrally between acromion and olecranon, per building a diagonal fold. And finally the skin fold at the iliac bone was measured one fingerbreadth proximal the iliac bone, per building a horizontal fold. The measurement was done by a special trained sports scientist. By summing up the four measurements and looking up the result in a respective list (established by DURNIN and WORMERSLEY [6], see Table 6A-1-2) the body fat percentage was determined.

Waist circumference and hip circumference were measured with a measuring tape. Waist to hip ratio (in accordance with HEYWARD and STOLARCZYK [14]) was computed per dividing the waste circumference and the hip circumference. The waste circumference was measured at the narrowest part of the trunk, between rips and iliac crest during expiration. The hip circumference was measured at the maximal extent of the gluteal region.

Table 6A-1-2: 4-Point-Skinfold Measurement (Calipometry) by Durnin and Wormersley [6] for Assessment of Total Body Fat Mass

men	29	39	49	50
15	4,8	-	-	-
16	5,5	-	-	-
17	6,2	-	-	-
18	6,9	-	-	-
19	7,5	-	-	-
20	8,1	12,2	12,2	12,6
21	8,6	12,6	12,8	13,2
22	9,1	13,0	13,4	13,8
23	9,6	13,4	14,0	14,4
24	10,1	13,8	14,5	15,5
25	10,5	14,2	15,0	15,6
26	11,0	14,6	15,6	16,2
27	11,5	15,0	16,2	16,8
28	12,0	15,4	16,7	17,4
29	12,5	15,8	17,2	18,0
30	12,9	16,2	17,7	18,6
31	13,3	16,5	18,1	19,1
32	13,7	16,8	18,5	19,6
33	14,1	17,1	18,9	20,0
34	14,4	17,4	19,3	20,4
35	14,7	17,7	19,6	20,8
36	15,1	18,0	20,0	21,3
37	15,5	18,3	20,4	21,7
38	15,8	18,6	20,8	22,1
39	16,1	18,9	21,1	22,5
40	16,4	19,2	21,4	22,9
41	16,7	19,5	21,8	23,3
42	17,0	19,8	22,1	23,7
43	17,3	20,0	22,4	24,1
44	17,5	20,2	22,7	24,4
45	17,7	20,4	23,0	24,7
46	18,0	20,7	23,4	25,1
47	18,3	20,9	23,7	25,5
48	18,6	21,1	24,0	25,9
49	18,8	21,3	24,3	26,2
50	19,0	21,5	24,6	26,5
51	19,3	21,7	24,9	26,8
52	19,5	21,9	25,2	27,1

men	29	39	49	50
53	19,7	22,1	25,5	27,4
54	19,9	22,3	25,7	27,7
55	20,1	22,5	25,9	27,9
56	20,4	22,7	26,2	28,2
57	20,6	22,9	26,5	28,5
58	20,8	23,1	26,7	28,8
59	21,0	23,3	26,9	29,0
60	21,2	23,5	27,1	29,2
61	21,4	23,7	27,4	29,5
62	21,6	23,9	27,6	29,8
63	21,8	24,1	27,8	30,0
64	22,0	24,2	28,0	30,2
65	22,2	24,3	28,2	30,4
66	22,4	24,5	28,5	30,7
67	22,6	24,7	28,7	31,0
68	22,8	24,9	28,9	31,2
69	23,0	25,0	29,1	31,4
70	23,1	25,1	29,3	31,6
71	23,3	25,3	29,5	31,9
72	23,5	25,5	29,7	32,1
73	23,7	25,7	29,9	32,3
74	23,9	25,8	30,1	32,5
75	24,0	25,9	30,3	32,7
76	24,2	26,1	30,5	33,0
77	24,4	26,3	30,7	33,2
78	24,6	26,4	30,9	33,4
79	24,7	26,5	31,1	33,6
80	24,8	26,6	31,2	33,8
81	25,0	26,8	31,4	34,0
82	25,2	26,9	31,6	34,2
83	25,3	27,0	31,8	34,3
84	25,4	27,1	32,0	34,6
85	25,5	27,2	32,1	34,8
90	26,2	27,8	33,0	35,8
95	26,9	28,4	33,7	36,6
100	27,6	29,0	34,4	37,4
105	28,2	29,6	35,1	38,2
110	28,8	30,1	35,8	39,0

men	29	39	49	50
115	29,4	30,6	36,4	39,7
120	30,0	31,1	37,0	40,4
125	30,5	31,5	37,6	41,1
130	31,0	31,9	38,2	41,8
135	31,5	32,3	38,7	42,4
140	32,0	32,7	39,2	43,0
145	32,5	33,1	39,7	43,6
150	32,9	33,5	40,2	44,1
155	33,3	33,9	40,7	44,6
160	33,7	34,3	41,2	45,1
165	34,1	34,6	41,6	45,6
170	34,5	34,8	42,0	46,1
175	34,9	-	-	-
180	35,3	-	-	-
185	35,6	-	-	-
190	35,9	-	-	-

red	age
yellow	Recorded skin fold value
light blue	Total body fat in %

Appendix 6A-2 – Guided Interview

GUIDANCE FOR THE INTERVIEWS (PHASE 1)

(To identify the sport-motor components relevant to Special Forces soldiers)

INTRODUCTION

Secrecy Regulations: This project is approved and supported by the Austrian Special Operation Command and the Special Forces Headquater. Data protection: data collected here will be subject to utmost discretion and will be used for scientific evaluation only. Interviewees will remain anonymous (personal data will not be passed on to scientists, comrades, and superior commanders). Tape recordings are welcome, but not mandatory.

Involved research institutes and military commands:

- Austrian Special Operation Command
- Austrian Special Forces Headquater
- Army Sports Science Service
- Research Group on Physical Performance Medicine and Defence Ergonomics
- Centre for Sports Science and University Sport/University of Vienna
- (NATO HFM-080/RTG 019 – Optimizing Physical Performance)

Brief description of the study:

Objective:

Determination of **physical requirement profiles for commando soldiers** (including individual specialties: Direct Action, Close Combat, Mountain Warfare, Paratrooping, Combat Diving) in order to, subsequently, develop well-founded **selection criteria** and **procedures** as well as **objective-tailored training recommendations**.

Procedure:

- Phase 1 (guideline-based interviews by experts):
  - Analysis of the mission
  - Deduction of typical operational scenarios
  - Deduction of typical military activities
  - Deduction of sport-motor components relevant to commando soldiers

- Phase 2 (written inquiry by experts):
  - Revision of information obtained in Phase 1 and development of a **standardised questionnaire** with the aim to weigh the significance of relevant sport-motor components
  - Written inquiry
  - Evaluation of data and deduction of requirement profiles; first presentation of results at international NATO summit; discussion of results in an international context.

- Phase 3 (sport-motor components testing profile)
  - **Comprehensive testing to determine the athletic performance** of Special Forces soldiers of the respective operational specialty
  - Evaluation of data and deduction of actual requirement profiles

- Phase 4 (recommendations to the unit)
  - Practical implementation of experiences in the unit

Guidelines for the interviewees

- Answers should be as **objective** as possible
- Answers should focus on relevant areas only
- The assessment should be made with the **operation** (worst case scenario) in mind

INQUIRY (PROTOCOL)

What is the **military mission** of your operational specialty (record in writing; source)?
………………………………………………………………………………………………...
………………………………………………………………………………………………...
………………………………………………………………………………………………...

How are direct action, close combat, mountain warfare, paratrooping, and combat diving defined in the militarily context?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Are there position or workplace descriptions for soldiers of your type of unit? If yes, what do they specify?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Which **operational scenarios** does the mission entail?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Please describe a typical operation in your specialty.
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

In your opinion, what must a commando soldier's physical capabilities be in order to accomplish his missions? (performance in marching, swimming, climbing, lifting, etc.)
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

What is the main emphasis in training?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

What is especially observed in the course of training?
……………………………………………………………………………………………...
……………………………………………………………………………………………...

……………………………………………………………………………………………...

What are the **typical physical military activities** for a soldier specialised in direct action, close combat, etc.? (e.g., marching, climbing, diving, etc.)
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

For how long must a solder be capable of carrying out such activities?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Which demands must a soldier primarily meet during an operation or in training?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

What are the most demanding physical activities?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

What are the usual equipment loads for these activities?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Are there any situations in which physically weaker and stronger soldiers perform differently?
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Personal data:

Rank: ………………………………………….
First name, last name:………………………………………….
Function: ………………………………………….
Age: ………………………………………….
For how long have you been active in this field (training courses in operational specialty, diving hours, parachuting, participation in international training courses, experience in operations, etc.):
……………………………………………………………………………………………...
……………………………………………………………………………………………...
……………………………………………………………………………………………...

Conclusion, thanks, inquiry whether examination results of Phase 1 and 2 should be mailed to interviewees, and **invitation** to the presentation of the results and their practical implementation in the unit.

Appendix 6A-3 – Questionnaire

- UNIVERSITY OF VIENNA
INSTITUTE FOR SPORTS SCIENCE AND UNIVERSITY SPORTS
- ARMY SPORTS SCIENCE SERVICE
- RESEARCH GROUP ON PHYSICAL PERFORMANCE MEDICINE AND DEFENCE ERGONOMICS
- AUSTRIAN SPECIAL OPERATION COMMAND
- SPECIAL FORCES HEADQUATER
- (NATO HFM-080/RTG 019)

QUESTIONNAIRE FOR THE DEVELOPMENT OF A SPORT MOTOR COMPONENT *REQUIREMENT PROFILE* FOR SPECIAL FORCES SOLDIERS

Mark your operational specialty!

☐	☐	☐	☐	☐
Close Combat	Direct Action	Mountain Warfare	Paratrooping	Combat Diving

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Interviewees remain anonymous!
Data will be used for scientific evaluation only!

INTRODUCTION

The following questionnaire consists of two parts. Please read the questions carefully and rate how important you think the individual athletic components (endurance, strength, rapidity, etc.) are for your activity. For this survey, it is important that your assessment focuses on your particular **operational specialty** rather than on the commando soldier in general. Therefore, it will be of relevance whether for a combat diving (close combat, direct action, mountain warfare or paratrooping) specialist endurance is rated as *not required, less important, moderately important* or *very important*. Please try to be **objective** in your grading. Of course, all characteristics below are relevant for a soldier's athletic performance. Nevertheless, only grade those abilities as *very important* which you believe are particularly significant for your specialty either during an **operation** or in **training**. Please mark the appropriate box

PART 1

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1) Aerobic endurance

How important is it to be able to march, run, climb, ski-hike, swim or do other physical activities **over one or several hours without interruption**?

☐ not required ☐ less important ☐ moderately important ☐ very important

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2) Anaerobic endurance

Is it important to be able to do **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)?

☐ not required ☐ less important ☐ moderately important ☐ very important

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3) Rapidity

Is it necessary to be able to cover/overcome short distances (of up to about 50m) and/or carry out **activities** (e.g. combat shooting or emergency procedures) in your operational specialty **at very high speed**?

☐ not required ☐ less important ☐ moderately important ☐ very important

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4) Reaction
Is it important for your commando specialty to **react** to various situations (combat situations, such as recognising friends, foes, dangers, contingency or emergency situations etc.) **as quickly as possible**?

☐ not required ☐ less important ☐ moderately important ☐ very important

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5) Coordination/Agility
During an operation or in training, is it necessary to be able to **do different activities** with your hands and feet **simultaneously**, expertly overcome obstacles, avoid moving obstacles or orientate and balance well?

☐ not required ☐ less important ☐ moderately important ☐ very important

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6) Strength endurance
Is it necessary to be able to carry **medium-weight loads** (e.g. ammunition box, your own body weight or when evacuating wounded persons in the group) over longer distances (100m and more) or repeatedly lift such loads over a **period of up to 30 minutes**?

☐ not required ☐ less important ☐ moderately important ☐ very important

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7) Maximum strength
How important is it to be able to lift **very heavy loads** (just about within one's capacity) with **maximum effort** (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)?

☐ not required ☐ less important ☐ moderately important ☐ very important

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8) Body constitution

Do you believe that body constitution (being rather small and squat, tall and slender or robust and muscular) influences the performance during an operation or in training? If yes, which constitution-type fits your specialty best?

☐	☐	☐
, squat/small high body fat	slender/tall low body fat	robust/muscular medium body fat

Are there any small or large body sizes that significantly interfere with task accomplishment in your operational specialty? If yes, which sizes do you consider as the upper and lower limits?

Size does not affect a soldier's performance ☐

Size does affect a soldier's performance ☐

Minimum size: …....cm, upper limit: …....cm

How important do you think is body constitution for a soldier's performance?

☐	☐	☐	☐
irrelevant	less important	moderately important	very important

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PART 2

Which of the two motor components (and/or activities or constitution types) do you think are more important for **your operational specialty** (close combat, direct action, mountain warfare, paratrooping, combat diving), please mark the appropriate box. If you are not certain which of the two components is more important, please choose one. Please take your decision always with the **operation** or **operational training** in your specialty in mind. If you are not sure about sport-scientific terms, please read the descriptions below.

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1) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill etc.)

Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course etc.)?

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2) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

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3) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

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4) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

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5) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

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6) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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7) Aerobic endurance ☐

Description: doing physical activities over several hours (e.g. marching, running, climbing, swimming, skiing, ski-hiking as well as close combat or weapons drill, etc.)

Body constitution ☐

Significance of body constitution types

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8) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

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9) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

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10) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

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11) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

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12) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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13) Anaerobic endurance ☐

Characteristic activities: doing **high-intensity activities for up to 2 minutes** (e.g. withdrawal and attack actions, combat tracks of all types, obstacle course, etc.)

Body constitution ☐

Significance of body constitution types

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14) Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

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15) Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

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16) Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

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17) Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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18) Reaction ☐

Description: reacting to various situations (combat situations, such as distinguishing between friends and foes, identifying dangers, ordnance etc. as well as identifying and reacting to contingency situations) as quickly as possible

Body constitution ☐

Significance of body constitution types

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19) Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

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20) Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

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21) Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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22) Rapidity ☐

Characteristic activities: covering short distances (up to about 50m) or carrying out activities (e.g. combat shooting, emergency procedures) as fast as possible

Body constitution ☐

Significance of body constitution types

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23) Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

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24) Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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25) Coordination/Agility ☐

This is the capability of **doing different activities** with one's hands and feet **simultaneously**, expertly overcoming obstacles, avoiding moving obstacles as well as orientating and balancing well.

Body constitution ☐

Significance of body constitution types

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26) Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

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27) Strength endurance ☐

Characteristic activities: repeated lifting of medium-weight loads (e.g. one's own body weight, ammunition boxes, evacuation of a wounded person in the group over distances over 100m or repeated lifting of such loads over a period of up to 30 minutes)

Body constitution ☐

Significance of body constitution types

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28) Maximum strength ☐

Characteristic activities: lifting **very heavy loads** just about within one's capacity with maximum effort (e.g. removing obstacles, loading heavy equipment onto vehicles, etc.)

Body constitution ☐

Significance of body constitution types

Thank you very much for your active support!

The evaluation of all questionnaires will show whether characteristic profiles can be identified. The questionnaires will be evaluated and their results discussed in the weeks to come. Findings will be made available to all participants. If you should have any questions, please do not hesitate to contact me (0660/XXXXXXX).

Wm. Mag. Mag. Günther Ch. EISINGER

Chapter 7 – INTRINSIC AND EXTRINSIC FACTORS AFFECTING OPERATIONAL PHYSICAL PERFORMANCE

Section 7.1 – INTRODUCTION

The preceding chapters in this report have addressed the performance of common military tasks. Performance has been dealt with in terms of physiological and fitness requirements and methods of training to achieve performance goals. This chapter will deal with factors outside the training realm that influence performance on these military tasks. These factors are either individual (intrinsic) or environmental (extrinsic) characteristics. In general, effects of these factors cannot be overcome completely by additional physical conditioning.

The intrinsic factors considered are age, gender, body dimensions, and genetics. The extrinsic factors that will be considered are effects of nutrition (including hydration), heat, cold, altitude, clothing, and extended operations. The sections in this chapter are intended to increase reader awareness that performance is not determined simply by training and execution. They are meant to be introductions rather than exhaustive coverage of fundamental concepts in each of the areas presented. The contributors hope you will find these presentations helpful and informative.

Section 7.2 – EFFECTS OF AGE ON OPERATIONAL PHYSICAL PERFORMANCE

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ABSTRACT

Age is widely regarded as the most important determinant of the loss of an individual's physical performance capability over time. Said loss is of concern for employers of personnel involved in physically demanding occupations, particularly military personnel. A minimum level of physical performance is a prerequisite for military personnel because the absolute physical job demands are often dictated by extrinsic factors that cannot be altered. A reduced work capacity may lead to inadequate performance, increase the risk of overuse injury, and, ultimately, compromise effectiveness of military operations. However, appropriate training can counter the effects of aging on strength and endurance and enable the individual to maintain adequate levels of performance late into life.

7.2.1 BACKGROUND

Increasing age leads to inadvertent changes in maximal performance capacity (Samson et al., 2000; Booth et al., 1994; Bemben, 2003). Physiological functional capacity (PFC), the ability to perform the tasks of daily life in an effortless and successful manner (Donato et al., 2003) also decreases. Muscular strength and endurance are the most relevant of all physiological measures limiting physical performance (Frontera et al., 2000; Fitzgerald et al., 1997; Janssen et al., 2005). Deficits in strength and endurance have a negative impact on performance in common tasks like locomotion, or lifting, handling, or carrying loads (Bemben, 2003; Leyk et al., 2006a; Leyk et al., 2006b). With the changing demographic structures in western societies, this will become a major concern not only in everyday life, but especially in physically demanding occupations like the automotive and shipping industries or the military services where exogenous factors often cannot be altered, thus dictating the physical demands of occupations.

7.2.2 AGE-RELATED CHANGES IN MUSCULAR STRENGTH

The human musculoskeletal system produces the strength and power to move and interact with the physical world. Its capacity determines the performance in primarily load-related tasks. For example, handgrip strength can play a crucial role in load-bearing or transportation tasks such as stretcher carriage (Bilzon et al., 2002; Leyk et al., 2006a; Leyk et al., 2006b). Various studies have described a peak in muscular strength and muscle mass around the age of 20 – 30 years (Janssen et al., 2000; Brooks et al., 1994; Booth et al., 1994; Reeves et al., 2006). A 10 – 15% loss of whole body muscle mass can be observed from age 20 to 80 years, with a concomitant increase in relative and absolute body fat (Janssen et al., 2000). Also, a two-staged decrease in muscular performance can be observed from age 30, with a moderate decline in muscular parameters up to age 55 – 65 years and an accelerated reduction thereafter (Booth et al., 1994). Extents as well as rates of decline appear to be dependent on individual factors, such as genetics, lifestyle, and habitual physical activity (Wilmore et al., 2004; Roubenoff et al., 2000).

Age-related changes occur in:

- Muscle mass;
- Muscle cross-sectional area (MCSA);
- Muscle fiber type composition;
- Reduced number of capillaries;
- Changes in enervation and neural drive;
- Myofibril protein content; and
- Muscle force production and power output.

