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STO TECHNICAL REPORT **TR-HFM-229**

Optimizing Hearing Loss Prevention and Treatment, Rehabilitation and Re-Integration of Soldiers with Hearing Impairment

(Optimiser la prévention et le traitement de la perte d'acuité auditive, ainsi que la réadaptation et la réintégration des soldats atteints d'une déficience auditive)

This report documents the findings of Task Group HFM-229 (2012 – 2015), which analyzed the impact of hearing loss prevention, treatment and rehabilitation of soldiers with hearing impairment in the military. It proposes the structure of a database for hearing screening and surveillance of hearing loss developed by this group and indicates fields of possible common research to be performed in the future.

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- 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 Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

AARQ	Agency for Healthcare and Research Quality
AAT	Acute Acoustic Trauma
ABR	Auditory Brainstem Response
ACALOS	Adaptive Categorical Loudness Scaling
ACGIH	American Conference of Governmental Industrial Hygienists
ACT	Air Conduction Threshold
AGC	Automatic Gain Control
AIMS	Adaptive Intelligibility Modification System
ALD	Assistive Listening Device
APHAB	Abbreviated Profile for Hearing Aid Performance
ASSR	Auditory Steady-State Response
b/TBI	blast Traumatic Brain Injury
BAER	Brainstem Auditory Evoked Response
CAP	Compound Action Potential
CAPD	Central Auditory Processing Disorder
CBN	Continuous Band Noise
CHHP	Comprehensive Hearing Health Program
CI	Cochlea Implant
CNNM	Cranial Nerve Neuromodulation
COMEDS	Committee of the Chiefs of Military Medical Services
COSI	Client-Oriented Scale of Improvement
CPT	Continuous Pure Tone
CWN	Continuous White Noise
dB	decibel
DNA	Desoxyribu-Nucleid-Acid
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOEHRS-HC	Defense Occupational and Environmental Health Readiness System for Hearing Conservation
DPOAE	Distortion Product Otoacoustic Emissions
DSOC	Defense Safety Oversight Committee
DTI	Diffusion Tensor Imagery
EEG	Electro Encephalography
ENT	Ear, Nose and Throat
EURO-QOL	European Quality Of Life
FAMAS	Fusil d'Assaut de la Manufacture d’Armes de Saint-Etienne (or “Assault Rifle from the Saint-Etienne Weapon Factory”)
FMRI	Functional Magnetic Resonance Imaging
FY	Fiscal Year
g/d	gramm per deciliter
GAO	Government Accountability Office
GCS	Glascow Coma Scale
GHABP	Glasgow Hearing Aid Benefit Profile

GHSI	Glasgow Health Status Inventory
GP	Gothenburg Profile
GSHI	Glasgow Scale Health Inventory
GST	Glutathione S-Transferases
HA	Hearing Aid
HCE	Hearing Center of Excellence (U.S. Army)
HDDA	Hearing-Dependent Daily Activities
HFM	Human Factors and Medicine (Panel)
HHI	Hearing Handicap Inventory
HINT	Hearing In Noise Test
HLSim	Hearing Loss Simulation System
HQ	HearCom Questionnaire
HUI	Health Utilities Index
Hz	Hertz
I/O	Input/Output
IaDPOAE	Index of abnormal Distortion Products of Otoacoustic Emissions
ICF	International Classification of Functions
IED	Improvised Explosive Device
IHC	Inner Hair Cell
IOI-HA	International Outcome Inventory for Hearing Aids
IOM	Institute of Medicine (United States)
IRES	Indicators for Rehabilitation Status (German questionnaire)
IWN	Intermittent White Noise
kHz	kilohertz
KQ	Key Question
MCL	Most Comfortable Level
MEG	Magneto Encephalography
MEMS	Multi-scale Electro-Mechanical Simulation
MP3	MPEG-1 Audio Layer-3 (personal music player)
MRI	Magnetic Resonance Imaging
MRT	Modified Rhyme Test
mTBI	mild Traumatic Brain Injury
NAD	Nothing Abnormal Detected
NATO	North Atlantic Treaty Organization
NCIQ	Nijmegen Cochlear Implant Questionnaire
NHP	Nottingham Health Profile
NIH	National Institutes of Health
NIHL	Noise-Induced Hearing Loss
OAE	Otoacoustic Emissions
OHC	Outer Hair Cell
OSHA	Occupation Safety and Health Administration
PAGO	Periodiek Bedrijfsgeneeskundig Onderzoek (Periodic Occupational Health Examinations; Dutch questionnaire for work-related health assessment)
PSNHL	Progressive Sensorineural Hearing Loss
PTA	Pure Tone Average
PTS	Permanent Threshold Shift
PTSD	Post-Traumatic Stress Disorder

QoL	Quality of Life
RIE	Risk Inventory and Evaluation
RMS	Root Mean Square
ROS	Reactive Oxygen Species
RTG	Research Task Group
rTMS	repetitive Transcranial Magnetic Stimulation
RTO	Research and Technology Organisation
SADL	Satisfaction with Amplification in Daily Life
SD	Standard Deviation
SF	Short Form
SII	Speech Intelligibility Index
SNHL	Sensorineural Hearing Loss
SNR	Speech-to-Noise Ratio
SPL	Sound Pressure Level
SPRINT	Speech Recognition In Noise Test
SRT	Speech Reception Threshold
SSQ	Speech, Spatial, Qualities
STI	Speech Transmission Index
STO	Science and Technology Organization
TBI	Traumatic Brain Injury
TDCS	Transcranial Direct Current Stimulation
TEOAE	Transitory Evoked Otoacoustic Emissions
THI	Tinnitus Handicap Inventory
TM	Tympanic Membrane
TTS	Temporary Threshold Shift
UCL	Uncomfortable Level
U.S./USA	United States of America
VA	Veterans Affairs
VEMP	Vestibulo Electoro-Myogenic Potential
WHO	World Health Organisation
WHO-DAS	World Health Organization Disability Assessment Schedule

Glossary of Audiological Testing

Pure-Tone Audiometry

Pure-tone audiometry is the most commonly used test to measure an individual's hearing. Pure-tone audiometry is used to determine the presence or absence of hearing loss, and defines the faintest tones a person can hear at selected pitches (frequencies), across the auditory spectrum from low to high. If hearing loss is present, a provider can determine the type and degree of the hearing loss. During this test, the subject is seated in a sound-proof room with headphones on, or in, your ears so that functional information for each individual ear can be obtained. A bone conduction oscillator can be placed on the test subject's head to determine a bone conducted auditory threshold which may be different than an air conducted threshold if there are problems with the outer or middle ear function. The audiologist or technician sits outside of the sound-proof room and instructing the test subject and manipulating the audiometry equipment to provide an accurate representation of the subjects hearing.

During this testing, the Audiologist will present tones of different pitches and loudness levels. The subject will be asked to respond to those tones by pushing a button or raising a hand. Responses are recorded on a chart or form called an audiogram. The audiogram is a graphic representation of the softest level for different pitches that detected by each ear. A pure tone audiometry test will take approximately 20 – 25 minutes to complete. Although this test provides a great overview of a person's ability to hear and respond to simple sounds in an idealized environment, the ability to hear and comprehend complex sounds such as speech requires more specific testing (e.g., speech audiometry).