The most noticeable and critical effect of the aging process is the loss of muscle mass, termed sarcopenia. Sarcopenia occurs around age 55 (Roubenoff, 2003; Booth et al., 1994), and is evidenced by a reduction in MCSA. This reduction is a function of cellular, nutritional, and hormonal changes (Brooks, 2003; Reeves et al., 2006; McArdle et al., 2001; Booth et al., 1994). Reduction in contractile tissue, thickening of Type I fibers, clustering of muscle fibers, and changes in muscle fiber composition concomitant to the reduction in MCSA are also observed (Brooks et al., 1994; Brooks, 2003; Reeves et al., 2006; Roos et al., 1999; Lexell et al., 1986). The loss of MCSA, combined with an increase of non-contractile tissue, results in lowered capacity for force production and, consequently, power output (Maharam et al., 1999; Doherty et al., 1993; Brooks, 2003; Reeves et al., 2006; Lanza et al., 2003). However, force production capability of the contractile tissue itself appears to be largely unaffected by aging (Maharam et al., 1999).

A promising hypothesis for the mechanisms underlying sarcopenia has been formulated. Sarcopenia can be explained as the combined effects of progressive neuromotor deterioration and chronic under-loading of the musculoskeletal system on the single motor unit level (Brooks et al., 1994; McArdle et al., 2001). Lack of use and suspected morphological aspects specific to Type II motor units, together with deterioration in motor unit remodeling capabilities, appear to cause the preferred denervation of Type II fibers (Brooks et al., 1994). The results are muscle fiber atrophy and ultimately the irreversible degeneration of end plate structures and muscle fibers (McArdle et al., 2001). However, denervated Type II fibers may be re-innervated by adjacent Type I motor units by the sprouting of motor nerves and end plates. This hypothesis can account for the observed loss of muscle mass, the change in muscle fiber composition, and the increase in non-contractile tissue. Sprouting of motor nerves to re-innervate previously denervated muscle fibers may provide an explanation for the increase in size of slow motor units as well as for the clustering of fiber types that was observed in both animals and humans with increasing age (Brooks et al., 1994).

7.2.3 AGE-RELATED CHANGES IN ENDURANCE

The relocation of units to remote areas where supplies and equipment must be carried over prolonged periods of time is not solely dependant on strength capabilities. Endurance plays a crucial role in sustained performance. Endurance capacity is typically predicted in a technical approach by determining the maximal rate of oxygen consumption (VO_2max) from respiratory gas exchange. Available data from numerous cross-sectional and a few longitudinal studies predict various rates of decline from approximately 5% to 20% per decade, beginning at the age of 25 years. Differences in rates as well as in timing and extent are probably due to differences in occupational or leisure time physical activity, lifestyle, genetic profile, disease, and other factors (Leyk et al., 2006c; Dehn et al., 1972; Maharam et al., 1999). However, even though VO_2max is the most frequently used criterion to evaluate endurance capacity, it is only one of the determinants for successful endurance performance. For example, it is not uncommon to see master athletes with lower VO_2max performing as good as, or even better than younger individuals with higher VO_2max values (Allen et al., 1985; Daniels, 1985; Sjödin et al., 1985; Sleivert et al., 1996). Thus, the age-related decline in VO_2max may not inevitably mirror changes in endurance performance.

Running times of endurance events such as marathon or half-marathon races provide an excellent opportunity to study age-associated changes in endurance performance. Leyk et al., (2006a) examined more than 400,000 results from marathon and half-marathon events and found endurance performance, as assessed by running times, remained virtually unchanged within an age group from 20 to 49 years with only minor decreases thereafter. The authors concluded that lifestyle factors have a considerably stronger influence on endurance capacity than age per se.

7.2.4 PREVENTIVE MEASURES TO COUNTER AGE-RELATED CHANGES

Both endurance and muscular capabilities deteriorate with age. This results in a decline in both maximal attainable performances as well as in decrements in PFC. However, it is often difficult to determine whether the observed reduction is a result of biological aging, or of lifestyle, physical inactivity, genetics, or disuse (Rittweger et al., 2004). Age-related changes recorded in physiological measures of highly trained, competitive master athletes can be regarded as a performance “ceiling”, reflecting mainly the results of primary aging with negligible additional margins for improvement through training (Leyk et al., 2006c; Fitzgerald et al., 1997; Rittweger et al., 2004). While the strictly age-elicited changes in maximal performance capabilities seem to be inevitable, physical exercise may still slow, delay, or reverse decrements in PFC. Physically active elderly individuals, such as master athletes, show a slower decline in VO_2max over time compared with their inactive peers, and it has been shown that adequate strength levels can also be maintained (Tanaka et al., 2003; Trappe et al., 1996; Wiswell et al., 2000; Krivickas et al., 2006).

Numerous studies have found that both the cardiovascular and the musculoskeletal system show remarkable plasticity late into life (Pollock et al., 1997; Wiswell et al., 2000; Reeves et al., 2006). As a result, the effects of age on PFC may be slowed, halted, or even be reversed. As seen in Leyk et al’s. (2006a) study, physically active elderly are able to maintain levels of performance equal to those of 20-year-old peers. This implies that endurance training can counter the age-related decrements in endurance that can be observed in less-active peers. Strength training also yields similar results as shown by (Pearson et al., 2002). While maximal lifting performance decreased with age, athletes consistently showed results that were significantly better than those of their age-matched controls. Isometric strength of 80- to 89-year-old weightlifters was higher than that of the less-active control group (ages 40 – 49 years).

The capacity for performance improvements for untrained subjects remains almost constant with increasing age. A roughly 10 to 20% increase in relative performance after a 3-month training regimen can be derived for both strength (Baum et al., 2003) and endurance training as measured in VO_2max from age 20 to 80 years (Hagberg et al., 1989; Meredith et al., 1989). Given the development of age structures in the western world, and the related impending impact on personnel in the workplace, who will have to work until an older age, physical exercise and activity may be the key to maintaining appropriate levels of fitness required both for work and everyday life. Appropriate strength- and endurance training at any age is the easiest and most effective way to counter the effects of age-related loss of performance (Mazzeo et al., 1998).

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Section 7.3 – EFFECTS OF GENDER ON OPERATIONAL PHYSICAL PERFORMANCE

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ABSTRACT

The most important gender-associated factors regarding physical performance are the well-known gender differences in weight, height, and body composition.

The impact of gender on physical performance, especially for military demands, must be differentiated in muscular strength and endurance capacity. Scientific literature strategies to minimize the gender-related differences are usually of minor practical or military relevance.

7.3.1 BACKGROUND

With the onset of adolescence, gender-specific hormone secretion leads to differences in body size and composition. In women, estrogen secretion increases fat deposition by stimulating lipoprotein lipase activity, especially in the thighs and hips. Furthermore, estrogen secretion increases the growth rate of bone for 2 to 4 years after the onset of puberty. In general, estrogen leads to an increase in fat mass and to a rapid but shorter period of growth and, consequently, smaller body height. In contrast to women, at the onset of maturation male subjects are affected by increasing testosterone levels, leading to increases in bone formation and muscle mass, primarily evoked by testosterone-stimulated protein synthesis. After maturation, men generally have a greater muscle mass and a smaller percentage of body fat.

The most common gender differences regarding physical performance are weight, height, and body composition. Male subjects are generally taller, heavier, and leaner (higher fat-free body mass) than their female colleagues. Of the multiple physiological differences between men and women, body composition is the most important factor affecting physical performance.

7.3.2 GENDER DIFFERENCES IN PHYSICAL PERFORMANCE

Physical performance is a widespread, undefined term. In the military setting at least two characteristics of physical performance generally have to be differentiated and analyzed regarding their diverse capabilities for men and women:

1) Physical performances that require muscular strength, and
2) Physical performances that require endurance capacity.

7.3.2.1 Muscular Strength

The impact of gender on muscular strength is most obvious in body composition. Strength variations between men and women are mainly related to the smaller amount of absolute muscle mass (about 60% of men) and a higher body fat percentage in women (Janssen et al., 2000). Besides genetic effects this might be caused by a weaker affinity to strength-demanding tasks in women. It must be taken into account that women are 40 to 60% weaker in the upper body and about 25 to 30% in the lower body than men (Shephard, 2000; Kraemer et al., 2001). These regional differences occur due to different muscle mass distributions and different day-to-day activities (Miller et al., 1993; Janssen et al., 2000).

The significance of these regional muscle strength differences is of major concern for several occupational tasks. For rescue, activity, manual load carriage is a very important part of the daily requirements, and handgrip strength is identified as the most crucial variable for this task (Leyk et al., 2006a, b). Recently, (Leyk and co-workers 2006d) investigated some 2000 age-matched young men and women with regard to their maximum handgrip strength. 90% of the female subjects produced maximal handgrip forces smaller than 95% of their male counterparts. Furthermore highly strength trained female elite athletes could not reach the handgrip strength level of the weakest 25th percentile from untrained and not-specifically trained men of the same age (Leyk et al., 2006d).

These physiologically-determined gender differences are disadvantageous for female military personnel who have to perform strength-demanding tasks. The absolute amount of body mass and especially the fat free body mass (FFM) are the predominant factors for physical strength performances. Heavy but lean persons can easily outperform lighter endurance-trained peers on common military tasks like load carriage (Bilzon, 2001; Lyons, 2005).

A common argument that differences in muscle fiber distribution are linked to the considerable strength differences between men and women has not been proven (Drinkwater K, 1984; Wilmore and Costill, 2004). However, the capability of strength development per muscle unit is equal in men and women (Schantz et al., 1983; Shephard, 2000). These findings support the importance of body composition, particularly the absolute amount of FFM, for physical performance that requires muscular strength.

For personnel selection processes, it should be noted that even highly trained female athletes hardly reached the average strength level of unspecific trained males (Leyk et al., 2006d).

7.3.2.2 Endurance Capacity

Endurance capacity can be determined either by the time needed to reach a given distance or in a more technical approach by measuring respiratory gas exchange as well as blood lactate concentrations at submaximal workloads. Most researchers regard the maximal oxygen consumption (VO_2max) as the best predictor of cardio-respiratory endurance capacity.

However, even though VO_2max is the most frequently used criterion to evaluate endurance capacity, it is only one of the determinants for successful endurance performance. For example, it is not uncommon to see master athletes with lower VO_2max who perform endurance competitions as well or even better than younger individuals with higher VO_2max values (Allen et al., 1985; Daniels, 1985; Sjödin and Svedenhag, 1985; Sleivert and Rowlands, 1996). Thus, the age-related VO_2max decline may not inevitably mirror changes in endurance performances.

Running times in endurance events (e.g. marathon, half marathon) provide an excellent opportunity to study age- and gender-associated changes in endurance performance. Leyk et al., (2006c) investigated more than 400,000 running times from marathon and half marathon events and showed that gender and age differences remained constant within an age group of 20- to 49-year-old marathon/half marathon runners. The authors concluded that lifestyle factors have considerably stronger influences on functional capacity than does age or gender. With regard to the gender-associated differences, female finishers required only about 10% more time than their male counterparts, despite VO_2max gender distinctions that are frequently reported to be about 20% (Wilmore and Costill, 2004; Drinkwater, 1983; Shephard, 2000).

The most important gender differences regarding endurance performance are:

- A greater body fat percentage among women means the addition of extra load, which decreases endurance performance.
- Lower blood volumes and hemoglobin levels lead to an increased heart rate at comparable submaximal workloads.
- As a result of their smaller body size, women's hearts are smaller.
- The combination of smaller heart size, blood volume, and hemoglobin level results in a lower absolute and relative ($ml•kg^{-1}•min^{-1}$) maximal oxygen uptake.

These biologically determined circumstances lead to a 10 to 20% gender difference in endurance performance. Weaker results for women are generally seen for running performances or VO_2max adjusted for body weight ($ml•kg^{-1}•min^{-1}$) (Leyk et al., 2006c; Shephard, 2000; Drinkwater, 1984). A further theoretical approach to quantify the sex differences is the expression of VO_2max values per kg FFM. If VO_2max is related to FFM ($ml•kg_{FFM}^{-1}•min^{-1}$) gender differences diminish to about 5 % (Cureton, 1981; Drinkwater, 1984). These differences could be attributed to an inherent biological male/female difference (see above).

However, variations in endurance performances within a gender group seem to be larger than differences between trained men and women. Lifestyle factors and the biological variability are likely to be better predictors for endurance capacity than the gender factor itself.

In contrast to strength-related tasks, highly endurance-trained female athletes are able to easily outperform moderately trained male peers (Drinkwater, 1973). The most popular example for excellent ultra-endurance performance in women is the German female athlete, Astrid Benöhr. Her actual world records in five- and ten-fold "iron man" distance competitions are 2 respectively 5 hours faster than of the fastest male athlete. These results support the scientific findings that women can equally or even out perform men in long-lasting endurance tasks (Bam et al., 1996; Sparling et al., 1998). Hence, for military tasks, which predominantly require endurance capabilities, trained women could reach comparable levels to men.

Independent of gender, subjects with identical body weight and body composition as well as the same endurance training status perform on a comparable level (Pate et al., 1985; Cureton and Sparling 1980).

7.3.3 PREVENTIVE MEASURES TO MINIMIZE NEGATIVE EFFECTS (TRAINABILITY OF MEN AND WOMEN)

Sections 7.3.1 and 7.3.2 showed that major physiological differences between men and women affect their physical performance. Particularly in tasks that require strength, the literature unambiguously reveals a widespread distinction in performances based on gender (Leyk et al., 2006d; Miller et al., 1993; Knapik et al., 1980). Hence, for military personnel selection and personnel assignment, knowledge about the potential margins of improvement in strength and endurance performance through physical training is of particular interest for both men and women.

In general, there are no significant gender specific differences in physiological adaptation processes due to physical training.

- Strength improvements of about 20% in a 10- to 16-week training program are well documented in the literature for both, men and women (Cureton et al., 1988; Kraemer et al., 2001; Staron et al., 1990). Women commonly adapt more easily to strength training processes because of their weaker baseline level. Nonetheless, compared with non-specific-trained men, most women cannot reach a comparable strength level in the upper body musculature (Knapik et al., 1980). However, strength level in the trunk and lower body area approaches among highly strength-trained female athletes and average-trained men.

- The large variance in muscle strength between men and women is a result of intrinsic, biological factors and the lower affinity for strength-demanding tasks or to resistance training. Nonetheless, as shown by the scientific literature and practical examples in sports, women are not only able to gain strength and power by resistance training, but they even more have to improve their strength level to enhance females readiness in the military setting.
- Improvements in endurance performance as well as physiological adaptation processes (i.e. increases in: stroke volume, VO_2max, peak ventilatory volume, and capillary and metabolic function) are about equal for men and women (Drinkwater, 1984). A 12-week training program yields a mean increase in VO_2max of about 20% (Drinkwater, 1984; Shephard, 2000).

Possible margins of improvement in physical performance depend less on the gender factor than on factors like training status (ceiling effect), training intensity, training volume, proportion of training to recovery periods, or being a responder/non-responder for a given training program. (Bouchard, 2001). Nonetheless, even if relative improvements in both groups (male/female) seem to be equal, the absolute increase, especially in strength-training activities, cannot reach a comparable level.

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Section 7.4 – EFFECTS OF VARIABILITY IN BODY DIMENSIONS ON OPERATIONAL PHYSICAL PERFORMANCE

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ABSTRACT

Anthropometry refers to the measurement of living human individuals. Variations are subjected to biological and demographical changes and must be updated continuously by anthropometric surveys. Anthropometric and especially body composition measurements deliver valuable data not only for development of equipment or selection of personnel but also for analysis of physical capabilities.

7.4.1 BACKGROUND

Anthropometry refers to the measurement of living human individuals for understanding human physical variation. These variations are subjected to biological and demographic changes in a given population and can be documented using anthropometric surveys.

For NATO, the methodology for anthropometric data is described in STANAG 2177. These measurements are necessary for the development of military equipment. In addition, at military workplaces anthropometric requirements are often important as selection criteria for appropriate personnel (Friedl, 1992; Hodgdon, 1992). In general anthropometric measurements generate valuable data for ergonomic aspects and give a rough impression of physical performance capability. Certain military workplaces like jet cockpits, tanks need anthropometric pre-selection criteria (e.g. height, sitting height, reaching height, leg length) because the workplace environment is fixed. Apart from these measures of length, characteristics like body weight and body composition (percentage of body fat) are of particular importance to physical performance and other requirements. As stated in Section 7.3, body mass and fat free body mass are important factors modulating physical performance. To assess physical capabilities using anthropometric measurements, body composition is the most important, irreplaceable variable. Therefore, weight-height tables and WHO Body Mass Index (BMI) standards are of minor significance in predicting physical performance. Being overweight (BMI) is not always a problem/issue but being over-fat almost always has a negative effect on physical capability. Without knowledge about the individual body composition, statements regarding physical performance can hardly be derived from anthropometric data.

7.4.2 IMPACT OF BODY WEIGHT AND BODY COMPOSITION ON PHYSICAL PERFORMANCE

As stated above, body composition is, aside from body weight, the most important anthropometric measure for predicting physical performance capabilities. The most accepted techniques for assessing body composition are:

7.4.2.1 Laboratory Techniques

- Hydrostatic weighing involves the subject weighing while he or she is totally immersed in water. After correction for lung volume, body volume can be estimated from the difference between weight measured underwater and that measured on land. Body volume and land weight are used to determine body density, which can be used in 2-compartment models to estimate body fat content as a percent of mass (Wilmore and Costill, 2004; Brodie, 1988 I+II).
- Many other laboratory techniques are available to assess body composition but most of them are quite expensive. These include radiography, computed tomography, magnetic resonance imaging, and isotope dilution technique. (Wilmore and Costill, 2004, 450-456; Brodie, 1988 I+II; Zahariev et al., 2005).

7.4.2.2 Field Techniques

- Body fat content can be estimated from anthropometric variables. The most commonly used variables are skinfold thicknesses measured at various sites with a skinfold caliper, and body circumferences measured with a measuring tape. These anthropometric variables are used in equations to predict either body density or percent body fat (Wilmore and Costill, 2004; Brodie, 1988 I+II). The United States military forces have body fat content standards. In each Service, percent fat is estimated from circumferences and stature.
- Bioelectric impedance is another field technique where the impedance, the conductivity or both are measured and transformed into estimates of relative body fat (Wilmore and Costill, 2004; Brodie, 1988 I+II).

If valuable information about the physical performance capabilities should be used from anthropometric data, percentage of body fat can give such information. If load-bearing capabilities are required, heavier subjects perform even better than lighter ones. But heavy and lean (low body fat percentage) persons have almost the best anthropometric prerequisites (Bilzon et al., 2001; Lyons et al., 2005; Harman and Frykman 1992). Irrespective of task requirements, if two individuals with identical body weight perform at the same task, the leaner person would always have the advantage (Wilmore and Costill, 2004; Vogel and Friedl, 1992).

However, anthropometric measures have to be interpreted in order to cope with different kinds of physical activities. Work that requires muscular strength usually leads to different anthropometric requirements than endurance-orientated tasks. The following paragraph explains how different anthropometric characteristics can affect physical performance.

7.4.2.3 Muscular Strength

Physically demanding tasks are common in day-to-day military activities. These physical demands have changed over the latest decades from a more endurance-orientated to a fast-and-short mode of operation. Thus, physical requirements have to be adapted.

With regard to physical performance, anthropometric measurements can add valuable information for selecting appropriate personnel. For activities that require strength, power, and/or muscular endurance subjects with high amounts of fat-free mass are needed. These soldiers are best suited for military tasks like load bearing or rescue activities using manual stretcher carriage (Bilzon et al., 2001; Lyons et al., 2005; Leyk et al., 2006a,b).

7.4.2.4 Endurance Capacity

In contrast to strength improvements, endurance performance does not improve with increased body mass or muscle mass because extra loading decreases endurance-orientated performance. For endurance activities, where rate of energy production is a limiting factor, extra load decreases performance. The work performed and energy required is directly related to body weight. Hence, lighter runners use less energy at a given speed in comparison with a heavier peer.

Anthropometric data can give baseline information about the potential endurance capabilities when looking at the parameters body weight and body fat percentage. Thus, from an anthropometric point of view low body weight or BMI-Values in combination with a low percentage of body fat favour endurance performance.

7.4.3 IMPROVEMENTS IN BODY WEIGHT AND BODY COMPOSITION

The modifiable potential of anthropometric measures is limited to body mass and body composition. Body height and other measures of length are intrinsically (genetic) determined. Even if body weight or body composition is predisposed (e.g. gender variations), they can be affected by several lifestyle or environmental conditions.

If anthropometric measures are used for personnel selection or medical assessment processes with regard to physical performance capabilities, body weight as well as body composition should be recorded. Furthermore, gender- and age-specific reference values are necessary and helpful as inclusion/exclusion criteria. Nonetheless, it should be considered that these data have to be interpreted with caution. Subjects with a comparable anthropometric profile will not necessarily perform in the same manner. Endurance capabilities are hard to assess using these anthropometric data because physiological adaptations to endurance training do not necessarily occur with measurable changes in body weight and/or body composition. However, strength and power capabilities could be predicted more accurately, even if body composition data provide no information about regional strength deficits (upper vs. lower body, extensors vs. flexors).

- Increasing fat-free body mass will usually increase strength and power performances. A greater muscle mass generates higher body strength values and is advantageous for individuals who lift and carry heavy loads.
- Decreasing body fat mass is often associated with increased endurance performance. However, a causal relationship to such changes has not been shown. The combination of endurance training and moderate energy intake will lead to an improvement in endurance capability and body weight.

Changes in body weight and body composition of populations in NATO member countries underline the need for improvements in anthropometric measurements in the military. Common definitions and selection criteria as well as training standards are of paramount importance for the near future.

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Section 7.5 – INFLUENCE OF GENETIC VARIATION ON OPERATIONAL PHYSICAL PERFORMANCE

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ABSTRACT

A high level of aerobic fitness, muscle strength, and flexibility are essential requirements for strong tolerance of military activities. The individual responses to external influences and the putative side effects of environmental factors are key determinants of maintenance of operational capacities. The considerable inter-individual variations in human responses to either physical exercise, operational stress, or climate strains reflect the interaction of environmental factors (e.g. specific training, nutrition, habitual use) with genetic elements. Several gene polymorphisms have recently been hypothesized to account for the individual responses to external operational strains not usually there and genotype associations have been suggested as at risk for illnesses in response to environmental stress.

7.5.1 THE ANGIOTENSIN-1-CONVERTING ENZYME (ACE) GENE POLYMORPHISM AND HUMAN PERFORMANCE

Recent studies have examined whether genetic background influences physical performance or the trainability of physiological markers linked to performance. The most significant example of this area of research is the possible association between human ACE (kininase II) genotypes and physical performance. ACE is important in controlling the circulatory system and degrades vasodilator kinins, and converts angiotensin I (Ang I) to the vasoconstrictor angiotensin II (Ang II). In addition, local muscle renin-angiotensin systems are important determinants of muscle function (Jones and Woods, 2003). The human ACE gene is located on chromosome 17 and contains a polymorphism consisting of the presence (insertion, I) or absence (deletion, D) of a 287-base pair sequence in intron 16. Hence, three genotypes exist, II, ID, and DD, the distributions of which within a Caucasian population are roughly 25, 50, and 25%, respectively. This polymorphism accounts for up to 47% of the variation in plasma ACE, and DD subjects exhibit high ACE activity, whereas genotype II is associated with low ACE activity in both serum and tissues (Rigat et al., 1990).

Because ACE polymorphism affects serum and tissue ACE levels, and because ACE is involved in the metabolism of substances that affect vascular remodeling, it has been hypothesized that the ACE genotype might account for inter-individual variations in human responses to physical exercise. Previous studies have suggested that the I allele may be associated with some aspects of endurance performance, found more frequently in elite long-distance runners, rowers, and mountaineers (Montgomery et al., 1998). Greater improvement in muscular endurance was observed in male British Army soldiers with ACE genotype II and ID submitted to a 10-week general training program, in comparison with soldiers with ACE genotype DD (Montgomery et al., 1998). Association of the I allele with improved endurance was suggested to derive:

1) From metabolic factors related either from changes in the nature of substrate used or the efficiency or substrate utilization; or
2) From an increase in substrate delivery due to changes in muscle capillarity.

It is likely the relationship between the I allele, and local muscle effects such as the increased half-life of bradykinin and reduced production of Ang II, that may determine the impact of the ACE genotype on performance, via enhanced, endothelium-dependent vasodilatation influencing substrate delivery to the working muscles (Woods et al., 2002).

Taken together, these findings suggest that the variants in the ACE gene may influence physical performance, the response to physical training, or both. Whether low Ang II levels induced by chronic ACE inhibition improve endurance performance and positively affect skeletal muscle metabolic efficiency was examined in an animal model (Bahi et al., 2004). ACE inhibition was not associated with improved endurance performance and oxidative capacity of skeletal muscles. Some experimental evidence showed that the ACE ID polymorphism affects the individual improvement of physical performance in response to a training program. In humans, the influence of the ACE II allele on endurance performance is not mediated by differences in the aerobic training response (Woods et al., 2002), but the mechanisms of the improvements in performance remain largely unknown.

Other studies failed to find a role of the ACE genotype in aerobic performance. The inclusion of athletes from mixed sporting disciplines, which produces phenotypic heterogeneity, often explains the lack of association between I allele frequency and endurance performance (Karjalainen et al., 1999, Rankinen et al., 2000). One study examined whether the association between ACE genotype and physical performance previously shown in selected populations holds true in a cohort drawn from the general population (Sonna et al., 2001). The results of this study showed that in an ethnically and geographically diverse population consisting of US Army recruits drawn from a wide variety of ethnic backgrounds, there is probably no major effect of the ACE genotype on physical performance based on aerobic power or muscular endurance.

Together, these findings fail to demonstrate a strong relationship between the ACE genotype and physical performance in young, healthy individuals from the general population, such as military recruits.

7.5.2 HUMAN ACE POLYMORPHISM AND DISEASES RELATED TO MILITARY ENVIRONMENT

Exertional heat stroke is a fatal risk of hyperthermia induced by exercise performed in a hot climate. A wide range of individual variability exists in normal thermoregulatory responses to exercise in hot environments. The variability in heat tolerance in healthy humans such as soldiers has been shown to be related to various factors, but taken together, all these factors fail to explain the inter-individual variations in heat-stress responses. Therefore, the role played by the genetic endowment on the variability in exercise heat-stress responses has recently been examined (Heled et al., 2004). The allele I of the human ACE gene has been associated with increased heat tolerance during exposure to exercise heat stress. Moreover, there was a dose effect of the existence of the allele I and individuals with ACE genotype II who had the best heat-tolerance results. Mechanisms responsible for this finding remain unclear but could be related to the effects of Ang II on vasomotor function and thermoregulatory response to exercise heat stress. Although these recent data should be interpreted with caution, they suggest that the ACE I allele may be a candidate prediction marker for better tolerance to exercise heat stress and preventing the occurrence of heat injuries.

Medically unexplained fatigue has been shown to occur quasi-epidemically in veterans following the first Persian Gulf War (McCauley et al., 2002). Because the cause of this disorder remains unknown, a genetic predilection to developing unexplained fatigue has recently been considered (Vladutiu and Natelson, 2004). Research suggests that many abnormalities in genes affecting endocrine regulation exert a possible genetic influence in the pathogenesis of medically unexplained fatigue. Moreover, other genetic factors known to affect physical performance in endurance in army recruits have been examined, including the

ACE ID polymorphism (Vladutiu and Natelson, 2004). A lower prevalence of the II genotype, with a concomitant increase in the DD genotype, was shown in Gulf War veterans with medically unexplained fatigue. Although preliminary, these findings suggest an association between medically unexplained fatigue in Gulf War veterans and the ACE ID polymorphism.

Taken together, these findings must be viewed as preliminary and only significant to predicting genetic susceptibility to the adaptive responses to stress (i.e. metabolic, physical, or psychological stress) or to the occurrence of intolerance-related injuries.

7.5.3 OTHER GENE VARIATIONS ASSOCIATED WITH INDIVIDUAL DIFFERENCES IN RESPONSES TO STRESS

This scientific domain is of considerable interest for future research. More than 90 genes or gene variations have been associated with differences in exercise performance and health-related fitness phenotypes (Perusse et al., 2003). Several recent studies examined the association between polymorphisms of local growth factors and cytokines with the adaptability of skeletal muscle following acute resistance exercise. Both ciliary neurotrophic factor and interleukin-6 (IL-6) genotypes have been associated with muscle strength (Roth et al., 2001, 2003). An association between IL-1 gene variations and the acute inflammatory response to resistance exercise has been recently reported, suggesting that cytokine function in response to exercise is, at least partly, genetically regulated (Dennis et al., 2004).

7.5.4 SUMMARY

Many gene polymorphisms likely contribute together to explain the inter-individual variations in the adaptive responses to environmental stresses. Many other gene or cluster gene variations likely cooperate and contribute to determine the individual susceptibility to the development of diseases in response to strains of the operational environment. Improving our knowledge in predicting genetic susceptibility to the development of such diseases would contribute to selecting recruits for specific jobs within the Army, thus promoting health of military personnel.

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Section 7.6 – NUTRITION AS A FACTOR INFLUENCING MILITARY PERFORMANCE

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ABSTRACT

Nutrition before, during, and after military operations, can be viewed not only as a means to enhance military performance, but also as a factor negatively affecting the efficiency of military personnel during operations. The availability of palatable food, properly packaged and planned, and application of good feeding practices in the field significantly help to maintain and likely to enhance human performance and morale. These positive factors contribute to the success of military missions. Nutrition during military activities and training, must meet the energy and nutritional needs. Providing a nutritionally inadequate diet, or, in contrast, overfeeding, has deleterious effects on health and performance.

In addition to the acute problems of nutrition in the field during military operations, eating well in garrison prepares to maximize the positive effects of physical and mental training. For civilians, educating military personnel to make appropriate food choices, based on physical activity level helps maintain healthy weight and maximize the effects of military training.

7.6.1 ENERGY REQUIREMENTS DURING MILITARY OPERATIONS

During operations, deployed military personnel may have very different tasks and thus very different energy requirements. Most studies showed that energy expenditure of military personnel generally exceeds that of civilians. In one study, energy requirements of military personnel ranged 2,300 kcal to 7,100 kcal (Tharion et al., 2005). The total energy expenditure of male military personnel averages 4,620 kcal across all activities, military specialties and environments, and is approximately 38% higher than the mean total energy expenditure of civilians.

Military occupational activities determine energy requirements. Members of combat units expended approximately 20% more energy than support soldiers during the same training period. Most studies showed that combat soldiers expend significantly more energy than combat-support soldiers. Total energy expenditure also varies according to the type of mission and environmental conditions. A 15% to 20% increase in energy expenditure has been reported in soldiers deployed to the field in comparison with garrison. This increase in expenditure during deployments and field training is mainly related to an abundance of ambulatory activities, carrying loads, and long workdays are a major factor increasing energy requirements. Military workdays in the field, often exceed 16 hours of activity, while in contrast, most soldiers in garrison work and train less than 12 hours per day.

One of the major problems with nutrition during field activities is that energy intake is unable to match expenditures. Military personnel usually consume insufficient energy, whether they are provided an adequate amount or not. Energy deficit is a constant observation in all field studies. The energy deficit amount varies according to the activity. Inadequate food intake has been attributed to a number of factors, including lack of time, poor ration palatability, menu boredom, lack of water, and decreased appetite.

Other factors, such as lack of specific meal time periods, lack of time to prepare meals, anxiety due to field conditions, play a role in inadequate food intake and energy deficit. Moreover, field studies clearly demonstrated the trade-off between providing sufficient energy for the soldier, versus carrying a lighter load with insufficient energy.

7.6.2 CONSEQUENCES OF UNDERFEEDING

Underfeeding has long- and short-term consequences on health and specific components of physical performance. The consequences of energy deficit on health are well documented and result especially in depression in immune function (Keusch, 2003), and impairment in recovery from illness and injury.

7.6.2.1 Short Term Effects

A short period of underfeeding has deleterious effects on the physiological responses to exercise, such as increased heart rate during aerobic work, and impairment in the subjects' orthostatic tolerance. An impairment in recovery is also reported, with complaints of fatigue, muscle soreness, and weakness after the period of physical work with energy deficit (Montain and Young, 2003).

Muscle strength is affected by an energy deficit; a reduction in muscle strength is reported after 6% body mass loss, with increasingly poorer performance with additional body mass loss. The effects of underfeeding on muscle power are less clear, and, the reductions primarily seen in anaerobic performance have been due to muscle weakness rather than short-term dietary effects. In contrast, the capacity to generate maximal aerobic power appears to be sensitive to underfeeding. Reductions seen in the maximal aerobic capacity have been reported following as little as 2% body mass loss. Alterations in the maximal aerobic capacity are related, at least partly, to a loss of body water. The reduction in aerobic capacity appears as a real consequence of short-term energy restriction, and likely has deleterious effects on physical performance.

Most experiments conducted in the field lead to the conclusion that short periods of moderate underfeeding have only limited impact on the ability of the soldier to perform occupationally relevant tasks. However, most of these studies were composed of relatively small sample sizes, with large within-group variability. It is likely that small but real decrements in performance consequent to underfeeding may have been missed because of lack of statistical power (Montain and Young, 2003). Moreover, mental and cognitive performance is one of the determining factors of military tasks. The effects of underfeeding on such performance has been poorly studied.

7.6.2.2 Long-Term Effects

Prolonged periods of underfeeding clearly lead to a marked reduction in body mass with fat mass decline, and are paralleled by a reduction in muscle strength, and maximal aerobic and anaerobic powers. Recent studies confirmed that a 62-d period of underfeeding resulting from both energy restriction and high total daily energy expenditure has deleterious effects on muscle strength and power (Shippee et al., 1995). Taken together, all studies consistently demonstrate that long-term underfeeding can have detrimental effects on soldier physical performance capability.

7.6.3 COMMON DIETARY GUIDELINES FOR GOOD HEALTH IN GARRISON

Eating well in garrison is essential to prepare the body to be physically fit to endure any condition encountered in the field and to meet the physical and mental demands of military training (Thomas et al., 2001). For military in garrison, the aim is to reach or maintain a healthy body weight. The diet should consist of a healthful assortment of foods that includes vegetables, fruits, grains, fish, lean meat, poultry or beans. Foods that are low in fat and in added sugars should be chosen most of the time. Whatever the food, portion sizes should be sensible to avoid any prolonged alteration of the energy balance.

7.6.4 GENERAL GUIDELINES FOR MILITARY RATIONS

Field feeding is mainly based on military rations that are defined as one day's supply of food. The type of ration is mostly dependent on the type of military mission. The packaging should provide longer shelf life for foods and make the rations more compact and lightweight for ease of carrying. One of the key problems with military rations is preservation of food palatability, and then to favor the voluntary consumption of all components of the individual ration. It is expected that the military rations could comply with the energy and nutrient requirements. An overview of guidelines and design of existing group and individual rations has been previously published (Thomas et al., 2001).

Alterations in the dietary content of macronutrients to improve soldier performance are a matter of discussion. The utility of carbohydrate-electrolyte drinks for sustaining athletic performance is widely accepted. The potential efficacy of liquid carbohydrate feedings has received considerable attention, and all recent studies consistently demonstrated that carbohydrate drinks are an efficient method to increase energy intake in soldiers in the field, and to maintain sustained performance when limited food is available (Montain and Young, 2003) (see below). The potential benefit of fat supplementation to optimize energy availability and to enhance the energy density of the ration has been examined. It appeared that there was no increase in physical performance to supplementing the ration with fat (Hoyt, 1991). Together with other results from non-military sources, military rations should provide adequate energy, mainly from carbohydrate, and protein to sustain metabolism and allow recovery from intense and prolonged exercises.

7.6.5 ARE NUTRITIONAL ERGOGENIC AIDS RECOMMENDED?

A growing list of ergogenic products claim to boost physical and mental performances. Like sportsmen, soldiers may take such supplements because they believe they do not consume enough food to meet their nutritional needs, or they want to improve their ability to meet the challenges of field training. Usually, garrison meals and military rations can provide enough energy in all operational situations. The best strategy for optimal health and military performance is to ensure availability of food and fluids, and to promote their consumption in the field. Several studies have been performed to determine whether creatine supplementation may help soldiers become more capable of performing their military operational tasks (Montain and Young, 2003). While creatine may have some ergogenic effects that improve performance on tasks requiring high muscular power, creatine has not been shown to enhance performance on occupationally relevant tasks (Bennett et al., 2001). The potential use of some specific amino acids, antioxidant vitamins, and trace elements under field conditions needs to be addressed to reduce the incidence of illness and to enhance recovery from illness or injury, especially when dietary intake might be compromised.

7.6.6 FLUID REPLACEMENT DURING MILITARY OPERATIONS

Soldiers can survive for extended periods with little or no food, and they can use supplements to meet their physical needs for even greater periods. Fluid replacement is the only way to avoid dehydration, reduce the risk of heat casualties, and thereby minimize military performance degradation. Water is the one item that the soldiers must have to remain combat effective; there are no alternatives. While a soldier can last several days without nutrition, in many environments he can only last hours before experiencing debilitating and life-threatening effects of dehydration.

7.6.6.1 Fluid Replacement

Dehydration in excess of 3% of total body water markedly reduces military performance and increases the thermal stress of exercise (Sawka et al., 1996). Drinking is the only way to replace fluid loss and prevent dehydration. Guidelines for fluid replacement provide recommendations for fluid replacement based on climatic conditions (Kolka et al., 2004). Actual guidelines have been shown to successfully minimize the incidence of significant serum sodium loss without increasing the risk of dehydration for soldiers in the military training environment. Available fluid replacement tables include activity level (energy expenditure) and upper limits for hourly and daily fluid replacement to provide safe guidelines that would reduce the incidence of hyponatremia (defined here as serum sodium concentration less than 135 mEq•L^{-1}) without increasing the incidence of dehydration in a military training environment (Montain et al., 1999).

During military training, water is the primary rehydration beverage, and the electrolytes replaced during meals as daily sodium intake for garrison or field diets are sufficient for replacing most sodium losses from sweat. Other electrolytes lost in sweat are potassium, calcium, and magnesium. Including sodium and other electrolytes can be an effective electrolyte replacement during prolonged periods of profuse sweating in hot weather, especially when meals are not available.

7.6.6.2 Potential Use of Dietary Liquid Carbohydrate Supplementation

Many studies conducted in the field provided evidence that carbohydrate-electrolyte drinks provide an accessible source of energy, which can be of advantage when limited food is available during prolonged military training (Montain and Young, 2003). The benefits of carbohydrate-electrolyte drinks were demonstrated by the ability of soldiers to sustain both uphill running and marksmanship performance in hot weather (Montain et al., 1997). The effectiveness of carbohydrate drinks is maximized with feedings during both rest and military exercise. Taken together, these studies demonstrate that both energy intake and the timing of intake are important variables for optimizing soldier performance. The use of such drinks is important for sustaining physical and mental performance by providing both adequate fluids and energy quickly available during activity.