Speech Audiometry

During speech audiometry testing, subjects are seated in a soundproof room with headphones on, or in, their ears. Speech audiometry most commonly consists of two different speech tests:

Speech Reception Threshold: This test determines the softest level at which the testee just begins to recognize speech. Audiologists determine the Speech Reception Threshold by asking the subject to repeat a list of easy-to-distinguish, two-syllable words that have equal stress on each syllable (e.g., baseball, cowboy, railroad, airplane). The audiologist will also capture the softest level at which the subject is able to repeat common words.

Speech Discrimination: This test assesses how well subjects understand one-syllable words with vowels and consonants that are distributed similarly to those words used in ordinary conversation (e.g., jar, this, box). For this test, the Audiologist plays word lists through the headphones at a decibel level louder than the previously determined speech reception threshold. This ensures there is no problem with the volume of the speech. In this way, the audiologist is able to measure the ability to understand speech.

Speech audiometry testing typically takes 5 –10 minutes to complete. In some cases, additional speech testing may be indicated. For example, tests aimed at identifying the ability to understand words or phrases in the presence of background noise may be employed.

Auditory Brainstem Response Evaluations

Auditory Brainstem Response (ABR) or Brainstem Auditory Evoked Response (BAER) testing is a measure of sensorineural hearing loss. In this test, recording electrodes are placed on the scalp and on each earlobe. Clicking noises are then sent through earphones. The electrodes monitor brain responses to the clicking noises and record the response on a graph. The Audiologist or Otolaryngologist then analyzes recordings of electric potentials generated by the auditory neurological pathway. The ABR or BAER can be used for two purposes:

- Assessment of hearing thresholds (usually reserved for specific populations and situations when behavioral audiometry cannot be obtained); and
- Assessment of the functional status of central neurological auditory pathways.

This objective testing is useful for site of lesion determination for central nervous system tumors or focal trauma. This procedure is performed while the patient is lying down in a soundproof room and typically takes between 60 – 120 minutes to complete. The patient is required to be still and quiet throughout the test.

Otoacoustic Emission Testing

Otoacoustic Emissions (OAE) testing objectively measures sensory outer hair cell function in the inner ear. An emission is a sound generated within the normal cochlea in response to stimulation. The primary purpose of an OAE test is to determine cochlear status, specifically outer hair cell function. This information can be used to:

- Screen hearing (particularly in neonates, infants, or individuals with developmental disabilities);
- Partially estimate hearing sensitivity within a limited range;
- Differentiate between the sensory and neural components of sensorineural hearing loss; and
- Test for functional (feigned) hearing loss.

The information from an OAE test can be obtained from patients who are sleeping or even comatose because no behavioral response is required. OAE testing is often used as a screening tool (e.g., newborn hearing screening) to determine the presence or absence of cochlear function, although analysis can be performed for individual cochlear frequency regions. OAEs cannot be used to fully describe an individual's auditory thresholds, but they can help question or validate other threshold measures, or they can add to site of the lesion determination when imaging is unavailable, delayed or contraindicated. The OAE test typically takes several minutes, but can take as long as 30 minutes. Abnormal OAE testing can be the result of blockage in the outer ear canal, presence of middle-ear fluid or other middle-ear pathology, and hearing loss which can be due to damage to the outer hair cells in the cochlea when other types of hearing loss are not present.

Auditory Steady-State Response

Like the ABR and OAE tests, the Auditory Steady-State Response (ASSR) test does not require active patient participation. It is often employed when ABR threshold testing or OAE testing is abnormal or inconclusive and when behavioral test measures cannot be used, or when they fail to produce reliable results. ASSR results are obtained by measuring brain activity while the person listens to tones of varying pitch and loudness. The brain activity is recorded using electrodes taped on the forehead and behind each ear. The use of electrodes eliminates the need for active participation of the patient. The results are detected objectively using statistical formulas that determine the presence or absence of a true brain response. ASSR testing provides an accurate estimate of the pure-tone audiogram.

Tests of Middle-Ear Function

For a complete picture of the auditory system, it is often helpful to take measurements of how well the middle ear functions. These measurements include tympanometry, acoustic reflex measures, and static acoustic measures. This type of testing is particularly important in preschool children (ages 3 – 5), for whom hearing loss is more often associated with middle ear disease, but is also relevant to assess the aeration system of the ear in with chronic otitis media and in trauma scenarios.

Tympanometry tests the compliance of the tympanic membrane. It may show abnormality in the presence of middle ear fluid, tympanic membrane perforation, or when foreign bodies, blood or wax block the ear canal. Tympanometry pushes air pressure into the ear canal causing the tympanic membrane to move back and forth measuring the mobility of the eardrum. Graphs are created, called tympanograms. Different graphical representations infer middle ear stiffness, tympanic membrane perforation, middle ear fluid, or malpositioned test probe, sustained negative pressure within the middle ear, and exaggerated mobility of the tympanic membrane.

Acoustic reflex testing assesses the ear's natural and involuntary reflex to lower the transfer of very loud and potentially damaging energy into the inner ear. The tensor tympani and stapedial muscles in the middle ear contract in response to loud sounds stiffening the ossicular chain. Testing is conducted like tympanometry, but in addition to using the pressurized probe, the audiologist delivers a sound of about 80 dB to see if the muscles in the middle ear contract to decrease the volume sent to the inner ear. The Audiologist keeps increasing or decreasing the volume to find the decibel level at which this reflex occurs. The loudness level at which the acoustic reflex occurs – or the absence of the acoustic reflex – gives information to the Audiologist about the function of this protective reflex. Conductive and mixed types of hearing loss as well as brainstem lesions or significant sensorineural hearing losses will disrupt the reflex.

Static acoustic impedance measures the physical volume of air in the ear canal. Variations in ear canal volume can help identify perforations of the tympanic membrane, and validate patency of ventilation tubes when the probe is placed correctly.

Following testing, providers review each component of the audiologic evaluation which offers a profile of hearing abilities and needs. Additional specialized testing may be indicated and recommended based on the initial test results.

Questionnaires/Inventories

Questionnaire contains a standardized set of questions to subjective aspects of hearing, which otherwise are not measurable. The questionnaires need to be validated before regular use. They can be classified as general, specific, disease specific. Most questionnaires are language-specific, but some are validated in several languages and can be used for international studies.

Hearing Fatigue or Hearing Effort

Hearing in noisy conditions requires more concentration to understand the words. This effort is higher in hearing impaired or very noisy conditions.

Foreword

Hearing is a critical sense that allows Military members to communicate, and hearing facilitates the effective performance of their duties. Auditory communication is the most effective form of information transfer. Oral communication is the fastest, surest and most effective way to communicate. Unfortunately, the noisy Military environment is not always conducive to troop communication and can be very difficult to overcome, i.e., very noisy environments with simultaneous speakers, multiple concurrent actions, and significant cognitive loads placed on soldiers who may be otherwise sleep deprived, fatigued, anxious and operating in environments where other sensory cues are subdued are all potential distractors from good communication.

Hearing is necessary to collect, distinguish and locate critical information on a mission. Therefore the programmatic application of hearing conservation is essential to:

- Mitigate noise when possible;
- Protect against the noise threat through education, training and appropriate hearing protection;
- Ensure the availability of the most appropriate communication options to optimize hearing as well as to prevent hearing loss;
- Identify those soldiers at greatest risk for hearing loss; and
- Identify early shifts in hearing so that intervention and rehabilitation can proceed as early as possible.