7.6.6.3 Water Availability, a Key Issue in the Field

Water availability during military operations affects the capacity of soldiers to carry heavy loads. Loads are rapidly becoming unmanageable, and a significant contributor to this problem is the soldier's need for water (DuPont and Dean, 2004). As temperatures climb, the soldiers carry even more water to compensate for the loss of body fluids.

Water availability affects drink packaging and design, re-supply operations, and soldier load. Soldiers cannot be expected to carry weights greater than 50% of their body weight. These weights have a negative impact on soldier endurance, situational awareness, and the ability to respond quickly and accurately to a threat (DuPont and Dean, 2004). A significant portion of this weight is attributed to the water that personnel are forced to carry. The Army must examine alternatives for supplying the soldier with water, in all environments, and across the full spectrum of operations.

7.6.7 IMPACT OF ENVIRONMENTAL CONDITIONS ON NUTRITIONAL NEEDS

Nutritional and fluid requirements during military operations vary according to environmental conditions.

7.6.7.1 Hot Environments

A hot environment has no detectable effect on military personnel's energy expenditure, and thus does not affect energy intake. The most critical need in a hot environment is adequate fluid replacement.

Total energy expenditure values observed in infantry soldiers conducting combat training during the summer were very similar to those measured during training in the cold (Tharion et al., 2005). Energy expenditure has been shown as lower in hot than in cold environments, likely because military personnel might perform less work in hot environments.

In hot environments, heavy work increases sweat rates and the likelihood of dehydration and other heat injuries. Failure to replace fluid lost through sweating can lead to dehydration and increase the individual's susceptibility to heat injury. Normal thirst does not ensure one will drink enough fluid voluntary to replace fluids lost through sweat. Because soldiers are unlikely to drink enough fluids voluntarily; leaders have to take an active role in minimizing the risk of dehydration and must enforce policies to insure that they consume enough fluids.

The impairment of food intake expected during military activities in the field can result in decreased salt intake necessary to replace minerals lost through sweating. Food is also a source of water and underfeeding can affect fluid replacement. Lastly, more than half of all fluids are consumed at mealtimes. If soldiers skip meals, the amount of fluid taken in will also decrease dramatically (Thomas et al., 2001).

7.6.7.2 Cold Environments

Total energy expenditure increases during military activities in a cold environment. A 30% increase in energy expenditure has been reported when military activities are performed under cold-weather conditions (Hoyt et al., 2001). The greater energy expenditure values are partly related to a longer, more physically demanding workday than during warmer weather exercises.

When working in cold environments, the weight of winter clothing can increase energy demands by 16% compared with demands of wearing desert clothing (Tharion et al., 2005). If clothing is insufficient, shivering can increase metabolic demand by as much as 430 $kcal \bullet h^{-1}$. The location of the weight of clothing or equipments on the body also influences total energy expenditures. For example, wearing heavy boots increases total energy expenditure to a greater extent than carrying the boots in a backpack, close to the center of mass. Energy expenditure of military personnel is thus increased when soldiers use or carry specialized winter equipment, and still increases as much as 30% for locomotion on hard-packed snow and up to 500% for deep snow (Tharion et al., 2005).

Military personnel often become dehydrated during cold weather operations. Dehydration can result from problems with frozen water and eating field rations with lower water content than most garrison foods. Thereafter, dehydration affects appetite and leads to fatigue and weakness. Moreover, it is suggested that dehydration can potentially increase the risk of frostbite, as a result of fatigue and mental changes which contribute to poor judgment and accidents. Thus, management of fluid intake should also be a major concern for leaders, to maintain adequate hydration and prevent cold injuries.

7.6.7.3 High Altitude

Many factors can explain the increase in energy expenditure that is often reported for military activities at high altitude. Hypoxia increases total energy expenditure, as do other factors, such as carrying specialized equipment, rough terrain, and additional clothing frequently worn at high altitude. High winds, snow, and cold temperatures also contribute to increased energy expenditure (Tharion et al., 2005). Military activities performed in this environment add to the energy cost above that already required when military personnel are exposed to the cold and snow at sea level. In addition to the specific effects of steep and mountainous terrain, high-altitude exposure increases basal metabolic rate, ventilation rate, and decreased ability to sleep. Taken together, energy requirements for high-altitude operations can be increased up to 10% above sea- level requirements.

Weight loss is a common observation during hypoxia exposure, mainly related to a loss of appetite, limited food availability, and difficulty in food preparation. During exposure to altitude, hypoxia is the major factor negatively affecting food intake. The weight lost consists of both body fat and lean tissue. At very high altitudes, lean tissue loss predominates. Accompanying the weight loss, are fatigue, loss of strength, and psychological changes, all of which interfere with mission success. Increased energy expenditure associated with loss of appetite results in a marked alteration of energy balance.

Carbohydrate supplementation improves physical performance and mental efficiency during military activity; carbohydrates are the preferred energy source at altitude, replenishing muscle glycogen stores and preventing protein degradation and amino acid oxidation. The potential use of carbohydrate-electrolyte drinks has been examined during sustained physical exercise at altitude (Montain and Young, 2003), with varying efficiency on performance. However, using carbohydrate-electrolyte drinks during military exercises in altitude, undoubtedly contributes to improved carbohydrate availability, the preferred energy source under these conditions.

The body's requirement for fluids is very high at altitude, often exceeding 4 liters per day. This is related to increased water loss from the lungs and urinary loss due to the diuretic effects of altitude and cold. Difficulties in consuming adequate fluids at altitude due to lack of potable water, restricted water availability by cold temperatures, and alterations of thirst all affect the body fluid balance.

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Section 7.7 – EFFECTS OF HEAT ON OPERATIONAL PHYSICAL PERFORMANCE

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7.7.1 EFFECTS OF INCREASED AMBIENT TEMPERATURE AND HUMIDITY

7.7.1.1 Body Heat Exchange

The normal comfort range for the body is an air temperature of 22°C to 25°C, when resting, lightly clothed, in a very light breeze with no radiant heat load (Anonymous, 1974, cited in Goldman 2001). Under these conditions, the body is able to dissipate the heat produced by resting metabolism to the environment and the body core temperature is stable at its resting value. The net heat stress is zero. The situation changes markedly when we begin to perform physical work.

The human body has been estimated to have an efficiency of 10 to 25% when carrying out physical work (Gonzalez, 1988, p. 176; McArdle, Katch and Katch, 1991). As a result, most of the energy that is expended to support physical work appears as heat within the body. The ability to continue to perform physical work depends on the ability to lose the excess metabolic heat produced. Most of this heat is exchanged at the body surface.

Heat can be lost from the body by several methods:

a) Radiation;

b) Conduction;

c) Convection; and

d) Evaporation.

Radiative heat loss involves the transfer of heat through electromagnetic waves to surrounding objects (walls, floors, trees, the sky). Conductive heat exchange is transfer of energy by direct contact with surfaces. Convective heat loss occurs through the transfer of heat to fluids moving across the surface of the body, usually air or water. Evaporative heat loss occurs when the body provides the heat needed to vaporize liquid water from the skin. Water may appear on the surface of the skin by passive movement from the interior of the body. Such water is known as insensible perspiration. Water may also appear at the skin surface as a result of active transport by the sweat glands. This water is known as sensible perspiration and contrasts with insensible perspiration in that the water accumulates in sufficient volume to be felt on the skin. A small amount of evaporative heat loss also occurs through the vaporization of water into the exhaled air.

In general, as the ambient temperature and humidity rise above neutral conditions (in which heat balance is maintained), the ability to lose heat to the environment decreases. Heat loss by radiation depends upon the environment having less thermal energy than the body. If the objects have less thermal energy than the body, heat can be lost the environment. Heat losses through conduction or convection are a function of the difference in temperature between the skin and the ambient air. Heat loss through evaporation depends on the water content of the air surrounding the skin (i.e. the relative humidity).

The environmental ambient temperature and relative humidity influence the effectiveness of these methods of body heat loss. For example, in the hot dry conditions of the desert, the temperature of the air and the surrounding objects is often greater than that of the body surface. The sun is the source of radiant heat, either by direct irradiation of the body (insolation), or indirectly in the form of heat waves that are reflected from objects or radiated from objects that have been heated by the sun. The sum of all the sources of radiant heat in the environment is usually measured as a black globe temperature (the temperature of the air inside a black metal sphere, which is placed in the environment being measured). Under hot desert conditions, heat cannot be removed from the body by radiation, conduction, or convection. In fact, under such conditions, heat exchange with the environment by these routes would result in a gain in body heat. Because desert air is dry, we are able to maintain our core temperature within normal limits because of our ability to lose heat by evaporation. The water that accumulates on the skin from sweating vaporizes into the dry air, extracting the heat of vaporization from the body.

In high-humidity (e.g. jungle) environments, the ability to lose heat through evaporation of sweat can be greatly decreased. As the temperature increases, the ability to lose heat through radiation, conduction, and convection is also decreased. It is possible under hot, humid conditions to reach conditions wherein heat loss is impossible. Such conditions generate what is referred to as uncompensable heat stress. Under those conditions one must move into a more-temperate environment or suffer a heat injury.

Goldman (2001) listed 6 “agents” of heat effects:

1) Ambient air temperature;
2) Air motion or wind velocity;
3) Air relative humidity;
4) Mean radiant temperature (globe temperature);
5) Metabolic heat produced; and
6) The clothing insulation (clo) and moisture permeability.

Goldman also provided a set of equivalences by which one can evaluate the effects of change in these agents:

- A 10% change in relative humidity is comparable to a 0.28°C change in ambient temperature.
- A 0.1 $m \bullet s^{-1}$ change in wind velocity is equivalent to a 0.55°C ambient temperature change (up to 2.8°C).
- A 1°C change in radiant temperature is equivalent to a 1°C change in dry air temperature.
- 0.1 clo (1 clo = 0.155 $m^2 \bullet °C \bullet watt^{-1}$)[1] of additional clothing is equivalent to 0.56°C in ambient temperature up to a work rate of 2.5 MET of activity, and 1.1°C at greater activity levels.
- A 25 $kcal \bullet h^{-1}$ is equivalent to a 1.67°C change in ambient temperature.

[1] Clo: The “clo unit” is a unit of thermal insulation on the body that is afforded by the clothing that is worn. The unit is based on the insulation of a standardised “suit.” See Section 7.6.

7.7.1.2 Physiological Response to Increased Body Temperature During Exposure to Compensable Heat Stress

In response to an increase in body core temperature, cardiac output is enhanced through increases in heart frequency and stroke volume. Blood flow to the skin is raised. This raises the temperature of the skin to aid in the exchange of heat with the environment, and boosts the blood flow to the sweat glands to raise availability of fluid for sweat production. Additionally, there is an increase in blood flow to the active muscles, which not only augments the supplies of oxygen and metabolic substrates, but also increases the rate of heat removal from the body (Sawka and Wenger, 1988; Werner, 1993).

7.7.1.3 Adaptation to Hot Environments

In response to repeated exposures to hot environments, several adaptive changes take place. Cardiovascular changes lead to a decrease in heart rate at any given exercise rate. Blood volume increases, at least initially. The core temperature at which skin vasodilatation occurs decreases. The rate of increase in skin blood flow per unit of core temperature rise increases, and, hypothetically, the maximal amount of skin blood flow is greater (Pawelczyk, 1993). The onset of sweating takes place at a decreased core temperature relative to that observed prior to acclimation, and the volume and rate of sweat production are increased for the same thermal exposure. In addition, the composition of the sweat changes, becoming more dilute. With these changes, there is an accompanying decrease in core temperature for a given work rate.

Acclimation to the heat is produced by repeated exposures sufficient to raise the core temperature and provoke at least a moderate degree of sweating (Goldman, 2001; Wenger, 1988). Moderate exercise in the heat for 1-hour each day is adequate to provoke an adaptive response in an unacclimatized person. With such a program, acclimatization can be achieved in 7 to 10 days.

7.7.2 EFFECTS ON PHYSICAL PERFORMANCE

One of the keys to maintenance of physical performance is the removal of heat from the working muscles. It should be clear that as the ambient temperature increases the ability to transfer heat to the environment is decreased, and the work rate that can be supported is decreased. According to data provided in (Goldman 2001), it is estimated that for every 1°C of effective temperature (a temperature scale developed to provide equivalent temperature sensation in a variety of dry air, relative humidity, and wind speed conditions) the 4-hour tolerated work rate decreases by 12.35 $kcal \cdot h^{-1}$.

One factor underlying this decrease in work capacity is that there is increasing competition for blood flow from the muscles, which requires blood to continue to perform work, and from the skin, which requires increased blood flow to support heat dissipation. Eventually, cardiac output becomes limiting (Pawelczyk, 1993; Sawka and Wenger 1988), and heat loss cannot be maintained at sufficiently high levels. If heat dissipation cannot keep pace with heat production, heat will be stored in the body, and core temperature will rise. The situation of rising body heat content and body core temperature has been shown to be related to onset of fatigue (González-Alonso et al., 1999). The rise in body temperature and heat content can also result in disruption of brain function (heat stroke).

A second factor is that the competition for blood flow is exacerbated by the fact that cooling the body by evaporation is associated with the fluid loss. Work in the heat is often accompanied by dehydration. Fluid is lost in sweat production, which can reach rates of 2 to 3 L of sweat per hour, at least for short periods of time. Loss of fluid contributes to decreased ability to adequately supply muscles with metabolic substrate, and to adequately transport heat from the muscles to the skin (Werner, 1993). It can also lead to circulatory collapse (heat exhaustion). The effects of dehydration on performance are discussed in a separate section of this chapter.

The phenomena described above suggest that problems with the heat result in circulatory problems, and that it is endurance performance that is compromised. There does not appear to be strong evidence of direct effects on muscle leading to decreased performance. Effects of increased ambient temperature have been shown to affect sprint performance (Drust et al., 2005) and isometric strength (Morrison, Sleivert and Cheung, 2004). However, in each of these studies, the authors concluded that the effects are centrally mediated and associated with increased core temperature.

7.7.3 STEPS TO AMELIORATE THE EFFECTS ON PERFORMANCE

If one anticipates the requirement to carry out physical work in the heat, one should make every effort to acclimate the body to such work. A program of endurance exercise in moderate heat can help accomplish this goal.

During work in the heat, it is important to stay as well hydrated as possible. While fluids cannot be taken up from the gut at rates that match maximal sweating, fluid intake can help delay the development of severe dehydration.

Clothing interferes with the body's ability to lose heat. Clothing, by virtue of its insulative and water-permeability properties, can decrease heat exchange between the skin and the environment. It is important to wear clothing that is as light and water permeable as possible when working in the heat. Current military operations often demand wearing body armor or even chemical, biological, radiological protective suits during operations in the heat. This equipment offers a substantial barrier to heat loss from the body. When wearing such gear, one must decrease the work rate to a level that can be sustained while wearing such gear, or must limit the work period to one wherein body heat storage does not become dangerously large.

Portable cooling systems, such as ice vests or liquid-cooled garments, can also be used to prolong work in the heat. However, these systems are often bulky, heavy, and difficult to "recharge" in the military operational environment.

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Section 7.8 – EFFECTS OF COLD ON OPERATIONAL PHYSICAL PERFORMANCE

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7.8.1 THREATS AGAINST OPERATIONAL PHYSICAL FITNESS IN A COLD ENVIRONMENT

In military operations soldiers are often exposed to various stressors, such as prolonged and strenuous physical exercise, sleep deprivation, and energy and fluid deficiency. In cold environments, countermeasures against these stressors are more laborious to perform than in moderate climates. Some of the countermeasures are stressors themselves, like the weight of cold protective clothes and other equipment or decreased dexterity caused by gloves. Cold-weather injuries are additional stressors related to operations in cold environments. This chapter reviews how cold environment affects physical performance, the physiology behind these effects, and how soldiers' physical fitness can be maintained in these conditions.

7.8.2 FINGERS IN COLD

Hand and finger skin temperatures are dependent on physical activity and thermal balance, thermal insulation of handwear, ambient temperature, wind, contact with cold objects, as well as wetting of handwear, hands, or fingers.

The risk of frostbite is low in ambient temperatures above –10°C. The risk is considerable at –20°C and pronounced at –25°C (Danielson, 1996; Joupperi et al., 2002). Frostbite is the end point in the series of adverse effects of tissue cooling. Lowered manual performance, cold sensations, cold pain, and numbness occur before frostbite and therefore are much more common than frostbite. Manual performance begins to decrease at finger skin temperatures of 30°C and weakens steeply below 13°C. Cold pain is experienced at skin temperatures of 13°C and numbness starts at skin temperatures below 7 to 8°C (Enander, 1984; Heus, Dannen and Havenith, 1995). Rintamäki et al., (2004) reported finger temperature measurements in 70 subjects in different winter weather conditions in Finnish military using standard handwear.

They selected a finger temperature of 13°C (temperature at which manual performance begins to decrease deeply) as the limit of serious deterioration of manual performance, and observed that in ambient temperatures between –20 and –30°C finger temperatures were 69% of operation time under 13°C. Finger temperatures were under 7°C 20% of operation time under 7 °C when fingers are already numb. These findings emphasize the important role of adequate handwear in winter military operations. Rintamäki et al., (2004) also observed that finger warming was achieved at core temperatures above 37.6°C, emphasizing the role of physical activity and whole-body thermal balance in maintaining sufficient finger temperature.

Contact cooling usually occurs with skin contact with metal surfaces. Even thin gloves or thin surface coating with material of low thermal conductivity (e.g. plastic) remarkably reduce contact cooling and the risk of contact frostbite (Havenith, Heus and Dannen, 1995).

7.8.3 DEXTERITY

Finger dexterity starts to decrease strongly below a hand skin temperature of 15°C (Dannen, 1993). Skin-receptor sensibility to touching shows only minor impairment between skin temperatures 25 to 8°C. A nervous block occurs at skin temperature of about 6°C. Thus at skin temperatures of 8 to 6°C the skin sensitivity drops rapidly (Morton and Provins, 1960; Dejong Hershey and Wagman, 1966).

Nerve conduction velocity reduces quite linearly between temperatures of 36 to 23°C (Morton and Provins, 1960), and somewhat deeper below 20 to 25°C. In general, nerve conduction velocity decreases 1.5 m/s per 1°C. A nervous block occurs at nerve temperatures below 10°C (Vangaard, 1975; Paintal, 1965; Basbaum, 1973).

Static endurance work with hands shows the best performance at a muscle temperature of 28°C, whereas the best muscular temperature for a short-term maximal contraction is 38°C (13). At lower temperatures, both maximal force and endurance time decrease rapidly. Maximal static force declined 66% from the initial value in 10°C bath water (Clarke, Hellon and Lind, 1958).

Data about the effects of temperature in joints and tendons are inconclusive but suggest that joint temperature below 24 to 27°C dexterity is compromised due to stiffening. Conclusively, it seems that the reduction in manual dexterity caused by cold is mainly due to cooling of joints and muscles.

7.8.4 ACCLIMATIZATION TO COLD

Although there is no conclusive evidence to support the role of cold acclimatization, the literature suggests that continued cold exposure leads to increased physical performance because the thermal environment is perceived as less uncomfortable. Manual dexterity and performance in cold is maintained better due to reduced cold-induced vasoconstriction. Shivering response is attenuated in repeated experimental cold exposures (Young, 1966; Castellani et al., 2003).

However, it seems that the physiological effects of cold acclimatization are so small that they have no practical importance for physical performance in cold environment (Young, 1966). Adaptation in the form of learning to live, work, and move in cold environments is the key element for ensuring good performance in cold environments.