As evidence accumulates suggesting that the sense of hearing is a vital asset that facilitates Service member's function, the need to focus on hearing, hearing readiness and hearing fitness for duty becomes more apparent. Further research will be necessary to optimize hearing performance, either through technical means or by auditory training. As many soldiers are highly trained and experienced specialists in their fields, it is important to support their continued service and maintain the lessons learned through their experiences as well as to prevent the costly process of retraining, replacing, and recruiting others to take their places. Therefore, it is also important to rehabilitate hearing loss and auditory injuries as a way to optimize manpower management and maximize the overall effectiveness of the military strength.

Aside from the awareness of the high-risk noise environment, or the important role that communication and hearing play in Military survivability and job performance, it is also necessary to stress that noise is ubiquitous outside of Military arenas, and, that hearing is one of the most important aspects of educational and occupational pursuits, a significant contributor to social and emotional interaction, and a substantial effector of quality of life. Hearing loss that occurs outside of Military settings effects Military performance and, hearing loss that happens as a result of Military service impacts overall and life-long quality of life.

Historically, hearing loss and tinnitus are the most prevalent disabilities in Veterans of Military service not only during eras of conflict, but during peacetime as well. These facts serve as the driving force of the STO HFM-229 Task Group effort. Enacting the concept of an international standardized database as the foundation of NATO-wide hearing health efforts will help to expand the common knowledge base, improve prevention programs and rehabilitative efforts, and define hearing readiness criteria. It will enable the comparison of current and future hearing conservation and care practices and promote a unified focus and effort to combine individual forces towards managing and improving the growing "workload" of improving hearing outcomes. In this time of limited resources collaborative work, to successfully implement common surveillance strategies and readiness programs stands out as the most efficient way to optimize hearing outcomes that will in turn improve professional performance in the Military.

Signed by COMEDS or other NATO authorities

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Optimizing Hearing Loss Prevention and Treatment, Rehabilitation and Re-Integration of Soldiers with Hearing Impairment

(STO-TR-HFM-229)

Executive Summary

Hearing is critical to Military performance. This is particularly true for Service members that have to rely on acoustic communication even in high-noise environments. Hearing is also a key survival sense that detects and identifies important and potentially hazardous information in combat and occupational situations thereby making hearing an important security factor. The ability to detect, identify and localize crucial sounds, and the ability to maintain spatial awareness on the battlefield and to control one's own noise production, can be vital to troop's stealth and survivability. Therefore, Military leadership must take proactive steps to ensure the hearing health, readiness and hearing protection for Service members that will in turn optimize troop performance and minimize injury risk and mishap.

A critical component in the prevention of hearing loss and promotion of hearing health and readiness among Service members is the establishment of a comprehensive operational hearing database that contains vital information on the hearing abilities, operational exposures, and hearing loss risk mitigation strategies being employed for all Military personnel. This database can play a critical role in monitoring and evaluating the auditory fitness-for-duty of service members, and in ensuring that hearing conservation strategies are being employed to mitigate the risk of permanent threshold shift for those Service members who are exposed to the highest levels of hazardous noise. At the same time, a comprehensive database of hearing health, noise exposures, and hearing conservation strategies can play an absolutely essential role in conducting epidemiological analyses to evaluate the effectiveness of hearing conservation programs, hearing protection systems, and auditory rehabilitation strategies.

At the present time, some NATO Nations have established databases to monitor hearing health in their Military populations. However, these databases differ substantially in terms of the type of information they contain. In order to provide the greatest benefit to all NATO Nations, it would be ideal if each of these national databases contained at least a subset of common data fields that could be used to make comparisons across the noise exposed populations of the different countries. The establishment of these common data fields will depend on the establishment of consistent procedures for conducting periodic hearing surveillance screenings and, when necessary, diagnostic exams. It will also depend on establishing standardization by recommending best practices for the data content, for hearing and occupational noise questionnaires, and for the coding of Military occupational and exposure information and hearing conservation and hearing rehabilitation strategies.

If a common NATO-wide standard for databasing of hearing conservation information can be established, it would become the cornerstone of a comprehensive multi-national hearing health effort founded on regular hearing surveillance programs, the development of common definitions of hearing requirements specific to various Military occupations, the establishment of standards for alerting systems and other auditory alarms, and the validation of hearing conservation, diagnosis, treatment and rehabilitation methodologies. The database would also facilitate ongoing epidemiological analyses to identify best practices related to hearing health education and protection. It would help identify weapon systems, practices, and personal protective equipment that result in an elevated risk of hearing loss and acoustic trauma and allow proactive

action to mitigate these risks. The combined action and collaboration of NATO Nations will enable achievement of these aims in a reasonable time frame, and with limited resources.

The report is divided into four major sections:

1) An overview of the current state of hearing health in the Militaries of NATO Nations;
2) A review of best practices for hearing screening, surveillance, and diagnostics;
3) Recommendations for the structure of a comprehensive international hearing database; and
4) A review of areas that could benefit from future collaborative research.

Optimiser la prévention et le traitement de la perte d'acuité auditive, ainsi que la réadaptation et la réintégration des soldats atteints d'une déficience auditive

(STO-TR-HFM-229)

Synthèse

Dans les forces armées, l'audition est essentielle à l'exécution des missions, en particulier pour les membres des forces qui sont dépendants des communications acoustiques, notamment dans un environnement très bruyant. L'audition est également un sens fondamental à la survie, qui détecte et identifie des informations importantes et de danger potentiel en situation de combat ou d'intervention. L'audition constitue donc un facteur déterminant de la sécurité. La capacité à détecter, identifier et localiser des sons cruciaux, ainsi que la capacité à conserver une bonne connaissance spatiale du champ de bataille et à maîtriser le bruit que l'on fait, peut être primordial pour la furtivité et la survie des troupes. Les chefs militaires doivent par conséquent prendre des mesures préventives pour garantir la santé auditive, l'état de préparation et la protection de l'audition des membres des forces, ce qui optimisera les performances des troupes et minimisera le risque de blessure et d'accident.

Il est donc fondamental, pour prévenir la perte d'acuité auditive et promouvoir la santé et la préparation auditive auprès des membres des forces, d'établir une base de données opérationnelles complète sur l'audition, contenant des informations vitales sur les capacités auditives, les expositions en opération et les stratégies d'atténuation du risque de perte auditive employées pour tout le personnel militaire. Cette base de données peut jouer un rôle capital dans le suivi et l'évaluation de l'aptitude auditive des membres des forces, tout comme dans la vérification de l'application de stratégies de préservation de l'ouïe devant atténuer le risque d'une dégradation permanente du seuil d'audition des militaires exposés aux niveaux les plus élevés de bruit dangereux. Parallèlement, une base de données complète de la santé auditive, des expositions au bruit et des stratégies de préservation de l'ouïe peut jouer un rôle primordial dans la réalisation d'analyses épidémiologiques évaluant l'efficacité des programmes de préservation de l'ouïe, des systèmes de protection auditive et des stratégies de réadaptation de l'ouïe.

Aujourd'hui, quelques nations de l'OTAN ont déjà créé des bases de données pour suivre la santé auditive de leur population militaire. Toutefois, ces bases de données diffèrent sensiblement du point de vue de leur contenu. Afin que tous les pays de l'OTAN en tirent le meilleur parti, chacune de ces bases de données nationales devrait dans l'idéal contenir au moins un sous-ensemble commun de types de données, ce qui permettrait d'établir des comparaisons entre les populations exposées au bruit des différents pays. La mise en place de ces types de données communs dépendra de la mise en place de procédures cohérentes permettant un suivi régulier de l'audition et, si nécessaire, des examens diagnostiques. Elle dépendra également d'une certaine normalisation, qui passera par la recommandation des meilleures pratiques pour le recueil de données, les questionnaires sur l'audition et sur l'exposition aux bruits professionnels, le codage des informations d'exposition et d'activité militaire et les stratégies de préservation et de réadaptation de l'ouïe.