7.8.5 HYPOTHERMIA

The danger of hypothermia is obvious when related to cold-water immersion or insufficient thermal insulation of clothing, and the countermeasures are obvious. During physical exercise the amount of clothing should be such that sweating would be minimal. During pauses the amount of clothing should be sufficient to ensure thermal comfort. However, in combat situations it is not always possible to adjust the amount of clothing, thus resulting in excessive sweating that can rise even to 3 to 4 L•h^{-1} (Young et al., 1998) and lead to compromised thermal insulation of clothing.

When considering the role of hypothermia in maintaining operational physical performance, the main problem seems to be protection against cold after exhaustive physical work. Young and co-workers (1998) reported of increased susceptibility to hypothermia associated with prolonged periods of high-intensity exertion, negative energy balance, and sleep deprivation. They studied their subjects immediately after a 9-week Ranger training course, after a 48-hr recovery, and 16-week recovery periods. During the training course the average weight loss was 7.4 kg. In an experimental cold exposure the core temperature decreased in the tests performed immediately and 48 hr after the training course, but not 16 weeks after the course. The set point for the shivering thermogenesis was lower immediately after the training course than after 48 hr or 16 weeks of recovery. Young and co-workers (1998) concluded that thermal balance was weakened during the training course due to loss of insulative body fat and suppressed thermogenic response to cold. The latter was normalized after 48 hrs of recovery. In a study of 48 hrs of sustained operations, Castellani et al., (2003) also reported a reduced mean body temperature threshold for the onset of shivering thermogenesis. The subjects had also lower core temperatures associated with enhanced vasoconstrictor response and no change in heat debt, suggesting insulative acclimation.

When soldiers rest after fatiguing physical work they may fall asleep and not awaken when they begin to shiver. These voluntary movements increase muscular heat production and can elevate body temperature. In mild hypothermia (33 to 35°C deep body temperature) psychological confusion develops, endangering rational behavioral responses, which include seeking or building shelter against cold and wind, making fire, continuing voluntary movements at an intensity sufficient to prevent shivering, and keeping their clothing dry. Soldiers should be aware of the minimal environmental temperature in which they can sleep safely in their standard equipment when dry or wet. These safety limits depend on the quality of the equipment.

7.8.6 DEHYDRATION IN COLD

The effects of dehydration on physical performance in warm or hot environments are well recognized. In cold environments the threat of dehydration for physical fitness is equally important. Fluid intake tends to decrease in cold-weather operations for several reasons. In subzero temperatures the drinking fluids are prone to freeze, and melting them is time-consuming, leading to unavailability of drinking fluids. The drinking fluid is not palatable if it is very cold. Soldiers may also reduce fluid intake intentionally because urination can be troublesome in heavy winter clothing. Soldiers not used to operations in cold environments often tend to wear too heavy clothing causing excessive sweating that promotes dehydration.

Moderately intense activity in moderately (1 to 3°C) cold weather requires a fluid intake of 2.7 L per day (Murray 1995; O'Brien et al., 1996) for maintaining body fluid balance. For monitoring, dehydration recommendations of urine specific gravity >1.029 and osmolality >1052 mOsm•kg^{-1} have been suggested, corresponding with the dark yellow color of urine (Wyannt and Caron, 1983; Armstrong, Maresh and Castellani, 1994). Dehydration of 2 to 5% of body weight has been noted (Coyle, 2004) as better tolerated in moderate (20 to 21°C) than in hot (31 to 32°C) environments. However, in military operations the negative effect of dehydration on physical performance should not be neglected because the effective thermal insulation of winter clothing tends to raise the body temperature to hyperthermic levels. Rintamäki et al., (Rintimäki et al., 1995) observed that dehydration of about 3% of total body weight resulted in about a 10% reduction in maximal working time but not in maximal oxygen uptake in a maximal exercise test done in a 15°C environment (after spending 1 hr in –15°C). At a submaximal work level (125 W) oxygen consumption was about 25% higher in dehydrated subjects as compared with the test repeated after correction for dehydration. In military operations with moderately intense activity in the cold or moderately cold, daily water need seems to be between 2 and 3 l (O'Brien et al., 1996; Wyannt and Caron, 1983; Rintimäki et al., 1995; Welch, Buskirk and Iampietro, 1959).

7.8.7 ENERGY BALANCE

In military operations, nutritional energy needs appear to depend primarily on physical activity level. The additional effect of cold environments is relatively small (McCarroll, Goldman and Denniston, 1979). However, a cold environment increases energy needs indirectly by making many physical tasks more laborious and time-consuming and by making it necessary to carry different types of cold-protective equipment and fuels. McCarroll and co-workers reviewed the extra energy cost due to wearing cold-protective garments in winter terrain (McCarroll, Goldman and Denniston, 1979). When compared with walking on blacktop roads, energy expenditure was reported to be 1.3-fold when walking on hard-packed snow and 5-fold when walking in deep snow. The energy cost of walking in soft snow (30 cm) reached 16 $kcal{\bullet}min^{-1}$ when the speed was 4 $km{\bullet}h^{-1}$ and load 9 kg. Snowshoeing in unbroken snow at a speed of 3.7 km/h and carrying load of 5 kg increased energy costs to 12 to 13 $kcal{\bullet}min^{-1}$. Skiing on a packed flat trail at 4.5 $km{\bullet}h^{-1}$ and carrying a load of 15.4 to 19.8 kg caused an energy cost of 7.4 $kcal{\bullet}min^{-1}$. Raising the speed of skiing to 10.5 $km{\bullet}h^{-1}$ increased energy cost to 14.4 $kcal{\bullet}min^{-1}$. Burstein et al., (1996) reported that the load carried by Israeli soldiers was 42 kg in the winter and 35 kg in the summer, the difference reflecting the weight of cold-protective personal equipments. The daily energy expenditures were 4281 kcal in the winter and 3937 kcal in the summer. The energy need of infantry soldier has been reported to be about 4000 $kcal{\bullet}day^{-1}$ (Jones et al., 1993), and during heavy physical efforts up to 6500 $kcal{\bullet}day^{-1}$ (Stroud, Coward and Sawer, 1993). A 1985 US Army regulation recommended 4500 kcal in cold environments (Department of the Army, 1985). In the literature there is no agreement about the proportions of carbohydrates and fats in the diet that would be optimal in cold environments (Stocks et al., 2004). However, it seems that the palatability of food in cold is important for sufficient energy intake (Edwards, 1991).

7.8.8 COLD WEATHER INJURIES

Cold weather injuries include hypothermia, chilblains, immersion foot and frostbite. Because most frostbite occurs in feet and hands it can significantly reduce a soldier's physical performance (DeGroot et al., 2003). In the US Army the incidence of cold weather injuries treated in military hospitals has reduced radically during 1980 to 1999. The yearly rate of hospitalizations due to all types of cold weather injuries in 1985 was 38.2 per 100,000 soldiers and 0.2 per 100,000 in 1999. For frostbite, the yearly rate of hospitalizations was about 14 per 100,000 soldiers in 1980 and less than 0.2 per 100,000 soldiers in 1999. This positive development can be explained by multiple factors. Personal equipment has become better in protecting against cold, and cold weather training has become more effective. Closing or downsizing US Army installations in northern latitudes and treating the patients in open care and hospitalizing only the severest cases have also affected the number of hospitalized soldiers with cold weather injuries statistics. African-American men and women were injured approximately 4 times and 2.2 times, respectively, more frequently than Caucasian soldiers.

Between 1976 to 1989 the annual incidence of frostbite in Finnish Defence Forces was about 4 per 1000 conscripts. Thirty percent of the frostbites were in fingers, 27% in toes, 26% in earlobes, and 10% in the nose. Ninety five percent of the frostbites occurred when the temperature was less than –15°C. Wet footwear increased the risk of frostbite in toes 6.5-fold (unpublished report). Modernization of soldiers' personal winter equipment has reduced the incidence of frostbite in Finnish military, but no statistical data are available for the present situation.

7.8.9 SUMMARY OF COLD WEATHER INJURY RISK FACTORS AND COUNTERMEASURES

In preventing cold weather injuries the first step is to understand the conditions that cause an increased risk of cold weather injuries: temperature below 5°C in dry conditions or below 15°C in wet conditions. The strong cold potentiating effect of wind is important to understand. The risk of cold weather injuries is also increased by inadequate clothing, shelter, and nutrition, sleep deprivation, little experience in cold weather operations, previous cold weather injuries, and low physical activity.

Key countermeasures are adequate shelter against cold and wind, as well as adequate clothing and the ability to use the cold-protective clothing correctly. During low physical activity cold-protective clothing must be sufficient to keep muscular shivering away; during heavier physical activity, the thermal insulation must be low enough to prevent excessive sweating. Clothing must be dry, this is especially critical in footwear and socks. Therefore, it is mandatory that soldiers have with them spare inner clothing layers, have the facilities to dry the wet pieces of clothing, and can keep their spare clothing dry. Protection against and management of cold injuries is described in detail in two recent documents: TB MED 508 "Prevention and Management of Cold-weather Injuries" (2005), and NATO RTO-MP-HFM-126 "Prevention of Cold Injuries" (2005), as well as a handbook for medical officers (US Army Research Institute of Environmental Medicine, 1993).

7.8.10 MENTAL PERFORMANCE

Marked whole-body cooling that causes a reduction in deep body temperature of 2 to 4°C impairs memory and concentration (Coleshaw et al., 1983; Giesbrecht et al., 1993; Lockhart et al., 2005). Body hypothermia (<35°C) is associated with symptoms of confusion, amnesia, and decreased alertness and consciousness. However, the results of studies using moderate, non-hypothermic cold-exposure have been inconsistent: decreased, unchanged, or improved mental performances have all been reported (Palinkas, 2001; Mäkinen, 2006). Mental performance seems to be impaired more by fast cooling than by slow cooling (Ellis, Wilcock and Zaman, 1985). In their study Marrao et al., (2005) observed during a 9-day cold weather operation no serious decrements in mental performance when normal deep body temperatures and hydration levels were maintained. Thus, we concluded that the cold environment itself does not compromise mental performance as long as adequate cold protection is maintained.

7.8.11 SUMMARY

It is essential that leaders train in advance their military units to operate and maintain physical performance in cold environments. Main training goals are:

1) Soldiers learn the correct use of personal cold-protective equipment (especially handwear and footwear);
2) They understand what are sufficient energy and fluid intake; and
3) They are aware of the danger of cold weather injuries and are trained to start countermeasures immediately when they observe the first signs or symptoms.

Military personnel must be aware that physical exhaustion is an important risk factor for cold weather injuries that often causes incapacitation of the soldier.

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Section 7.9 – EFFECTS OF ALTITUDE ON OPERATIONAL PHYSICAL PERFORMANCE

by

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7.9.1 BACKGROUND

Military operations in mountain terrain can be associated with environmentally related medical problems and performance decrements that can have significant impact on mission attainment. Military personnel may be more at risk for problems than civilians, because military operations can increase exposure to harsh conditions, such as *hypobaric hypoxia, cold, insolation, dry air, and complicated mountainous relief etc.* In addition, external stresses such as increased load carriage and rugged terrain features, unpredictable weather conditions, snow-covered ground, and mountain sickness can lead to decreases in functional capacities. In mountainous regions, the load carried will almost certainly increase – because of the additional weight of protective clothing and technical equipment. Military physical performance in the mountains may also be adversely affected by sleep deprivation, increased physical and/or emotional stress, caloric and fluid restrictions, reduced visibility, equipment failures, inadequate communications, and lack of specialized medical equipment.

Two characteristics of military operations are particularly important in shaping the interaction with mountain environments: the wide range of activities associated with military operations, and the frequent lack of choice as to when and where to participate in those activities. Behavioral and psychological incompatibility of personnel may cause great harm to a soldier's health, and his ability to work. It can also cause large social and economic losses. Therefore, when forming military units including border guards to serve at high altitude, it is extremely important to screen for individuals who are at risk to get "adaptation" sicknesses.

7.9.2 DEFINITION OF TERRESTRIAL ALTITUDE

The concept of high altitude is an arbitrary one. It can mean an elevation of 1500 m. Terrestrial altitude can be defined as follows:

- Intermediary altitude: 1500 to 2500 m; physiological changes due to hypoxia are detectable, but arterial oxygen saturation remains above 90%; altitude illnesses is possible (Mason et al., 1994).
- High altitude: 2500 to3500 m; altitude illnesses are common with rapid ascent to above 2500 m.
- Very high altitude: 3500 to 5800 m; arterial oxygen saturation falls below 90%; altitude illness is common and marked hypoxemia occurs during the exercise.
- Extreme altitude: above 5800; further successful acclimatization cannot be achieved. Progressive deterioration occurs, and survival cannot be maintained permanently. Marked hypoxaemia occurs at rest.

At increasing altitudes above sea level, barometric pressure (PB) decreases and with it the partial pressure falls. At the summit of Mont Blanc (4807 m) the partial pressure of oxygen (PO_2) is about half of that at sea level, and on the summit of Mount Everest (8848 m) it is one third of sea level pressure. For a given altitude, barometric pressure is higher at the equator than at the poles and is higher in summer than in winter. The PO_2 in the atmosphere falls as PB falls. Temperature and ultraviolet radiation also change at high altitudes: temperature decreases with increasing altitude at a rate of approximately 6.5°C per 1000 m and UV radiation increases approximately 4% per 300 m due to decreased cloudiness, dust, and water vapor. In addition, as much as 75% of ultraviolet radiation can be reflected back by snow, further increasing exposure at high altitude. Survival in high altitude is dependent on adaptation to and protection from each of these elements.

7.9.3 PHYSIOLOGICAL RESPONSE TO ALTITUDE

The major effects of high altitude on humans are related to changes in PB and subsequent changes in the ambient pressure of oxygen.

The inspired oxygen partial pressure (PIO_2) falls with increasing elevation. This decline has almost linear character: 100 m terrestrial elevation causes a decrease of PIO_2 1.18 mm. (West et al., 1980). PIO_2 149 mm. at sea level and 43 mm Hg at Mount Everest. Although the major determining factor of PIO_2 is PB, and body temperature, that determines the partial pressure of water vapor (PH_2O), also can affect PIO_2.

Oxygen must constantly be transported from the atmosphere through the respiratory system to the tissues' mitochondria in insufficient quantities to meet tissue demands.

Hypobaric hypoxia causes altitude illness and physical and cognitive performance decrements. At high altitude, lowlanders (natives or acclimatized inhabitants of low-altitude regions) are incapable of as much physical exertion as they were at sea level. Further, they may not feel well, and may have impaired mentation.

7.9.3.1 Acclimatization

Acclimatization is the process by which individuals gradually adjust to altitude hypoxia. It is an inadequately understood physiological process, involving a series of adjustments that occur over a period of hours to month. These changes all favor increased oxygen delivery to cells and efficiency of oxygen use.

The most important component of acclimatization is hyperventilation (increase in rate and depth of respiration). This begins to occur at altitudes of about 1500 m. The increased ventilation at altitude is driven primarily by the increased carotid chemoreceptor activity. With increased ventilation come hypocapnia and respiratory alkalosis, which limit further increased ventilation. The resulting hypocapnic alkalosis, which accompanies the increased ventilation, may be partially responsible for delaying the full increase in ventilation (i.e. ventilatory acclimatization), which can require a week or more to develop at moderately high altitudes. Hyperventilation raises alveolar oxygen tension and limits the fall in the PO_2 pressure gradient from the inspired air to the alveolus. The increased ventilation also increases the removal of carbon dioxide from the blood.

As acclimatization proceeds, there is gradual renal compensation by excretion of bicarbonate that tends to restore arterial pH to near-normal values. Heart rate (HR) increases with ascent, although, with acclimatization, resting heart rate approaches sea level values (except at extreme altitudes). At extreme altitudes resting and maximum HR converge as the limits of acclimatization are approached. Erythropoietin secretion in response to hypoxemia stimulates production of erythrocytes, resulting in increased hematocrit and hemoglobin concentrations.

The ability to acclimatize to altitude is quite individual: some people acclimatize rapidly; others require longer periods of time to acclimatize fully and are more prone to acute mountain sickness (AMS).

Successful acclimatization is characterized by the absence of altitude illness and improved sleep (Lyons et al., 1995).

Acclimatization in adults seems to be possible up to about 5000 to 5500 m. above this elevation there is a fine balance between the adjustment to altitude and deterioration as a result of chronic hypoxia. At more extreme altitude, deterioration becomes increasingly prominent, and above 8000 m, no acclimatization occurs.

The adjustments to hypoxia that begin immediately with acute hypoxic exposure, together with the continuing processes of acclimatization, collectively comprise the altitude adaptations. Altitude acclimatization can prevent altitude illness and improve performance, but the time and circumstances to achieve acclimatization may not always be available to units in a rapidly changing tactical situation.

7.9.4 EFFECT OF ALTITUDE ON PHYSICAL PERFORMANCE

The hypoxia associated with mountain (actual) or altitude (experimental) exposures reduces sustained physical performance capabilities to a degree directly proportional to the elevation, with the magnitude of the reduction associated with initial exposure usually greater than that associated with continued exposure.

The altitude limitations in total body oxygen transport begin to appear above 2000 m, where these respiratory limitations might be expected. Thus, the respiratory system imposes greater limitations on overall exercise performance at altitude than at sea level. Even if respiratory factors limit maximal oxygen uptake at high altitude more than circulatory factors, this does not mean the systemic oxygen transport and muscle energy metabolism adjustments that occur at high altitude do not affect physical performance.

After altitude acclimatization, systemic oxygen transport requirements during exercise at altitude can be satisfied with a lower cardiac output, and thus reduced cardiac work, than on arrival. In large part, this adaptation is enabled by the higher arterial blood oxygen saturation (SaO_2) resulting from ventilatory acclimatization, which, along with hemoconcentration due to high-altitude diuresis during the initial weeks at altitude and expanded erythrocyte volume after several months, raises CaO_2. The development of a glycogen-sparing adaptation further contributes to the improvement in exercise performance. Thus, in lowlanders ascending to high altitude, maximal performance appears to be limited by respiratory factors and submaximal performance by non-respiratory factors, but both respiratory and non-respiratory factors contribute importantly to performance improvements with acclimatization.

At sea level, circulation is the dominant factor limiting maximal exercise performance. Indeed, maximum oxygen uptake at sea level varies markedly among subjects, and that variability is closely linked to the variability in maximum cardiac output. However, this variability among subjects in their maximum oxygen uptake is markedly reduced as elevation is increased. Considering the limitation imposed on the number of oxygen molecules that can be ventilated at high altitude, and the limitation of lung diffusing capacity at altitude, one might conclude that the respiratory rather than circulatory system limits maximal oxygen uptake at high altitude. If oxygen does not reach the arterial blood, then increasing cardiac output might not greatly facilitate oxygen transport to the tissues. Wagner's analysis (1997) indicates that at the summit of Mount Everest, a doubling of maximal cardiac output will increase maximum oxygen uptake by less than 10%.

Altitude may affect the heart rate response to exercise. Maximal heart rate decreases after prolonged exposure to hypoxia. Cunningham and colleagues showed that plasma and urine catecholamine levels are elevated at high altitudes. At high altitude there is an increased parasympathetic tone at maximal exercise. This may be secondary to increased sympathetic tone and the baroreceptor reflex. Mean heart rate does not increase with the administration of supplemental oxygen, and so the impaired heart rate response is not attributable to hypoxia alone.

7.9.4.1 The Effects of Altitude on Maximal Aerobic Power

Maximal aerobic power can be affected by factors that alter any of the processes involved in oxygen transport or utilization. At altitude, a person is exposed to a progressive decrease in atmospheric pressure, with resultant declines in inspired, alveolar, and arterial oxygen pressures. As a consequence of the progressive hypoxia associated with increasing altitude, VO_2max declines at a rate inversely proportional to the elevation.

The minimal altitude at which a decrease in VO_2max has been detected and the rate at which it declines with increasing elevation Buskirk and colleagues suggested (1967) that there is minimal decrement in VO_2max until approximately 1524 m, with an average linear decline of 3.2% for every additional 305 m of altitude. In more recent years, VO_2max has been determined in subjects of varying fitness levels at lower and higher altitudes. Using information from some of these studies, Grover, Weil, and Reeves (1986) suggested that the decline in VO_2max begins at about 700 m, with a linear reduction of 8% for every additional 1000 m of altitude up to approximately 6300 m. Gore and colleagues reported (1996) that at 580 m, VO_2max declines 3.6% in fit, untrained individuals and 7% in elite athletes for every additional 1000 m. These and other data suggest that small declines in VO_2max begin at a much lower altitude than had been previously assumed by Buskirk and colleagues, and by Grover, Weil, and Reeves. In addition, it would appear that there is a more rapid, non-linear decline in VO_2max at altitudes in excess of approximately 6300 m. This more rapid decline may be linked with reduced blood flow, reduction of muscle mass, or metabolic deterioration, conditions that in any combination are often associated with chronic hypoxic exposure.

Potential sources of variation of the mean percentage of decline in VO_2max in competition at altitude includes subjects' fitness levels, and residence at altitude prior to a study; subjects' gender, changes in conditioning level resulting from increased activity during the exposure; subjects' smoking status, motivation, age, hypoxic ventilatory response; altitude sickness (AMS, high-altitude pulmonary edema, and high-altitude cerebral edema); rate of ascent to altitude, duration of exposure, timing of VO_2max measurements (e.g. pre-acclimatization and post-acclimatization); differences between training and exercise testing modes; use of inappropriate exercise mode (e.g. elite runners tested with bicycle ergometers); and altitude-induced muscle wasting.

7.9.4.2 Muscle Strength and Power

Muscle strength and maximal muscle power are generally not adversely affected by acute or chronic altitude exposure as long as muscle mass is maintained. In addition, alpha motor neuron excitability, nerve- and muscle conduction velocity, and neuromuscular transmission are not impaired, even at altitudes exceeding 4300 m. Unchanged maximal force and maximal power generation at altitude may relate to one or both of the following factors: maintenance of low resting levels of metabolites that, if higher (as during more-prolonged exercise), could potentially impair function of the contractile machinery; and preservation of normal resting levels of high-energy phosphates sufficient to support the rate of adenosine 5'-triphosphate turnover (1 – 2 $mmol \cdot s^{-1}$) for brief maximal muscle performance (Fulco, Cymerman, Muza, 1994).

It is obvious that military personnel are involved in many physical activities other than athletic events (e.g. running). Such activities are typically work- or mission-specific and can encompass extremely light to very demanding efforts that use different muscle groups for varying periods of time. In a sense, many work-related tasks have similarities to exercise performance in terms of effort intensity, volumes of active muscle involved, and activity duration.

With initial altitude exposure, arterial oxygen content is reduced. But for any specified submaximal exercise (exercise level when the individual reaches 85% or 90% of predicted maximal heart rate for age) or work intensity, oxygen transport to the working muscles is maintained because of a compensatory increase in cardiac output. For maximal levels of exercise or work, maximal cardiac output cannot increase to levels greater than those at sea level, and thus cannot compensate for the reduced arterial oxygen content (CaO_2) (Young, et al., 1980). The result is a reduction in maximal oxygen transport and VO_2max. With sustained exposures of 2 to 3 weeks, CaO_2 increases toward sea-level values, owing to both hemoconcentration due to the loss of plasma volume and an increase in SaO_2. As a consequence of the decreased plasma volume, however, stroke volume and cardiac output are both reduced. During submaximal levels of exercise or work, the restored CaO_2 compensates for the reduced cardiac output such that oxygen transport to the working muscles is maintained (Burse, Cymerman and Young, 1987). But during maximal levels of exercise or work, the restored CaO_2 cannot compensate for the altitude-induced decline in maximal cardiac output, and maximal oxygen transport and VO_2max do not improve. Additionally, many other ventilatory, hematological, and metabolic adaptations may aid oxygen transport and improve exercise capabilities or military task performance.

7.9.5 HIGH ALTITUDE ILLNESSES

The term "high altitude illness" describes those medical conditions that are directly attributed to hypobaric hypoxia. Regardless the overlap between these symptoms, it is convenient to separate them into three types: acute mountain sickness (AMS), high-altitude cerebral edema (HACE) and high-altitude pulmonary edema (HAPE).

Rapid ascent to altitudes above 2500 m. often results in the syndrome known as AMS, which is the collection of symptoms (headache, nausea, vomiting, fatigue, anorexia, dizziness, sleep deprivation) that occur gradually, typically 6 to 12 hours after arrival at high altitude, and usually resolve within 1 to 3 days if further ascent does not occur. The most important risk factors for the development of AMS are sleeping altitude and rate of ascent. AMS is being increasingly recognized at altitudes of between 1500 and 2500 m. Descent to low altitude effectively and rapidly reverses AMS. It should be remembered that AMS represents the mild end of the spectrum of AMS. The major concern is that it may progress to life threatening high-altitude cerebral and/or pulmonary edema. A recent hypothesis of mechanisms of above-mentioned diseases is that hypoxemia elicits various neurohumoral and hemodynamic responses that ultimately lead to elevated cerebral blood flow, altered blood-brain barrier permeability, and cerebral edema. These changes result in brain swelling and elevated intracranial pressure.

High-Altitude Cerebral Edema is a rare but life-threatening form of altitude illness and has symptoms. Indeed, AMS and HACE probably represent two ends of a spectrum, the distinction between them being inherently blurred. It is likely to occur above 3500 m.

High-Altitude Pulmonary Edema usually occurs in the first 2 to 4 days after ascent to altitudes above 2500 m. As many as 10% of those ascending very rapidly to 4500 m will develop HAPE (Bärtsch et al., 1990), although incidences of 1 to 2% are more likely for standard ascent rates. HAPE is non-cardiac pulmonary edema, characterized by exaggerated pulmonary hypertension leading to capillary leakage through over-perfusion and/or stress failure. Inflammation may occur as a secondary event that results from alveolar flooding.

Low-altitude residents who spend prolonged periods (months) at very high altitude (above 5500 m.) may develop signs and symptoms of congestive heart failure. This condition has been referred to as **subacute mountain sickness**. It is characterized by right ventricular hypertrophy, pericardial effusion pulmonary hypertension, and resolution of symptoms and signs with descent.

Chronic mountain sickness is a disorder of long-term high-altitude residents and is characterized by high erythrocythemia and hypoxemia (Reeves and Weil, 2001). Signs and symptoms reflect profound polycythemia and hypoxemia: neuropsychological problems predominate, with headache, poor concentration, somnolence, dizziness, and poor exercise tolerance.

While ascending and residing at altitudes in some individuals several other disorders may occur as a result of influence of harsh environment: peripheral edema (Hackett and Rennie, 1979), high-altitude retinal hemorrhage, sleep and periodic breathing, neurological disorders (e.g. TIA), thrombosis, high-altitude anxiety and high-altitude cough, high-altitude deterioration and worsening of appetite. In addition, it is noted that infections are common at high altitude and are often slow to resolve (Murdoch, 1995; Durmovicz et al., 1997; Meehan, 1987).

7.9.5.1 Other Altitude-Related Injuries

While residing at terrestrial altitude, humans can get injuries related to other environmental factors: including cold, heat, UV radiation, and avalanche.

Hypothermia; the decrease of body temperature above 35°C, often occurs in individuals in the setting of inadequate clothing or shelter.

Frostbite; is more likely to occur in the presence of high winds, high altitude, contact with heat-conducting materials such as metal and water, dehydration, hypovolemia, tobacco use, or any other factors that reduce blood supply to the extremities.

Trench foot; is the result of prolonged exposure of the lower extremities to temperatures between 0 to 15°C without freezing of tissues. Injury is caused by decreased perfusion that lasts more than 1 to 2 days.

There is a possibility at altitude to suffer **heat exhaustion and heat stroke**, especially during exercise in the sun and hot weather, and when wearing improper clothing. Heat illness results from salt and water loss through sweating, inadequately replaced by oral intake.

At high altitude there is an increased risk of UV radiation from the sun forced by the thinner atmosphere to deflect and absorb the solar radiation and snow on the ground and hillsides that reflects the rays and increases the chance of burning, skin ageing, and neoplasia.

In snowy areas, the reflected sun can be very intense and can result in **snow blindness**, solar damage to the cornea and conjunctiva.

Risk of accidents and traumatic injuries while ascending, residing, and working in high altitude is markedly increased due to all mountainous environmental factors, and lack of mountaineering skills. For example, hypoxia leads to the impairment of mentation that causes decreased ability to concentrate while performing complicated activities (e.g. climbing, load carrying, skiing).

7.9.5.2 Prevention of Illnesses and Injuries on Mountains

An important aspect of preventive medicine on mountains involves ensuring that an individual has appropriate skills. All mission participants should be well trained, familiar with the use of a map and compass, and adequately dressed, equipped and proficient in base rope techniques and use of safety equipment. In remote settings rescue and evacuation plans should be made before they are needed. The mission participants should be selected according to the operational scenario, and ascending rate must be determined based on group members' capacities. In addition, the appropriate equipment (emergency kit, portable hypobaric chamber) can be also very helpful in urgent cases. If altitude illness symptoms occur, it is necessary to descend and/or take appropriate medications, if needed.

7.9.6 TRAINING STRATEGIES FOR IMPROVING PHYSICAL PERFORMANCE AT ALTITUDE

Mountaineering training is essential to fully appreciate the complexity of the problems encountered in mountain environments.

Because of hypoxia-induced physical performance decrements, military personnel rapidly transported from low to high terrestrial elevations should not be committed immediately to patrolling operations, entrenchment, combat, or other physically demanding duties, nor should they be expected to perform as well as they did at sea level (Levine et al., 1997).

Training modifications at altitude to increase the probability of successfully completing the tasks, compared with sea level, would include at least one of the following: an increase in task duration, a reduction in task intensity, or more-frequent rest breaks.

The specific amount and type of modification will depend on factors such as type of task involved, task difficulty, elevation, time at altitude, urgency, weather, terrain, and involved muscle mass (e.g. arm or leg work).

Acclimatization at altitude improves the oxygen-carrying capacity of the blood and aids exercise performance. It is nearly impossible to train at the same intensity as that engaged in at sea level when at altitudes above 2300 m. To improve performance at intermediate altitude, it is preferable to train at the same altitude, particularly for endurance events.

Two different regimens of altitude training have been proposed to improve performance: living at altitude and training at sea level or training at sea level and living at altitude. Living at altitude and training at sea level may offer the greatest physiological advantage for sea-level competition, since the physiological adaptation favor improved performance (Bailey and Davies, 1997).

During training at altitude, greater exercise intensity may not be desirable because of issues such as not being able to sustain a given task for a required duration. An altitude exercise training regimen should be successful in improving exercise performance more at altitude than at sea level. It would seem to be the net result of a complex interaction of conditioning level, training stimuli, deconditioning, altitude acclimatization, and level of hypoxia (Faulkner et al., 1967).

Why living at sea level and training at altitude may be more beneficial for improving exercise performance than both living and training at altitude is not well understood. Possible differences in success rates between these two experimental approaches do not seem to be related to differences in absolute exercise intensity, training altitude, training program duration, subject fitness levels, and peripheral muscle changes.

Living at altitude but training at a lower altitude ("living high and training low") theoretically allows both the advantageous changes of acclimatization to develop and the opportunity to train without reducing exercise intensity.

Levine and colleagues (1997) concluded that altitude acclimatization with sea-level training improves exercise performance at sea level. Because of these findings, Levine and Stray-Gundersen and Levine, Roach, and Houston hypothesized 1 year later that altitude acclimatization rather than hypoxic exercise per se was the key to altitude training because the natural form of "blood doping" (increased blood volume and hemoglobin) enhanced oxygen transport. In contrast, hypoxic exercise training has been reported to increase VO_2max without inducing changes in hemoglobin concentration or blood volume. Perhaps hypoxic exercise training increases the "training effect," as evidenced by greater increase in aerobic enzyme activities and other peripheral changes.

7.9.7 SUMMARY

In ascending to altitude, an individual is exposed to a progressive decrease in atmospheric pressure that is associated with reductions in inspired, alveolar, and arterial oxygen pressures. As a consequence, VO_2max also declines. The minimal elevation at which a decrease in VO_2max is detectable is approximately 580 m. Fitness level, pre-exposure elevation, gender, and duration of exposure should be qualitatively assessed to determine their contribution to the overall variability. Because VO_2max declines, the relative exercise intensity is increased, therefore submaximal exercise performance is adversely affected. To maintain the same level of perceived difficulty at altitude for training or working on civilian or military tasks, the exercise or workloads must necessarily be reduced. Long-duration activities will be impaired more than shorter-duration activities at a given altitude. Muscle strength, maximal muscle power, and, likely, anaerobic performance are not affected at altitude as long as muscle mass is maintained. Physical performance may be improved at altitude compared with sea level in activities that have a minimal aerobic component and can be performed at high velocity (e.g. sprinting). Altitude acclimatization is associated with a multitude of ventilatory, hematological, and metabolic adaptations that have been thought to induce a beneficial effect on exercise performance. Training or living, or both, at altitude can improve altitude exercise performance in athletic events or military activities. Any potential benefit induced by altitude acclimatization for subsequent sea-level performance may be offset by the inability to maintain exercise intensity. Living at altitude but training at a lower altitude permits the theoretical advantage of both acclimatization and training, without reducing exercise intensity.

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Section 7.10 – EFFECTS OF CLOTHING ON OPERATIONAL PHYSICAL PERFORMANCE

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This section is intended to provide a brief overview of some of the means by which clothing can aid performance in operational environments, and some costs associated with use of clothing in those environments. There is not space to provide a complete treatise on military clothing. Not all types of military clothing are discussed, nor are specific military operations considered. This section does not specifically discuss footwear, respiratory masks, chemical defense ensembles or specific survival gear. The general principles discussed in this section do apply to these clothing items, and hopefully the reader will be able to extend the discussion provided below to those items.

We use clothing to protect us against the effects of the environment. In most instances, clothing provides a barrier between that environment and us that allows the creation of a comfortable microenvironment next to the body. From a performance point of view, wearing clothing is what often allows us to carry out work at all, especially as the environment becomes more extreme.

Clothing provides protection from thermal extremes, hot and cold, on land and in the water. Clothing allows us to survive the range of atmospheric pressures, from the extremely great pressures encountered in deep diving to the near-zero pressure of the vacuum of space. Our clothing helps us tolerate the increased gravitational acceleration encountered in flying high-performance aircraft. Clothing protects our bodies from mechanical trauma, ranging from cuts and scratches to the ballistic protection offered by body armor. Clothing also provides protection against threats posed by chemical, nuclear, and biological hazards.

By creating a barrier between the warfighter and the environment, clothing can interfere with the thermoregulatory process, particularly dry heat loss and the loss of heat through evaporation of sweat. Clothing can also interfere with performance because it provides added weight to be moved and may restrict freedom of movement.

7.10.1 PROTECTION

The properties of clothing that allow it to protect us from the environment include

1) Thermal protection;
2) Fluid permeability; and
3) Mechanical protection (Havenith and Heus, 2000).

7.10.1.1 Thermal Protection

Clothing offers protection against thermal insults through provision of insulation or by modifying the thermal reflectance or absorbance of radiant energy.

7.10.1.1.1 Insulation

Insulation is the resistance to heat transfer. In the United States, clothing insulation values are expressed in units of clo. One clo is the insulation provided by a typical 1940s business suit. One clo is equal to 0.155 $m^2 \bullet °C \bullet W^{-1}$, which implies a heat transfer limit of 6.45 watts per square meter of surface area per degree Celsius difference between the air and skin temperatures (Goldman, 1988b). One clo of insulation will maintain a sedentary person comfortably at 21°C, 50% relative humidity and no wind, indefinitely. In Europe, clothing insulation is often expressed in units of tog. One tog is equal to 0.645 clo or 0.1 $m^2 \bullet °C \bullet W^{-1}$.

The insulation provided by clothing is a function of the material used, its thickness, and the amount of air that is trapped in the weave of the fibers or between layers of clothing. In general, the thicker the cloth, the greater the insulation provided. Air is a good insulator, and the more of it that is trapped in the material of the clothing or between the layers of clothing, the greater the insulation provided by the clothing.

We need some degree of insulation when the environmental conditions fall below our comfort zone. The colder the environment the greater the amount of insulation needed.

We also need insulation when the environmental temperatures are much greater than is comfortable, such as in firefighting.

7.10.1.1.2 Reflectivity

Reflectance is the ability of clothing to reflect electromagnetic waves, including infrared (heat) and ultraviolet rays. By varying the reflectance of clothing, we can vary the ability to absorb the energy carried in such waves. By wearing white, reflective clothing, we decrease the amount of heat absorbed by our clothing and increase the ability to survive and work in hot climates. By wearing black, non-reflective clothing, we increase the amount of heat absorbed by the clothing and increase our ability to remain warm. An extreme example of use reflective clothing is the use of so-called “silver suits,” firefighting ensembles with shiny metallic coatings to reflect the intense heat of aircraft fires.

7.10.1.2 Permeability

Permeability refers to the ability to allow the transport of fluid substances through the clothing material. Usually the concern is the transport of water vapor, liquid water, or air through the layers of a garment because movement of these substances is important in maintaining thermal balance. In general, clothing represents a barrier to fluid exchange.

7.10.1.2.1 Water-Resistance

Garments can be designed to limit or prevent the penetration of water into the garment. Clothing that resists but still allows water penetration is categorized based on the pressure required to cause water to enter the material. A material is considered “water repellent” if it takes >0.5 psi to push water into the fabric. It is considered “waterproof” if it takes >25 psi, and “storm proof” if it requires >30 psi to force water into the fabric (Holmes et al., 1988). The degree of water protection needed varies with the use to which the garment will be put. Foul-weather gear to protect sailors on deck during storms needs to be storm proof. Survival suits designed to protect aircrew in the event of a water landing needs to be impermeable to water.

7.10.1.2.2 Water Vapor

Water vapor permeability is expressed as i_m, a permeability constant that takes on values from 0 (impermeable) to 1 (water vapor passes through freely).

Uniforms for use in hot climates should have a high water vapor permeability to allow sweat to evaporate from the skin and to provide cooling. Some garments are not completely permeable to water vapor but still can support cooling by evaporation of water. The clothing can be made of materials that can absorb the liquid from the skin and "wick" liquid water away from the skin and transport it to the clothing surface for evaporation. Such evaporation cools the garment rather the skin directly and is not very efficient at cooling the body. But the skin is left dry and the wearer feels more comfortable than if the skin were wet. Sports wear often has such wicking layers.

It is sometimes desirable to allow water vapor to exit a garment but also keep liquid water out. Examples are clothing to be worn while working outdoors in the rain or snow. A series of materials have been developed to meet these needs. These materials have pores that are too small to allow water droplets to move in through the fabric (waterproof), but large enough to allow water vapor to pass out of the garment. In this way, they provide protection against rain or snow, but allow the fabric to let water vapor out and allow body cooling during work. One might note that these fabrics are not impermeable to water. If you fall into a lake, the water pressure gradient will force water through the pores.