S'il est possible d'établir une norme commune à l'OTAN pour les informations de préservation de l'ouïe, celle-ci deviendra la pierre angulaire de tous les efforts multinationaux de santé auditive basés sur des programmes de suivi régulier de l'audition, le développement de définitions communes de l'acuité auditive nécessaire à la conduite de diverses activités militaires, l'élaboration de normes pour les systèmes d'alerte et autres types d'alarmes sonores et la validation des méthodologies de préservation, de diagnostic, de traitement et de réadaptation de l'ouïe. La base de données faciliterait également les analyses épidémiologiques en cours qui cherchent à identifier les meilleures pratiques d'éducation et de protection de la santé auditive. Elle aiderait à identifier les systèmes d'armes, les exercices et l'équipement personnel de protection qui présentent un risque élevé de perte d'audition et de traumatisme acoustique et permettrait de mettre en place des mesures préventives pour atténuer ces risques. L'action combinée et la collaboration des nations de l'OTAN permettront d'atteindre ces objectifs dans un délai raisonnable et avec des ressources limitées.

Le rapport est divisé en quatre grandes parties :

1) Une présentation générale de l'état actuel de la santé auditive des militaires des pays de l'OTAN ;
2) Une revue des meilleures pratiques d'échantillonage, de suivi et de diagnostic de l'audition dans les forces ;
3) Des recommandations concernant la structure d'une base de données internationale complète sur l'audition ; et
4) Un examen des domaines qui pourraient tirer parti de futures recherches en collaboration.

Chapter 1 – INTRODUCTION

Hearing is a critical sense, crucial to Military job performance. To effectively operate in Military surroundings, it is essential to be able to communicate in noisy surroundings, to detect and identify critical noises and to ensure stealth so as to avoid being detected. Recent studies have identified hearing as a critical measure of Military task performance which can be related to soldier survival, the quality and timeliness of decisions made by the troops, and the efficiency and effectiveness of the transfer of information for operative command and control. In NATO Alliances and coalition work forces, communication is further handicapped by non-native speakers, and non-native listeners exchanging information in the English language. There is a high risk of miscommunication and misunderstanding posing a challenge to enhance the communication and effectiveness of future international missions.

Hearing loss is a particularly salient problem in Service member's lives, endangering their fitness-for-duty, their emotional well-being, the ability to cope with post-traumatic stress and the overall quality of life. Modern Militaries have highly trained and experienced specialists which cannot easily or cheaply be replaced without impacting the mission. Modern societies have acknowledged a responsibility to care for troops, whose lives and health are put at risk due to mission requirements. From an ethical point of view, Military members that support and defend our Nations deserve the best options and efforts to preserve their health and function. Our collective Nations also owe an inestimable debt to those that have been injured in the course of protecting and sustaining our freedoms. The best rehabilitation and restorative services should be afforded those members if and when their health is compromised. The ability to return to duty is one of the best benchmarks for successful rehabilitation.

Hearing loss is a common problem that affects up to half of the population in advanced ages. In the Military, noise, munitions, weapon systems, transport vehicles, explosions and headsets are known risk factors for hearing loss. Although hearing protection devices are available, many are not ideal as they degrade hearing, interfere with communication or hearing in noisy surroundings (i.e., battlefield), reduce situational awareness, and are not easily applied unless the noise threat is predicted. The common use of personal headphones, power tools, attendance at sporting venues, and many hobbies render additional risk and explain why hearing loss is quickly becoming a population health risk even outside of the Military.

On the other hand, tactical communication and protective devices are available which are protective and may offer functions superior to normal hearing. Simple foam ear plugs, level dependent hearing protection, and blast protective devices are among an assortment of tiered options for hearing protection, any one of which may be the ideal or most practical solution for the various hearing and prevention demands and environments that are encountered in Military service. Collecting data related to how these devices impact the effectiveness, safety, and retention of troops on a broad scale is important to leadership decision-making. Large-scale longitudinal observations are often absent, but could impact important decisions when factoring cost of protective equipment and return on investment.

Sometimes hearing function recovers spontaneously after noise-free periods. When it doesn't, restoration of hearing in cases of acute losses can be facilitated when treated with oral or injectable therapies in a timely fashion. Successful rehabilitation with various techniques and devices including hearing aids and implantable devices (middle ear, bone conduction, and cochlear implants for more severe to profound hearing losses) is often beneficial when hearing loss persists. This improves hearing function for impaired individuals in most cases and offers the option for many to return to duty. Currently, successful rehabilitation outcomes are measured by pure tone average, and speech discrimination testing, however, more sensitive and more functional outcome assessments are necessary. Audiometry may be insensitive to cochlear damage on a cellular and molecular level missing sub-clinical injury that may cause sensitivity to, or lower resistance to subsequent hazardous noise exposures, and which may cause unappreciated deficits in hearing function that aren't appreciated in an isolated audiometry test booth condition. Tests correlating the ability to perform one's duties with hearing impairment, or with rehabilitation devices, tests showing compatibility of devices with other protective equipment and communication systems, and tests that documents tactical communication and protective system's ability to optimize performance parameters for professional requirements are needed. Prioritization of soldier's operational hearing capabilities needs to be shared with research teams, prevention and communication industries, and rehabilitation device manufacturers to develop and improve prevention options, hearing aids, and hearing implants. To aid in developing these performance requirements, the Military's primary interests lie in identifying the criteria for auditory readiness and fitness for duty, in other words, in defining the essential hearing performance needs for various Military career fields.

Protection programs for Military members focused on preventing hearing loss and preserving residual hearing function are indispensable. To effectively address risk areas, and the soldiers at risk, (understanding that off duty risks place every Service member at risk, and loss of hearing from off duty causes effects Military members on the job as well), a comprehensive surveillance system and database of hearing ability and hearing loss is necessary. It is the task of the employer to protect their employees from risks that may derive from miscommunication of employees with hearing loss. This is particularly true in the Military, where survival of the whole team relies on adequate hearing abilities of each individual. This stresses the importance of establishing regular hearing screenings to identify soldiers that cannot fulfill hearing readiness criteria. Early detection also enables the Military to start an early rehabilitation processes for the affected soldiers with hearing loss. Early intervention and rehabilitation will return the soldier to the "fight" quicker, reduce overall loss, and allow for a longer and more productive career.

In the following chapters, a concept for a comprehensive hearing database is detailed. The design reflects an understanding of current limitations on resources and an attempt to build in efficiencies. The majority of the suggested database is laid out to enable international compatibility and comparability, and in a manner by which both subjective and objective data can be entered automatically without the need for specialty providers or technical experts. Additionally, self-automated hearing screening options are time limited to less than 30 minutes to decrease time demands in a time constrained Military environment. It was agreed that performing the tests in-theater, as near to the injury or exposure as possible, is advantageous over delaying diagnosis until troops can be transferred to centralized screening posts. Within this model, all normal hearing soldiers can be checked and cleared, easing stress on the evacuation and health systems within the Military. By setting the non-pass criteria appropriately, soldiers at high risk for, or soldiers with hearing loss would be transferred for further examination.