7.10.1.2.3 Air

The air permeability of a fabric determines its resistance to air penetration. Increased airflow through a garment aids in cooling the body. Garments such as windbreakers, that are designed to block the wind, have low air permeability. Clothing designed for use in hot weather is usually quite permeable to air flow to allow the air to assist with cooling. Using porous materials or adding vents to a garment can enhance air permeability.

Allowing a "loose fit" can also enhance airflow through a garment. As the garment wearer moves, the material of the garment will flex and fold, resulting in a "pumping" action that promotes some air movement within the garment.

7.10.1.3 Mechanical Barrier

Clothing offers a wide range of mechanical protection. The outer fabric protects the skin against chaffing, scuffs, cuts, abrasion, or other trauma that might result from equipment carried, contacting objects, or diving to the ground.

A greater level of mechanical barrier protection in military clothing is offered by body amour, which offers protection against shell and grenade fragments and even bullets. Body armor consists of several layers of woven fabric made of para-aramide fibers (e.g. Kevlar, Twaron, or Technora) or high-tenacity polyethylene fibers (e.g. Dyneema or Spectra), augmented with hard ceramic plates. When a bullet or projectile strikes body amour, it is caught in a "web" of high performance fibers that absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Hard body armor works by disrupting the aerodynamic shape of the bullet and dissipating the energy by shattering the ceramic top layer.

Body armor offers three different levels of protection:

1) Spall protective (fragments from amour),
2) Shell fragment protective, and
3) Bullets protective (van de Linde and Lotens, 1988).

Levels 1 and 2 can be met using the soft body armor, but the bullet-protective level would require such a large number of aramide panels that the additional protection of the ceramic plates is needed.

It is important to have the appropriate level of protection. If the protection provided is less than that required, the projectile may deform without completely dissipating its energy. This deformed fragment may cause more damage as it passes into or through the body than would an undeformed fragment. Less protection than necessary could conceivably be worse than no protection.

7.10.2 PERFORMANCE DECREMENTS

As noted above, the protection offered by clothing can come with a performance cost. Clothing can interfere with the body's ability to exchange heat with the environment, and wearing clothing can increase metabolic demands because of the weight of the clothing and the freedom of movement restriction imposed by clothing.

7.10.2.1 Heat Exchange Disruption

As discussed in Section 7.1.1, the body gains or loses heat through radiation, conduction, convection, and evaporation. Clothing poses a physical barrier to all these methods of heat exchange. Exchange of heat by radiation is greatly reduced by most clothing ensembles. The insulation provided by clothing decreases the possibility of heat exchange by conduction, heat exchange by convection is limited by the air permeability of the garment, and heat exchange by evaporation of sweat is limited by the water and water-vapor permeabilities of the clothing. These effects are most often positive ones, because clothing is worn to maintain a comfortable level.

The amount of insulation must be varied to match both the environment and the physical work demands. If one is engaged in physical work, the clothing must allow the excess metabolic heat produced to escape to the environment to prevent the body from overheating. If one is sedentary, the clothing must provide sufficient insulation to prevent the loss of heat from the body. Dressing for work in the cold can be particularly challenging. One must dress warmly enough to avoid becoming chilled when resting, but the clothing must allow for sufficient heat loss when working (e.g. marching with a load). One of the dangers is that if one works hard enough to cause sweating, the presence of water in the clothing decreases the insulation value of the clothing and leads to more-rapid cooling when one stops working (Richards et al., 2005). To combat this problem one should wear removable layers of clothing, or clothing that can be easily opened up to allow heat to escape when preparing for work in the cold. By these means, the insulative value of the clothing can be varied to meet situational demands.

Water and water vapor permeabilities determine the rate and route by which perspiration can be removed from the surface of the body. If the water vapor permeability of the garment is large enough, water can evaporate from the skin and the vapor can move out through the garment. In this instance, the skin is cooled directly. If the water vapor permeability is not so large, the water vapor will condense in the clothing. If the water permeability of the clothing is sufficiently great, the water will move to the outer surface of the garment and evaporate there (conditions permitting). In this instance, cooling takes place at the surface of the garment. Body cooling is achieved, in part, by contact with the cooled clothing material, rather than by evaporation. Heat exchange in this way is not as effective as when garments have high vapor permeabilities.

When a garment is impermeable to water vapor, liquid water can build up inside the garment. Because the vapor does not leave the garment to evaporate, this avenue of heat loss is cut off. This is the situation that pertains when one wears chemical defence clothing. These garments have a rather large insulative value ($\approx$ 2 clo; (Goldman, 1988b)) so heat transfer is impeded. Additionally, such garments have relatively low permeability ($i_m \approx 0.3$; (Goldman, 1988b)). Water vapor from sweating cannot evaporate. As a result, heat builds up inside the garments when working and cannot be dissipated. This heat build-up severely limits the ability to work while wearing these garments unless an external method of cooling is available (e.g. ice vests, plunging hands in cold water, or an external source of moving air blown inside the suit.). A similar situation occurs when wearing body armor, which is impermeable to water vapor (van de Linde and Lotens, 1988).

7.10.2.2 Weight

Another limitation imposed by working in garments with heavy insulation or mechanical barriers (e.g. body armor) is that the weight of the garment is increased, adding to the physical workload associated with motion. The metabolic cost of walking or running is proportional to the weight being moved, and the weight of the clothing contributes to this cost. The metabolic cost of walking 3 mph is approximately 12 ml O_2•kg^{-1}•min^{-1}. At this speed, every kilogram of clothing adds about 12 ml O_2•min^{-1}. If a set of upper-body torso body armor weighs 4.5 kg (Danielsson and Bergh, 2005; Lotens, 1988; van der Linde and Lotens, 1988) the additional cost of walking at 5 km h^{-1} would be 0.54 l O_2•min^{-1}. The impact of such an increase varies with body size and fitness. The load will represent a smaller proportion of carrying capacity for larger and more-fit individuals.

7.10.2.3 Mobility Costs

However, there is an additional metabolic cost associated with the restriction of movement caused by bulky, stiff or multilayer clothing ensembles. Lotens reviewed the effects of mobility costs in 1988. He reports that the energy cost of movement goes up linearly with the number of layers of clothing (an indicator of bulkiness) when the garments were adjusted to be equal in weight. A 6 to 7 layer suit has an 18% greater energy expenditure when walking at 5.6 km h^{-1} than a garment with 1 – 2 layers (Teitlebaum and Goldman, 1972; cited in Lotens, 1988). Dorman and Havenith (2005) also studied this effect and found additional metabolic costs range from 5 to 20% above the cost of walking on a treadmill at 5 km h^{-1} in trainers and a track suit, after controlling for the weight of the protective gear compared with this control condition. Some values of interest are army fatigues + body armor, 109% of control metabolic cost, Army fatigues + NBC ensemble, 117%. Clearly, decreasing the mobility costs associated with clothing ensembles is a necessary research and development goal.

7.10.3 CURRENT TRENDS

Development of clothing materials and clothing items continues to be an active area of research. The aims of this research are, in part, to continue to address the problems outlined in this section: improved protection against the operational environment and specific battlefield threats, maintenance of thermal comfort in extreme conditions, and reduction in weight and bulk, with the overall goal of providing protection to the warfighter while maintaining his or her full combat effectiveness. Specific threat areas being addressed include ballistic protection, surface heat and blast, detection identification (camouflage, and concealment against a variety of threats), biological and chemical protection, nuclear and radiological protection, directed-energy weapons, and mobility and load carriage (Scott, 2000). Approaches include the development of smart/reactive materials that change their properties in response to changing conditions. New clothing systems that utilize nanotechnologies as sensors to detect environmental conditions, as power supplies to support protective systems, and as mechanical activators of material properties changes are being considered. These new systems will be needed to counter the threats of tomorrow's battlefield.

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Section 7.11 – EFFECTS OF EXTENDED OPERATIONS ON PHYSICAL PERFORMANCE

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7.11.1 BACKGROUND

The increasingly fast-paced deployments to operational theatres and advances in technology, such as night-vision capabilities, have pushed the boundaries of modern warfare. The "24-hour battlefield" is a common reality among militaries around the globe. As a consequence, today's soldiers rapidly deploy across time zones all over the world and are expected to have the stamina to fight for longer periods of time without rest or sleep. Continuous operations (CONOPS) are defined by a period of continuous land combat with opportunity for sleep, although this sleep may be brief or fragmented. Sustained operations (SUSOPS) are defined as continuous land combat with no opportunity for sleep. By definition, CONOPS will likely involve periods of SUSOPS. Extended operations will potentially have negative effects on soldiers' physical performance because they will most likely be engaged in prolonged physical work, possibly be underfed, and be subject to sometimes difficult environmental conditions during those operations. The impact of negative caloric intake and environmental conditions were already covered in this chapter, therefore it will not be discussed further. Factors that will be examined in greater detail are sleep deprivation and trans-meridian travel.

7.11.2 SLEEP DEPRIVATION

When adults get considerably less than 7 hours of sleep per 24-hour period, they begin to feel the effects of sleep loss (Armstrong, 2000). Sleep deprivation can de described as a lack of sleep ranging from a couple of hours to many days. Partial sleep deprivation is when an individual regularly gets less than 5 hours of sleep per night, short-term sleep deprivation is defined as less than 45 hours of wakefulness, and long-term sleep deprivation is when someone is kept awake for a period of time greater than 45 hours (Pilcher and Huffcutt, 1996). Sleep deprivation is predominantly detrimental to cognitive functions and decision making. For every 24-hour period without proper recovery sleep, individuals will experience a 25% decrease in cognitive performance, making them virtually militarily inefficient after only a few days of SUSOPS (Haslam, 1984). Individuals suffering from sleep loss will have great difficulty concentrating, even on simple tasks; they will lose much of their creative thinking, and they will feel more confused and fatigued than if they were properly rested. They will also tend to pay less attention to self-care, such as eating, hydrating, staying dry and clean, thereby exposing themselves to other potential problems. Moreover, mood and motivation are greatly affected by sleep deprivation and can eventually play a predominant role in physical performance. The effects of sleep deprivation have a dose-response relationship with cognitive functions and appear to be exacerbated by the circadian trough (0300 – 0600 hrs). Although the literature is clear on the negative impacts of sleep loss, some studies have reported that incentives such as promised sleep or warm shelter could maintain or even improve mental performances (Haslam, 1983).

7.11.3 EFFECTS OF SLEEP DEPRIVATION ON PHYSICAL PERFORMANCE

7.11.3.1 Cardiorespiratory Function

Studies examining the effects of sleep loss on physical performance range anywhere from between 24 and 84 hours of wakefulness (Armstrong, 2000; Castellani et al., 2003). Although some report minor effects of sleep deprivation on physical performance, surprisingly most of them have found very little physiological changes in cardiorespiratory functions in partially or totally sleep-deprived subjects. Even in severely sleep deprived individuals, VO_2, VCO_2, minute ventilation, blood pressure, and heart rate did not differ from non-sleep-deprived control measures (Martin and Chen, 1984; Martin and Gaddis, 1981; Symons et al., 1988). Blood lactate levels and respiratory quotient for varying intensities remained unchanged, suggesting that sleep deprivation does not cause any major fuel-selection shifts during exercise (Martin and Chen, 1984; Symons et al., 1988). A study involving only female subjects demonstrated that women's response to exercise after sleep loss is identical to men's (Goodman et al., 1989). Hence, sleep deprivation resulting from SUSOPS is not detrimental to the aerobic or the anaerobic capacity of the soldiers.

7.11.3.2 Muscular Function

Similar to the cardio-respiratory function, muscular function is not affected by sleep deprivation. After 30 to 72 hours of sleep loss, subjects did not display any changes in maximal isometric or isokinetic strength (Symons et al., 1988) or electromechanical responses to exercise (Van Helder and Radomski, 1989). Physical performance can be expected to decrease during SUSOPS, not by lack of sleep but simply because the same muscle groups tend to be overutilized over a long period of time without adequate recovery (VanHelder and Radomski, 1989).

7.11.3.3 Thermoregulation

A soldier's ability to tolerate heat or cold will certainly affect his or her effectiveness in the field. As mentioned earlier, SUSOPS often involve multiple stressors, including sleep deprivation, negative energy balance, and physical exertion. Sleep deprivation has been shown to have a detrimental effect on the body's capability to properly maintain core temperature. Studies have found that prolonged sleep loss reduces dry heat loss, sweat rate, and sweat sensitivity, meaning that the onset of evaporative heat loss comes at a higher temperature (Kolka et al., 1988; Sawka et al., 1984). These changes result in higher risk of heat stroke when sleep loss is combined with moderate or extreme exercise (Armstrong, 2000). Obviously, considering that soldiers already carry equipment that impairs their thermoregulatory mechanisms, sleep loss will most likely result in a decrease in physical performance when exposed to extreme temperatures. On the other hand, the effect of sleep deprivation on cold-exposure tolerance is not as clearly defined. In a study of 84 hours of SUSOPS, researchers found that the thermoregulatory response may be altered by sleep loss. In that particular experiment, sleep deprivation induced greater decline in core temperature among the subjects compared with controls due to either a delay in the shivering response or by heat redistribution caused by insulative acclimation (Castellani et al., 2003).

7.11.3.4 Perceived Exertion

Contrary to the physiological data, the subjective measures of performance, such as perceived effort, breathing, pain, and fatigue, seem to be more significantly affected by lack of sleep. Many studies have reported higher ratings of perceived exertion (RPE) for submaximal and maximal intensity exercise. For the same heart rate or work rate, sleep-deprived subjects perceive to be working and breathing harder and feel more fatigued (Rodgers et al., 1995; Martin and Gaddis, 1981; Symons et al., 1988; Armstrong, 2000). These higher ratings of perceived exertion are undoubtedly linked with the greatest effects of sleep loss on physical performance, which is the exercise time to exhaustion. In studies involving more than 48 hours of sleep deprivation, researchers reported decreases of up to 20% in exercise time to exhaustion despite any changes in physiological parameters (VanHelder and Radomski, 1989; Symons et al., 1988; Martin and Chen, 1984; Rodgers et al., 1995).

7.11.3.5 Motivation

During SUSOPS, soldiers may have the physiological capability to perform physically demanding tasks over prolonged periods of time, but their attitude and motivation to carry out those tasks will be severely challenged by sleep loss. Mood is most severely affected by sleep deprivation as are most other psychological and cognitive functions, and it will be the leading indicator of physical performance (Nindl et al., 2002). Decreased mood state will result in a decrease in physical performance and on the willingness of individuals to push their bodies to exertion (Belenky et al., 1987; Pilcher and Huffcutt, 1996; Symons et al., 1988). The nature of the task also plays a role in motivation to perform physically. Boring and repetitive or continuous tasks at low intensity (35 – 40% VO_2) will be more subject to a decrease in performance (Rodgers et al., 1995). Soldiers' attitudes will dictate their level of physical performance; therefore, a positive change in attitude may override the pure effects of sleep deprivation (Haslam, 1983). In military operations, leadership plays a critical role in the overall performance of soldiers. Well-led troops can perform for longer periods of time while maintaining their work output (Belenky et al., 1987). Soldiers who believe in their leaders will tend to feel less fatigued and be able to tolerate higher intensities than soldiers who have little faith in their leadership. Consequently, leadership styles during SUSOPS become a critical factor in the success or failure of a potentially physically demanding mission.

7.11.4 COUNTERMEASURES TO SLEEP DEPRIVATION DURING SUSOPS

Finding solutions to counter the effects of sleep deprivation during CONOPS is simpler than applying them during SUSOPS where the schedule, environmental conditions, and the stress level are completely uncontrollable. In CONOPS that don not necessarily involve combat, using well-established shift-work schedules will help maintain cognitive and physical performance at acceptable levels for weeks at a time. Shift work should be set according to the level of cognitive demands: longer shifts for tasks that require limited cognitive demands, and shorter for ones that are more complex (Belenky, 1997). As for SUSOPS, it is almost impossible to apply the concept of shifts. So military planners and leaders need to use other solutions in order to ensure proper vigilance, psychological, and physical performance of their troops.

7.11.4.1 Naps

Naps can sometimes be perceived negatively in a military environment but they can certainly be very beneficial to soldiers. Thus leaders should be well aware of this perception and address it in SUSOPS situations. The recuperative value of sleep depends on the duration and the timing of that sleep. A prophylactic nap of 2 to 4 hours can be as effective as 1.5 – 3 cups of coffee and can help maintain alertness and cognitive performance near baseline level over a 24-hour period (Armstrong, 2000). Although naps can be valuable, they can also be detrimental. Brief or fragmented sleep has little or no recuperative value and can be as debilitating as total sleep deprivation (Belenky, 1997). Furthermore, individuals choosing to take naps might suffer from a period of sleep inertia upon wakening. Sleep inertia can range from 15 to 30 minutes and can make the individual feel groggy or sluggish. Sleep inertia is amplified by both the depth of sleep of the individual and its timing in the circadian rhythm. This condition can potentially contribute to decrease in military performance.

7.11.4.2 Medication

There may be some situations where soldiers will be required to go to sleep in preparation for certain missions. That sleep opportunity may not necessarily come at the right time of day. In those instances, hypnotics such as Temazepam, Zaleplon, and Zolpidem may be used as a viable solution to promote sleep. These medications are either sleep maintenance or short-duration sleep agents. Caution should be used when utilizing such medications since they are not recommended when individuals are "on-call" or can be sent on a mission on a moment's notice, because they exacerbate sleep inertia and may result in decreased performance and vigilance (Caldwell and Caldwell, 2005). In the opposite situation, when soldiers are required to be alert for prolonged periods of time, the use of stimulants may be valuable. The most common stimulant is caffeine and is readily available in military rations. Besides helping prevent sleepiness, caffeine has a positive dose-response effect on cognitive performance, reaction times, and mood (Lieberman et al., 2002; Caldwell and Caldwell, 2005). The fact that caffeine is widely used by many may diminish its stimulant effect on certain severely fatigued individuals who are accustomed to large caffeine doses (Caldwell and Caldwell, 2005). Unfortunately, caffeine does induce some side effects, such as increased heart rate, blood pressure, nervousness, anxiety, restlessness, and reduced fine-motor skills. Additionally, caffeine is a diuretic will increase frequency of urination and potentially increase the risk of dehydration (Caldwell and Caldwell, 2005). However, its positive performance enhancement may overrule these side effects and in fact support its use in critical situations.

The use of amphetamines has also been reported in military operations. Amphetamines are much more efficacious than caffeine on promoting alertness and maintaining cognitive functions but need to be prescribed under medical supervision, which can be problematic in the field. They also lead to more-serious medical conditions, such as palpitations, increased blood pressure, tachycardia, restlessness, and euphoria (Caldwell and Caldwell, 2005). Although amphetamines can be addictive, the length of SUSOPS is not likely to cause such dependence. In the last decade, a drug used in the treatment of narcolepsy has been used by soldiers to enhance alertness during SUSOPS. Modafinil is a stimulant that provides the same positive effects as amphetamines but without most of the side effects. Modafinil presents no risk of dependence and does not affect recovery sleep (Caldwell and Caldwell, 2005). Soldiers can to nap or sleep if they have the opportunity, even if they are still under the effects of the drug. Considering its positive effects and potential undesired side effects, Modafinil seems to be a drug of choice for SUSOPS (Caldwell and Caldwell, 2005).