In addition, this concept calls for standardized data collection lending to better surveillance for soldiers who share a high risk of noise exposure and potential for subsequent hearing impairment as well as for those who have already suffered hearing losses. Surveillance and rehabilitation outcomes data standardized in this way across NATO Nations could help identify best prevention and rehabilitation practices which could then be adopted across NATO prevention and care systems. This database concept minimizes the effort of managing the data, by providing the relevant classification items.

The design of the database includes a focus on improving the following areas:

- Hearing prevention and education;
- Auditory fitness standards;
- Hearing rehabilitation techniques;
- Hearing loss risk identification; and
- Return-to-duty after rehabilitation.

The data available in the database will improve epidemiological understanding, and build foundational outcomes knowledge for the above-mentioned focus areas. It will serve as the default database for further research in these areas. As all tests and data fields support all NATO languages, data collected from each country can be compared and used in comparison research. This means, that the efforts to improve hearing abilities, hearing restoration, hearing prevention or auditory fitness can be shared by NATO members.

NATO members can transfer the concept of the proposed database into almost any other database in use. The use of automated systems for data input and data transfer is recommended. Furthermore, identifying a central location for data analysis in each country and to provide a hearing health report annually is recommended. The structure of the database is modular and can be expanded to include other specialties that would offer the ability to correlate hearing injury with other comorbid states. Our position strongly recommends adopting such a database concept as broadly as practicable because such a comprehensive hearing health and readiness assessment tool and reporting mechanism will provide essential information to minimize the hearing health risk for each soldier, as well as the enterprise risk to our Military forces.

Chapter 2 – HEARING LOSS IN THE MILITARY

2.1 PREVALENCE OF HEARING LOSS IN THE MILITARY

It is well established that auditory system injuries are highly prevalent in Service members and Veterans. Exposure to high-level sustained and explosive noise is a threat to the hearing health and fitness for duty of Service members in theatre and in garrison. Improvised Explosive Devices (IEDs) have been the signature weapon of war against U.S. forces in the wars in Afghanistan and Iraq, and auditory dysfunction due to blast is currently among the most frequent service-connected disabilities in Veterans. Auditory system injuries including tinnitus, hearing losses, central auditory processing deficits, as well as vestibular impairment are among the most prevalent sequelae of blast injury.

The U.S. Institute of Medicine reported on the long-term health effects of exposure to blast on organ systems, to include auditory and vestibular systems. The review was instrumental in identifying research gaps to better understand the long-term consequences of blast exposure on auditory thresholds, tympanic membrane, balance dysfunction and vertigo, tinnitus, and central auditory processing.

2.1.1 Scope of Auditory System Injury

Hearing impairment is the most frequent sensory deficit in human populations, affecting more than 360 million people in the world. Noise-Induced Hearing Loss (NIHL) is second to presbycusis as the leading cause of adult-onset hearing loss. NIHL has been one of the most prevalent occupational health concerns in the United States over the last 25 years as reported by the United States Bureau of Labor Statistics.

Ten to fifteen percent of adults in the United States have hearing loss and approximately 30 million U.S. workers are exposed to hazardous noise levels with an additional nine million exposed to ototoxic chemicals. The National Institutes of Health (NIH) estimated that 22.7 million adult Americans stated they were affected by tinnitus for more than three months during 2009. According to some studies, approximately 80% of personnel who show NIHL may also have tinnitus [2].

The risk of NIHL in Military communities is believed to be even higher. When assessing severe hearing injury among Veterans, all Veterans were 30% more likely to have significant NIHL than demographically and occupationally matched non-Veteran controls. Veterans who served after September 2001 were four times more likely than non-Veterans to have significant NIHL (adjusted prevalence ratio = 4.0). According to the United States Department of Veterans Affairs (VA), in FY 2013 auditory injuries were the two most prevalent disabilities in Veterans with 2.12 million Veterans receiving compensation for auditory body system conditions. Most of these, 1,121,709 suffered from tinnitus and 854,855 from hearing loss. Among Veterans of current combat operations (2001 – 2013) there have been over 465,000 with hearing loss and tinnitus disabilities making a majority of the nearly 765,000 U.S. troops that had hearing loss during that time period. Hearing Loss and tinnitus have been the most prevalent disabilities of U.S. Veterans across all eras of war [9].

Trends show that the incidence of tinnitus and hearing loss claims are increasing 13 – 18 % annually [3]. Data from the Defense Occupational and Environmental Health Readiness System for Hearing Conservation (DOEHRS-HC) documents the annual rate of significant auditory threshold shifts to be between 11 – 14 % of the total U.S. forces between 2004 and 2012, with unique incidents of permanent threshold shift rates at 1 – 2 % per year. The best methods of protection against hearing injuries provide helpful but inadequate protection against many extreme, and even some day-to-day noise environments to which Military Service members are routinely exposed. Weapons systems such as jet engines, ship operations, tracked and transport vehicles, high-caliber weaponry, and the impulse blast effects of IEDs can overpower current protective technologies. Scherer (2009) [60] reported that blast exposures and subsequent mild Traumatic Brain Injuries (mTBI) account for 85% of all battlefield injuries. Nearly one third (32%) of U.S. Service members evacuated for combat wounds to the Walter Reed Army Medical Center since January 2003 have been diagnosed with TBI. Some newer, non-lethal weapons technologies capitalize on intense acoustic energy effects to inhibit communication, distort situational awareness, and temporarily paralyze a human operator's functional capabilities.

The ear is typically one of the first organs to sustain damage from a blast event, and is the organ most susceptible to primary blast injury. Injury to the external ear is possible from secondary, tertiary, and quaternary effects of blast exposure, but primary blast injury to the middle and inner ear is much more common and likely to affect auditory function. Traditionally, clinical attention has focused on Tympanic Membrane (TM) perforations, hearing loss, and tinnitus complaints as the primary manifestations of auditory dysfunction after blast exposure. However, those clinical outcomes do not adequately capture the array of auditory dysfunction that may be associated with acute trauma from blast. Normal auditory function requires an intact ear but also relies on the complex signal transduction, transmission, and processing mechanisms that are involved in central translation and integration of sounds. Blast may affect microcirculation, apoptosis, shearing of neural networks, and other mechanisms which may also be associated with additional implications for the auditory system and the processing of auditory information, especially in complex environments.

The TM is extremely sensitive to pressure (its primary function is to sense sound wave vibrations), so it is highly susceptible to blast overpressure. Perforation of the TM is the most common form of injury to the middle ear associated with blast exposure [10]. It is the most common visible primary blast injury in the current conflicts in Afghanistan and Iraq occurring in 10 – 35 % of Service members wounded by combat explosions. The average surface area of TM perforations involved ranges from 35 – 41 % with approximately 83% experiencing hearing loss and tinnitus [13]. Spontaneous healing occurs in less than half of these resulting in surgical intervention in 52%. Long-term hearing loss impacts the ability to continue Military service. Sixty-percent of blast-exposed Military personnel seen between 2003 and 2005 at the Walter Reed Army Medical Center Audiology Clinic sustained hearing loss, with nearly 50% having a sensorineural (permanent) component. Thirty-two percent had tympanic membrane perforations, 49% manifested residual tinnitus, with otalgia in 26% and dizziness in 15%.