Regardless of their effects, drugs will never be a substitute to sleep to prevent long term consequences of sleep deprivation on cognitive or physical performances. Regularly scheduled recovery sleep is an absolute necessity for any soldier. Medication such as stimulants can only help sustain alertness for so long before the soldier becomes less battle efficient.

7.11.5 TRANS-MERIDIAN TRAVEL OR "JET LAG"

Rapid movement of troops across multiple time zones will cause shifts in a soldier's internal clock or circadian rhythm. These shifts will cause a desynchronization of the circadian rhythm, which will take time to readjust to the new local environment. During this adjustment period, several physical performance capabilities may be decreased; therefore, some attention should be given to the type of work or missions that soldiers carry out upon arriving in a new theatre of operation. Some of the psychological effects of what is commonly called "jet lag" include sleep disorders, difficulty concentrating, irritability, and distorted estimation of time, space, and distances. Physically, individual may feel light-headed, and experience loss of appetite and gastrointestinal disturbances (Manfredini et al., 1998). The direction of flight is reported to also affect the magnitude of symptoms. Westward flights, which are characterized by a delay in circadian rhythm, generally take less time to adapt or resynchronize than eastward flights, which are characterized by an advance in the body's biological clock. The mean re-entrainment time for westward travel shift rate is 92 minutes/day whereas it is 57 minutes/day for eastward flights (Caldwell and Caldwell, 2005).

7.11.5.1 Effects of Jet Lag on Physical Performance

All physiological systems have a certain cycle that follows the body's circadian rhythm. A desynchronization in the rhythm will disrupt many functions in any given individual. Body temperature, heart rate, blood pressure, gastrointestinal and urinary functions, and ventilation may all be adversely affected by traveling across time zones (Armstrong, 2000; Caldwell and Caldwell, 2005). In turn, optimal physical performance is dependent on most of these systems, so a desynchronization in circadian rhythm is bound to have an impact on one's ability to produce best performances upon arriving in a new environment. Arm strength, sprint times, hand-eye coordination, performances on lifting and carrying tasks, which are all essential to soldiers involved in SUSOPS or combat situations have been reported taking anywhere from 1 to 5 days to reach baseline levels (Armstrong, 2000). Consequently, any air travel involving more than 5 time zones should be planned carefully in advance and countermeasures should be used to ensure that troops are not put in a physically disadvantageous situation.

7.11.5.2 Measures to Prevent or Reduce Jet Lag

The simplest way to try reduce effects of jet lag is to modify sleep patterns to the destination schedule several days in advance, taking in consideration the direction of travel when delaying or advancing sleep times. Unfortunately, this may be very difficult to achieve when troops are deployed rapidly or the schedule pre-travel is out of their control (Manfredini et al., 1998). Ideally, soldiers should have a few days to adapt to the local environment before being tasked on critical missions. During the first few days, individuals should quickly follow the local time cues for their sleep and mealtimes and try to avoid taking long naps. Exposure to bright light and no light at appropriate times is a key concept for rapid adjustment of the circadian rhythm and can be done by having rooms with windows or access to outdoor cues (Waterhouse et al., 2004). Moreover, mild exercise during the early days can help the body's internal clock readjust faster. On the other hand, very-intense exercise may have detrimental effects since it may cause disturbed sleep (Armstrong, 2000).

Although clear scientific relationships have not yet been demonstrated, the composition and timing of meals can help improve adjustment times of trans-meridian travel. Meals high in carbohydrates and low in proteins will help tryptophan uptake, an amino acid that converts to serotonin, by increasing drowsiness. Similarly, meals high in proteins and low in carbohydrates will improve tyrosine uptake and its conversion to adrenaline, thus augmenting arousal level (Manfredini et al., 1998). Timing those meals with their desired effects according to the local schedule has led to positive results on sleep disturbances and subjective feelings of fatigue in military personnel compared with controls (Manfredini et al., 1998). In addition to nutrition, the use of caffeine at appropriate times to enhance alertness will help shift the sleep wake cycle (Armstrong, 2000). The use of chronobiotic drugs that affect biological time structure can also be helpful (Waterhouse et al., 2004). Melatonin, a pineal hormone normally secreted at night, can be administered orally to promote sleepiness. Similar to meal composition, administration of melatonin should obviously follow the direction of travel so morning administration delays the circadian rhythm and evening administration advances it (Manfredini et al., 1998).

In summary, measures to prevent negative effects of jet lag have not all been scientifically validated and may vary from one individual to another. So the safest approach in military operations is to allow for a few days of local "acclimation" before initiating any meaningful operations with new arriving troops.

7.11.6 SUMMARY

Continuous and sustained operations have a direct impact on the soldiers' overall performance capabilities and thus, should be planned and led with the appropriate information and strategies to minimize the adverse effect of such operations on the human body. Included in those strategies are some that would not be desired in normal conditions, such as certain types of medication, but given the circumstances surrounding what the soldiers need to accomplish, would certainly be warranted.

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Appendix 1 – FITNESS TESTS IN NATO

Table A1.1a: Incumbent Testing – UK

Service: RN / **Test Name:** RNFT

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Multi-stage fitness test or 1.5 mile run	All	Annual	20 mins	Yes	Yes	No	Max	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
2001	Gym kit	12 week Remedial trg	No promotion	80%	53%	Yes, 1 hour a week	SofPT, Temeraire

Service: Army / **Test Name:** Personal Fitness Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
1.5 mile run, press ups and sit ups	All aged 17 – 50	Annual	30 mins	Yes	Yes	No	Max	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	Gym kit	Remedial trg and line managers action				Line managers discretion	Maj Danny Bryan, Upavon

Table A1.1a: Incumbent Testing – UK (cont'd)

Service: Army / **Test Name:** Basic Combat Fitness Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
12 km loaded march	All under age 50 (different loads for each branch/trade)	Semi-annual	2 hours (to pass test)	No	No	Yes	Cut score	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	Combat clothing, helmet, weapon and boots	Remedial trg and can be discharge					Maj Danny Bryan, Upavon

Service: RAF / **Test Name:** RAF Fitness Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Multi-stage fitness Test, press ups and sit ups	All under age 50	Annual	20 mins	Yes	Yes	No	Max	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1994	Gym kit	Remedial trg	Direct action on attitude towards fitness	93.9%	85%	No	Andy Reay: 8701277C@ cosford.raf.mod.uk

Table A1.1a: Incumbent Testing – UK (cont'd)

Service: RAF / **Test Name:** RAF Regiment Operational Fitness Assessment

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Loaded march, speed march, single lift, man drag, jerry can carry	All Regt personnel, up to age 50	Annual	2 days	No	No	Yes	Cut score	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
2002	Combat clothing	Remedial trg					Andy Reay: 8701277C@ cosford.raf.mod.uk

Table A1.1b: Incumbent Testing – CANADA

Service: All / **Test Name:** Expres Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
20m shuttle run, push ups, sit ups and hand grip test	All (17 to 60)	Annual	30 mins	Yes	Yes	No	Max	Yes

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1988	Gym kit	3-month Remedial trg and decision after 2nd failure to take 5 common tasks test	No promotion on initial failure Discharge from the service (if fail 5 common tasks)	97%	77%		Pat Gagnon: gagnon.p2@ forces.gc.ca

Table A1.1b: Incumbent Testing – CANADA (cont'd)

Service: Army (Army operational units utilise the LFCPFS instead of the Expres) / **Test Name:** Land Force Command Physical Fitness Standard (LFCPFS)

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
13 km weight-load march Casualty Evacuation Entrenchment Dig	All Land Force (Army) Personnel (17 to 60)	Annual	Weight-load march: must complete 13 km in 2 hours and 26 min 10 minute rest, Casualty Evacuation 100 metres in 60 seconds or less Shovel .486 cubic metres of pea gravel in less than 6 minutes	No	No	Yes	Cut score	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1991	Full Fighting Order (24.5 kg total kit, i.e. weapon, helmet, webbing, and field pack)	Placed in remedial physical fitness training for up to 6 months Includes multiple attempts the MPFS and continue to train for the environmental standard	No sanctions unless failure on MPFS	98%	76%		Pat Gagnon: gagnon.p2@ forces.gc.ca

Table A1.1c: Incumbent Testing – AUSTRIA

Service: Army / **Test Name:** General Conditioning

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
2400 m run on athletics track, and push ups ("pull ups modified" for over 35 as compensation)	All up to age 50 (over 50 suspended until final decision)	Annual	30 mins	Yes	Yes	No		

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	Gym kit				60 – 70%		Robert Enne: Robert.enne@ bmlv.gv.at

Table A1.1d: Incumbent Testing – FINLAND

Service: Army, Navy, Air Force / **Test Name:** Military Personnel Field Duty and Fitness Tests

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Fitness Tests 12 minutes running test or ergometer test Sit-ups, push ups and squats in 60 sec, hand grip and BMI **Field Test** Rifle and pistol shooting tests Orienteering test (5 km) One march test in a year (options 25 km by foot, 30 km by skiing or 80 km by cycling)	All age groups up to 55 years and after voluntary	Annual	**Fitness Tests** Approx 2 hours **Field Test** March limited 6 hours Shooting 4 hours Orienteering limited 1.5 hours	Yes	No	Partly yes	Max	Yes

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1999	**Fitness Tests** Gym kit **Field Tests** Combat clothing Rucksack Weapon	Remedial trg control by fitness officers and occupational health service	No promotions, no participation to battle exercises, no international missions		97%	Yes, 2 hours in a week	Matti Santtila: matti.santtila@mil.fi

Service: Air Force and Navy / **Test Name:** Same as Army

Table A1.1e: Incumbent Testing – NETHERLANDS

Service: All / **Test Name:** CP (Defence Fitness Test)

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
12-minute run Sit-ups Push-ups	All	Annual	30 minutes	Yes	Yes	No	Maximal	No

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1993	Gym kit	Input in sports medical advice team	Yes	90%	70%		Bertil Veenstra BJ.Veenstra2@mindef.nl

Service: Army / **Test Name:** FIT (task-specific fitness test)

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
March Obstacle course Lifting/carrying Speed-march March	All	Annual	± 6 hours	No	No	Yes	Cut-off	Yes

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
2000	Combat clothing	Input in planning of training	No				Bertil Veenstra BJ.Veenstra2@mindef.nl

Table A1.1f: Incumbent Testing – USA

Service: Navy / **Test Name:** Physical Readiness Assessment

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Sit and Reach, curl-ups, push-ups, 1.5 mile walk/run or 500 yard or 450 metre swim or 12 minute work bout on an elliptical trainer or stationary cycle	All (age 16 – 50+)	Semi-annual	45 mins	Yes	Yes	No		

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1981	Gym kit	Remedial trg	3 failures leads to discharge from service			Yes, 3 x 0.5 hours a week, line managers discretion	www.navy-prt.com

Service: USAF / **Test Name:** Physical Fitness Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
1.5 mile run, push ups, sit ups, waist circumference	All							

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
2004							

Table A1.1f: Incumbent Testing – USA (cont'd)

Service: Army / **Test Name:** Army Physical Fitness Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
2 mile run, sit ups, push ups	All	Semi-annual	1 hour	Yes	Yes	No	Max	No

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	PT clothes	Remedial training, no favorable personnel actions and can be discharged.				5 d/wk, 1 hr/d	heather.pouncey@navy.mil lisa.finlayson@navy.mil

Service: Marines / **Test Name:** Physical Fitness Program

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
3 mile run, pull ups (men), flexed arm hang (women), abdominal crunches	All			Yes	Yes	No	Max	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	PT clothes						heather.pouncey@navy.mil lisa.finlayson@navy.mil

Table A1.1g: Incumbent Testing – CZECH REPUBLIC

Service: Czech Republic / **Test Name:** Annual Physical Check-up

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
Sit-ups, push-ups, pull-ups, shuttle run, 4 times 10 m, granate throw, komplex jumping and acrobatic exercise, 2000 m run, 300 m swimming	All up to 50	Annual	1 day	Yes	Yes		Cut scores	

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1985	Gym kit	Remedial trg	No promotion, discharge after 3 years	95%	100%	2 hours twice a week	

Table A1.1h: Incumbent Testing – GEORGIA

Service: Army / **Test Name:** General Conditioning

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
2400 metres run, push ups, pull-ups	All up to age 55	Annual	30 min	No	Yes			

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
2002	Males: combat dress; Females: Gym kit						Liza Goderdzishvili liza.genesis@ access.sanet.ge

Table A1.1i: Incumbent Testing – GERMANY

Service: All / **Test Name:** Physical Fitness Test / PFT

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
4 x 9 m shuttle-run Push ups Sit ups Standing jump Cooper-Test	All up to the age of 39	Annual	2 h	Yes	Yes		Cut scores	No

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
1993	Gym kit		No	Not known	Not known		olivererley@ bundeswehr.org

Service: All / **Test Name:** Allgemeines militärisches Ausdauertraining – Test / AMilA-Test

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
30 min-run Marching	All	Three times per year		Yes	No		Cut scores	No

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	Gym kit for the run and Combat clothing with 10 kg in a back-pack for the marching		No	Not known	Not known		olivererley@ bundeswehr.org

Table A1.1i: Incumbent Testing – GERMANY (cont'd)

Service: All / **Test Name:** Deutsches Sport-abzeichen / DSA

Test Summary	Target Population (Trades and Ages)	Frequency	Test Duration	Age Adjusted	Gender Adjusted	Content-Valid	Maximal Test / Cut Score Test	Predict Task Performance
The participants can choose out of a test-battery consisting in: swimming sprint running long distance running long jump high jump shot put	All	Annual		Yes	Yes		Cut scores	No

Year Introduced	Dress	Remedial Action	Sanctions	Pass Rate	% Taken	Duty Time Ped	POC / Action and Email
	Gym kit and bathing suits		No	Not known	Not known		olivererley@ bundeswehr.org

Table A1.2a: Entry Tests – UK

Service: RN / **Target Population:** All, before entering the RN

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
1.5 mile treadmill run	10% below RN FT	Yes	Yes	No	2002	Gym kit	Civilian

Action on Failures	Number of Attempts	POC / Action and Email
No selection	No limit	SofPT, Temeraire

Service: RAF / **Target Population:** Officers and Airmen Aircrew

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
Multi-stage fitness test	Pass to 10% below RAFFT standards at selection, pass to RAFFT standard on entry	Yes	Yes	No	2006	Gym kit	Military

Action on Failures	Number of Attempts	POC / Action and Email
No selection	2	Andy Reay 8701277C@cosford.raf.mod.uk

Table A1.2a: Entry Tests – UK (cont'd)

Service: RAF / **Target Population:** Airmen

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
1.5 mile treadmill run	10% below RAFFT standard	Yes	Yes	No	2006	Gym kit	Civilian

Action on Failures	Number of Attempts	POC / Action and Email
	No limit	Andy Reay 8701277C@ cosford.raf.mod.uk

Table A1.2b: Entry Tests – CANADA

Service: All / **Target Population:** As of October 2006, the Canadian Forces no longer have an entry test for applicants

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
The Expres test is administered upon arrival in Basic Trg. Unfit individuals are placed under special training program.							

Action on Failures	Number of Attempts	POC / Action and Email
		Pat Gagnon: gagnon.p2@ forces.gc.ca

Table A1.2c: Entry Tests – AUSTRIA

Service: Army / **Target Population:** Applicants

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
All before entering Army (after obliged military service for men)	2400 m run Pull ups modified Push ups Jump & reach Swimming 1 m jump into water	Yes	Yes	No		Gym kit, swim wear	Military

Action on Failures	Number of Attempts	POC / Action and Email
	No limit	Robert Enne: Robert.enne@ bmlv.gv.at

Service: Air Force / **Target Population:** Same as Army, special selection later

Table A1.2d: Entry Tests – CZECH REPUBLIC

Service: Czech Republic / **Target Population:** Applicants

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
All, before entering	Sit-ups, pull-ups, standing broad jump, sitting jack-knife, W170	Yes	Yes	No	2003	Gym kit	Military

Action on Failures	Number of Attempts	POC / Action and Email
No selection	No limit, not sooner than 6 months after failure	www.novakariera.cz

Table A1.2e: Entry Tests – GERMANY

Service: All voluntaries for the military task before entering the Bundeswehr / **Target Population:** Applicants

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
4 x 9 m shuttle-run Push ups Sit ups Standing jump Cooper-Test		Yes	Yes	No		Gym kit	Civilian

Action on Failures	Number of Attempts	POC / Action and Email
No selection	Not known	olivererley@ bundeswehr.org

Table A1.2e: Entry Tests – GERMANY (cont'd)

Service: Instead of the PFT the voluntaries can bring the record for passing the DSA / **Target Population:** Deutsches Sport-abzeichen / DSA

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
The participants can choose out of a test-battery consisting in: swimming sprint running long distance running long jump high jump shot put		Yes	Yes	No		Gym kit and bathing suits	Civilian

Action on Failures	Number of Attempts	POC / Action and Email
	Not known	olivererley@ bundeswehr.org

Table A1.2f: Entry Tests – NETHERLANDS

Service: Army / **Target Population:** Applicants

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
All, before entering the RNLA (except for the ones performing the "field test IOKL")	Anthropometry static strength and cycle ergometry Prediction of performance on military tasks	Norms depending on type of job (4 clusters). ± 50% of the men are fit for "fighting positions"; ± 50% of the women are rejected for all jobs in the RNLA	No	Yes	1996	Gym kit	Military

Action on Failures	Number of Attempts	POC / Action and Email
Training advice for the next try (after 3 or 6 months)	2 per year	Bertil Veenstra BJ.Veenstra2@mindef.nl

Table A1.2f: Entry Tests – NETHERLANDS (cont'd)

Service: Army / **Target Population:** Applicants participating in a high school 'orientation year'.

Test Summary	Test Standard	Age Adjusted	Gender Adjusted	Task-Related	Year Introduced	Dress	Deliverer (Civilian or Military)
16 to 17 years old students who participate in a high school 'orientation year' in preparation of working for the RNLA	1. Running test 2. Lifting / carrying test 3. Marching test	Norms depending on type of job (4 clusters) See attachment	No, except for the running test in the lowest clusters	Yes	2004	Gym kit / combat clothing	Military

Action on Failures	Number of Attempts	POC / Action and Email
Training advice for the next try (after 3 or 6 months)	2 per year	Bertil Veenstra BJ.Veenstra2@mindef.nl

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14. Abstract

With the conclusion of the RSGs 4, 8, and 17, as well as the Workshop on Optimizing the Performance of Women in the Armed Forces of NATO, there remained open questions concerning mission-related testing and training. The Research and Technical Organization (RTO) recognizes the need to address these issues in light of the wide range of missions (coordinating humanitarian relief, coordinating emergency and relief operations in the event of a disaster, both nature and man-made, civil emergency measures, addressing instability caused by regional and ethnic conflicts, defence against terrorism and countering other threats to modern society) and increased deployment of NATO personnel on operations since 1997 (NATO in the 21st Century @ http:www.nato.int/docu/21-cent/html). The revised spectrum of NATO missions requires a new approach to operational physical fitness. Specifically, a new necessity to define, assess, evaluate and optimize physical capability by setting appropriate criteria and methodology was identified by an exploratory team that met in Spain in 2002. As a result of the exploratory meeting, Task Group 019 on Optimizing Operational Physical Fitness was established to determine the requirement for physical fitness for military personnel in order to prepare military personnel for physical task requirements, to prevent physical overburdening, and to reduce injuries. The efforts of RTG-019 Optimizing Operational Physical Fitness will represent the international agreement for evidence-based findings which may provide the basis for policy decision.

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