Some cases of TM perforation close spontaneously over weeks to months after blast exposure. Damage to the ossicular chain is less common than damage to the TM. Patients who have sustained damage to the middle ear from primary blast injury may present with ear ache and conductive hearing loss, which may be temporary and resolve with the healing of the TM [10]. It is possible that cholesteatoma and infection can develop from a primary blast injury to the middle ear and potentially lead to erosion and destruction of important structures of the middle ear, temporal bone, and skull base [10]. Primary blast injuries to the inner ear can also involve and disrupt the vestibular apparatus and cochlea, and can result in sensorineural hearing loss and vertigo due to temporary or permanent damage to sensory hair cells. These delicate sensory structures responsible for amplification of sound and its transduction to the auditory nerve and central auditory nervous system can also be damaged by second order effects such as metabolic compromise, infection, and inflammation, or, by medications used to treat infection and pain.

Of note, studies documenting spontaneous closure rates after blast-related TM perforation reflect lower spontaneous TM healing rates (approximately 50%) compared to non-blast controls (approximately 80%) [13]. Unpublished civilian reports of poor spontaneous healing after blast injury to the TM (approx. 50%) sustained during the 2013 Boston Marathon bombing are consistent with rates reported for spontaneous healing of Military TM perforations [61]. This may be the consequence of methodology and triage artifact because these injuries are less pressing in a mass casualty situation, and often times more pressing comorbid injuries receive focused immediate attention. Less pressing injury is deferred and small TM perforations which have higher propensity to close spontaneously could potentially heal before a focused evaluation of the ear and hearing can occur as a non-urgent outpatient. This may negatively skew spontaneous TM closure rates in blast studies.

Damage to sensory organs and exposure to IEDs are highly associated with Traumatic Brain Injury (TBI). Dizziness is nearly a universal symptom of TBI. Blast overpressure can disrupt mechanical transduction of sound energy and the sensory processing of sound, by impacting the ear canal with blood, debris, or foreign bodies; causing fluid or blood to accumulate behind the ear drum; tearing the eardrum; separating the ossicles; causing leakage of perilymph; and by transmitting injury, infection, and related inflammation to important neurological sensors, cranial nerves, and central auditory processing areas [13], [14], [15]. Resulting symptoms of pain, hearing loss, tinnitus, dizziness and/or disorientation can threaten personal and unit effectiveness on the battlefield. Injuries may be transient, but most will cause some degree of permanent disability [1], [12]. The combination of hearing loss, tinnitus, and altered balance function in polytrauma patients with multi-sensory deficits, TBI, and post-traumatic stress symptoms are especially challenging [24], [25].

Another challenge when considering the epidemiology of NIHL in the Military is that hearing is an invisible, insidious, cumulative injury that generally accumulates severity slowly over time. Individuals may compensate for NIHL until it becomes obvious to the individual, their co-workers, family, or friends. Surveillance programs can catch subtle incremental loss. Even obvious sudden NIHL may evade detection if more significant trauma care takes precedence and the hearing exam is delayed. Because many acute injuries to the auditory system appear to recover to various degrees, incremental improvement may mask subtle, but significant changes from a patient's baseline and go undetected without monitoring. Ultimately, longitudinal registry systems and standardized, consistent data collection may help identify epidemiological associations of hearing loss and focus solutions between preventive efforts and hearing preservation.

DSOC has posted accessible information on hearing and hearing loss for hearing conservation education purposes of their Comprehensive Hearing Health Programs (CHHP). The categories of information include:

- Hearing Loss and Tinnitus in the United States;
- Hearing and auditory injury in the Military;
- Dangerous Decibels;
- Understanding Auditory Injury;
- Appreciating the Impact of Hearing Loss; and
- Fun Facts.

2.2 MAIN OCCUPATIONAL AND ENVIRONMENTAL NOISE SOURCES

2.2.1 Occupational Noise

Occupational noise is defined as noise in the workplace. High levels of occupational noise can lead to Noise-Induced Hearing Loss (NIHL), one of the most prevalent occupational health concerns in the United States. The United States Department of Labor's Occupation Safety & Health Administration (OSHA) has reported that more than 30 million workers in the USA are exposed to hazardous noise each year and thousands of workers every year suffer from preventable hearing loss due to high workplace noise levels. Recently, Career Builder reported on some of the nosiest occupations in the USA. Its list included agriculture, mining, plumbing, and the Military, among others. A number of authoritative sources and studies, including the U.S. Government Accountability Office's (GAO) **Report on Hearing Conservation**, have re-affirmed the impact of Military service on one's hearing capabilities and documented the **growing incidence and prevalence of noise-induced hearing loss** in America's Service members and Veterans. As such, Service members need to take special care to protect their hearing from occupational noise. This involves working together with the Service's hearing conservation programs and leadership as well as taking control of personal health by adopting proper preventative measures and healthy hearing habits [26]-[29].

2.2.2 Noise in the Military Workplace

Service members may find that they are being exposed to a variety of sources of occupational noise. Some examples are listed in HCE's "**Exposing an Invisible Injury: Understanding and Preventing Hearing Loss**" infographic [11]. They include:

- Jackhammer: 130 dB;
- Gunfire: 145 dB;
- Jet engine: 155 dB; and
- Bomb blast: 175 dB.

Regardless of the source of occupational exposure to noise, it is imperative to wear the appropriate **hearing protective devices** during any exposure to ensure protection, quality performance, and to promote mission readiness, remembering that harmful noise can occur in both non-combat and combat-situations [30]-[33].

Previous analyses related to Military noise environments have been made by the U.S. Defense Safety Oversight Committee's (DSOC) High Noise Source Reduction Working Group and prior NATO research technical groups of the Human Factors in Medicine (HFM) panel. According to DSOC, the following ten high steady-state noise producing systems were identified for prioritized mitigation efforts which are ongoing (Table 2-1) [34]-[39].

Table 2-1: Sound Level Ranges for DoD Noise Sources and Estimated Exposure Times With and Without Double Hearing Protection.

Source	Low Level dB(A)	High Level dB(A)	Allowed Worst Case Unprotected Exposure Time	Estimated Exposure Duration With Double Hearing Protection*
Diesel	98	120	9 seconds	2.5 hours
Gas Turbines	85	101	12 minutes	Unlimited
High-Speed Craft	85	126	2 seconds	40 minutes
Aircraft Operations – Topside	115	167	Less than 1 second	Less than 1 second
Aircraft Operations – Interior Compartments	85	113	45 seconds	12 hours
Tracked Vehicles	90	118	14 seconds	4 hours
Wheeled Vehicles	85	112	57 seconds	16 hours
Cockpit Interior	85	121	7 seconds	2 hours
Shipboard Equipment	84	114	36 seconds	6 hours
Abrasive Blasting	85	145	Less than 1 second	28 seconds
Capsule	70	70	Promising Technology	Promising Technology

* Estimate using 30 decibel (dB) reduction for double hearing protection, realizing this may be a conservative best case scenario.

Based on averaged high and low levels of noise measured at these sources, estimates are considered for allowable exposures with various levels of hearing protection. This is based on the 3 dB exchange rate as illustrated in Table 2-2 below.

Table 2-2: Noise Level Exposure Standard Based on Duration Per Day*.

Allowable Unprotected Sound Level (dBA)	Duration Per Day	Unit of Time Per Day
80	**24**	Hours
82	**16**	Hours
85	**8**	Hours
88	**4**	Hours
91	**2**	Hours
94	**1**	Hour
97	**30**	Minutes
100	**15**	Minutes
103	**7.5**	Minutes
106	**3.75**	Minutes
109	**1.88**	Minutes
112	**0.94**	Minute
115	**28.12**	Seconds
118	**14.06**	Seconds
121	**7.03**	Seconds
124	**3.52**	Seconds
127	**1.76**	Seconds

* This is the DoD Standard which is based on the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values for Noise.

To illustrate how the 3 dB exchange rate affects exposure time, the following examples are provided. If the noise source level is reduced by 3 dB, the allowed exposure time would effectively double; a reduction by 6 dB would quadruple the exposure time and a reduction by 12 dB would allow 16 times the exposure time [40]-[43].

A previous NATO RTO HFM-123 Working Group reported on the noise environment of Military weapon systems, "Noise: A Limiting Factor for the Use of Modern Weapon Systems?" Detailed information related to noise levels and environmental exposures are documented therein [44]-[49].

2.2.3 Recreational Noise

Harmful noise exposure is not limited to the workplace. Whether on or off duty, on the battlefield or at home, vigilance and care must be taken to always protect against damaging noise. Noise is measured in decibels (dBs). Although a variety of personal, situational, and environmental factors influence noise tolerance, noise levels at or above 85 dB, when experienced for prolonged periods of time, can cause hearing loss. Although being aware of decibel levels is an important factor in protecting one's hearing, increasing distance from the source of the noise and decreasing the duration of exposure to the noise are equally important strategies to preserving hearing. A good rule of thumb is to avoid noises that are "too loud" and "too close" or that last "too long", because everyday activities such as listening to a personal music player (MP3) can be a potential source of harmful noise. Some other examples include:

- Noise levels at video arcades can be as high as 110 dB.
- Firecrackers create sound levels from 125 – 155 dB at an average distance of 10 feet.
- Sound levels at live music concerts can be measured at 120 dB and beyond.
- The noise level of gunshots can be measured at 150 dB – 167 dB.
- Noise levels at movie theaters have been measured up to 118 dB.
- Sound levels in health clubs and aerobic studios can be as high as 120 dB.
- Personal stereos with headphones produce sounds as loud as 105 – 120 dB if turned up to maximum levels.
- Sound levels at a sporting event can be measured up to 139 dB.
- Motorboats emit sound levels ranging from 85 – 115 dB.
- Motorcycles have been measured at levels ranging from 95 – 120 dB.
- Noise levels of snowmobiles are as high as 99 dB.
- Many children's toys emit sounds which are measured at 135 dB – 150 dB.
- Noise levels from "Boom Cars" have been measured at 140 dB and beyond.

HCE's "**Exposing an Invisible Injury: Understanding and Preventing Hearing Loss**" infographic lists several common noise sources and their noise levels.

2.2.4 The Hazards of Recreational Firearms

Almost all firearms create impulse noise that is over 140 dB. Impulse noise has sharp peak pressures of short duration, but due to the intensity of the energy generated can damage delicate inner ear structures after single unprotected exposures. The noise tolerances for chronic noise limits recommended by OSHA and other occupational hearing conservation programs based on the 85 dB safe threshold level and 3 dB exchange rate does not apply to impulse exposures. Still such exposures are intense enough to cause permanent damage to one's hearing. For instance, a small .22-caliber rifle can produce noise around 140 dB, while big-bore rifles and pistols can produce sound over 175 dB. Firing guns in a place where sounds can reverberate, or bounce off walls and other structures, can make noises louder and increase the risk of hearing loss. Also, adding muzzle brakes or other modifications can make the firearm louder. Data suggests that people that use firearms are more likely than others to suffer from hearing loss. This may be partially because only about half of shooters report wearing hearing protection. This is alarming given the fact that people who do not wear hearing protection while shooting can experience severe permanent hearing loss with as little as a single shot if conditions are right. Often these exposures are repeated cumulating the effect. Firearm users tend to have high-frequency hearing loss, which means that they may have trouble hearing speech sounds like "s," "th," or "v" and other high-pitched sounds. Luckily, there are a number of hearing protective devices on the market that can protect one's hearing while using firearms without jeopardizing one's ability to hear subtle sounds, such as range directions or approaching game.

2.3 IMPACT OF HEARING LOSS ON FITNESS FOR DUTY

2.3.1 Introduction

In virtually all kinds of Military operations, hearing is a critical sense that is absolutely essential to ensuring a warfighter's survivability and lethality on the battlefield. The ability to detect, identify, and appropriately respond to auditory signals has relevance across the full spectrum of Military operations [54]:

- **Communication:** Modern Military operations are almost completely dependent on voice communications that are transmitted electronically through internal intercom systems or external radio systems. The ability to understand these electronic voice communication signals is absolutely essential to mission success. Unfortunately, Military personnel are often required to listen to these communications signals under the most difficult conditions imaginable, which may include distortion of the radio signals themselves due to transmission noise and/or electronic jamming as well as interference from ambient environmental noise caused by vehicle machinery, electronic cooling systems, and nearby weapon systems on the battlefield. Dismounted soldiers must also be able to communicate verbally both by speaking quietly, when stealth is required, and by shouting, when communication over a large distance is necessary. And, in all cases, Military personnel must be able to effectively process verbal communication signals while they are distracted by other extremely demanding Military tasks, such as flying a combat aircraft or engaging in a firefight.
- **Detection:** Military members must be able to detect all kinds of alarms and warning signals in all kinds of environments, including those that might occur at a distance, in the dark, from locations outside their field of view, or at times when they are distracted by other tasks or asleep. Dismounted soldiers on patrol must be able to detect enemy incursions, incoming fire, civilian activity, and other critical environmental signals, even when visual cues are obscured by darkness, smoke or haze, or intervening terrain.
- **Localization:** Dismounted soldiers on patrol must also be able to localize critical sounds on the battlefield, which may include footsteps, gunfire, voices, or warning sounds.
- **Acoustic Stealth:** Dismounted Military operations may also require Service members to maintain acoustic stealth and ensure that they are not making noise that might compromise their position, which could occur due to loud footsteps, clothing rubbing on clothing, clanking equipment, or any of a myriad of other possible sources. These kinds of sounds are very difficult to prevent when they cannot be heard.

Even under the best circumstances, most listeners would find it challenging to properly detect and respond to all the critical auditory information that is present in the Military environment. Unfortunately, in the operational world, these already challenging listening tasks are made even more difficult by the presence of noise in the environment, the use of hearing protection devices that distort or attenuate the auditory signal, and the effects of noise-induced hearing loss, which is endemic in the active duty Military population as the result of years of inadequately protected noise exposure during combat operations in Afghanistan and Iraq [16]-[22].

2.3.1.1 The Importance of Assessing the Operational Impact of Hearing

Although there is almost universal agreement that most combat operations could not be successfully completed by individuals who are deaf, there is very little consensus beyond this extreme case in terms of the amount of degradation in hearing acuity that can be tolerated before a listener will become a danger to themselves or others on the battlefield. Current auditory fitness-for-duty standards in the Military are based on pure-tone audiometric thresholds and, in some cases, a speech in noise test such as the Hearing In Noise Test (HINT) or the Speech Recognition In Noise Test (SPRINT). These fitness-for-duty standards include cut-off criteria based on the pure tone audiogram for segregating Military members into low, medium, and high-risk categories based on their hearing acuity. Unfortunately, these cut-off values are often viewed with suspicion both by Military audiologists and by the line officers who conduct medical evaluation boards because they are based on historical precedent rather than on validated tests that have shown a direct link between the amount of hearing loss measured on a clinical test and the impact that hearing loss will have on the operational performance of an individual in combat operations. Consequently, hearing-related issues tend to account for a large portion of the medical boarding actions that occur in the Military, but only for a small percentage of the individuals who are reassigned or medically discharged as a result of their disabilities.

A similar issue occurs in the development of performance-based standards for hearing protection devices and other types of Military equipment that have the potential to negatively impact hearing acuity on the battlefield. There is general agreement that equipment that is intended to be used by Military operators in combat conditions needs to preserve a certain level of hearing acuity in terms of the ability to detect, localize, and identify sounds on the battlefield – but there are no validated measures for determining the amount of auditory acuity required for successful completion of Military activities. This makes it difficult for the acquisition community to make informed decisions about the importance of hearing acuity relative to other considerations in the acquisition process, such as cost, weight, comfort, and the level of hearing protection provided.

A final situation where information about the operational impact of impaired hearing is necessary to make informed decisions is in the use of engineering noise controls to reduce the level of ambient noise that occurs inside command and control rooms, ships, vehicles, aircraft, and other weapon systems. In most of these systems, the level of ambient noise could be reduced through the use of better design and different materials. However, without a firm knowledge of the operational benefits that could be obtained by these noise controls, the benefits of reduced ambient noise cannot be weighed appropriately against other design considerations like cost and weight.

Thus, it appears that the ability to accurately assess the operational impact of impaired hearing is an important issue that has implications not only in the development of validated auditory fitness-for-duty standards but also in the development and acquisition of more effective personal protective equipment and weapon systems. In each case, what is needed is a curve similar to the one shown in Figure 2-1, which relates some objective measure of “Hearing Acuity” to the overall probability of “Mission Success” in a Military environment. This is a challenging problem, but not an intractable one. The next section describes an approach to this problem that uses real-time hearing loss simulation to assess the importance of hearing in operational environments.

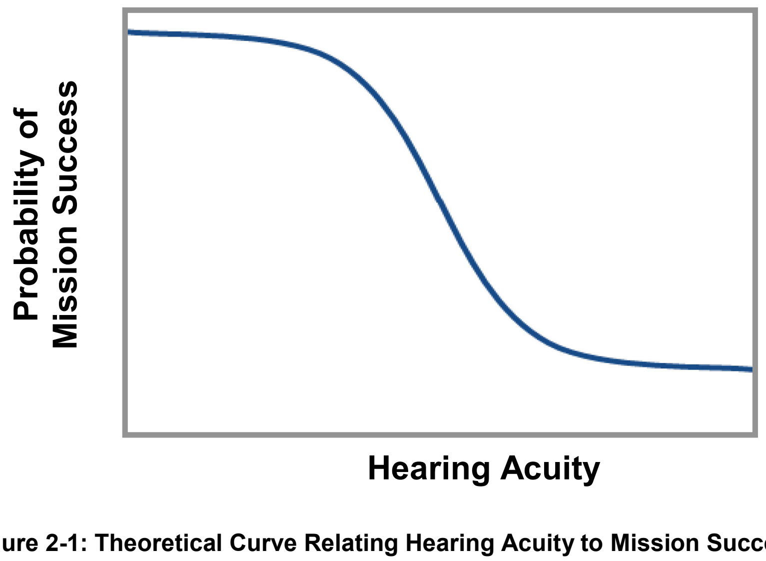

Figure 2-1: Theoretical Curve Relating Hearing Acuity to Mission Success.

2.3.2 Assessing the Operational Impact of Hearing with Real-Time Hearing Loss Simulation Systems

In theory, the optimal way of measuring the operational impact of impaired hearing would be to go to a real operational environment and run a full-factorial experiment that measured objective performance in the operational task with each possible way that hearing acuity could be impaired in that environment. In the case of evaluating the impact of noise-induced hearing loss, this would mean finding trained operators with all possible levels of hearing impairment, and evaluating their performance in the operational task. However, clearly this approach is infeasible. Even if it were possible to find enough trained operators with hearing impairment, the differences in individual skill level across the different operators would likely contaminate the overall results of the experiment.

In terms of operational testing with hearing protection equipment or other personal protective equipment, it may be theoretically possible to run a full-factorial design where every operator participates with every device – but the costs of running the operational test with each possible type of hearing protector would likely be prohibitive. Furthermore, the complexity of the task would probably make it impossible to directly compare the results from one operational test with one set of hearing protectors to the results of a future test with a different set of hearing protectors. This would make it necessary to conduct a full operational test each time a new hearing protection device needed to be evaluated for suitability.

In order to address these potential pitfalls, we have developed a method of evaluating the impact of impaired hearing on operational performance that uses *real-time hearing loss simulation systems* to simulate the effects of hearing impairment in listeners with normal hearing. These systems allow us to devise experiments where we:

1) Recruit trained operators with normal hearing;
2) Systematically degrade their hearing with hearing loss simulation systems; and
3) Measure their operational performance as a function of the amount of simulated hearing loss.

This approach has a number of important advantages. First, it allows us to recruit subjects from a much larger pool of normal hearing listeners rather than trying to target operators with specific levels of hearing impairment. Second, it allows us to use a within-subjects design that tests each subject at each possible level of hearing impairment, which allows us to counterbalance away any impact that individual differences in skill level might have on the overall results. And, finally, it allows us to run experiments that isolate individual components of auditory acuity (for example, the detection threshold of sounds, or speech intelligibility, or localization ability) and measure the impact each of these individual components has on operational performance. This in turn allows us to conduct later tests in the laboratory that evaluate these individual components of acuity in a hearing-impaired individual or on a new hearing protection device and to use the results of these tests to make predictions about the impact that the hearing loss or hearing protection device will have on operational performance *without repeating the full operational test.*

The following sections describe two real-time hearing loss simulation systems we have developed to allow us to evaluate the impact of hearing on complex operational tasks. The first, the *HLSim,* is designed to simulate the effect that reduced audibility (i.e., elevated hearing thresholds) has on operational performance in dismounted Military operations. The second, the *Adaptive Intelligibility Modification System,* was designed to simulate the impact that reduced intelligibility has on Military operations. The next two sections describe these two systems, and the types of experiments they are being used to conduct, in more detail.

2.3.2.1 The *HLSim* Wearable Hearing Loss Simulator

The *HLSim* wearable hearing loss simulator is a wearable hearing loss simulation system that is designed to simulate the increased audibility thresholds associated with noise-induced hearing loss in listeners with normal hearing. Each system consists of a battery-powered digital signal processor (Figure 2-2, left panel) connected to a pair of tube-based insert earphones (Etymotic ER-2) that have been modified to hold an ambient-sound pick-up microphone (FG-23742, Knowles, Itasca, IL) immediately outside the foam tip that is inserted into the ear (Figure 2-2, center panel). This microphone placement was selected because it is most likely to pick up the spatial sound cues caused by spatial filtering by the external ear or pinnae. The systems are packaged in a three-lobed enclosure designed to fit on the back of a standard combat helmet (Figure 2-2, right panel). Each system also includes I/O controls, a USB interface, and a microSD card reader for system control, programming, and log file recording. The software architecture that handles system programming and real-time audio processing is based on the commercially available HeLPS headsets [62]. The algorithm for simulating hearing loss is designed to produce for the listener the absolute detection thresholds (i.e., hearing levels) and the sensation of loudness recruitment (i.e., abnormally-rapid growth in perceived loudness) that are associated with a specified hearing loss. In this manner, sounds that are below the specified threshold at a particular frequency are no longer audible. However, sounds well above the threshold are perceived as having the same loudness as they would for an unimpaired listener. This phenomenon is referred to as loudness recruitment. The validity of a hearing loss simulation that incorporates threshold shift and recruitment is supported by numerous other studies that have used similar noise-masking simulations [46], [47], [48].

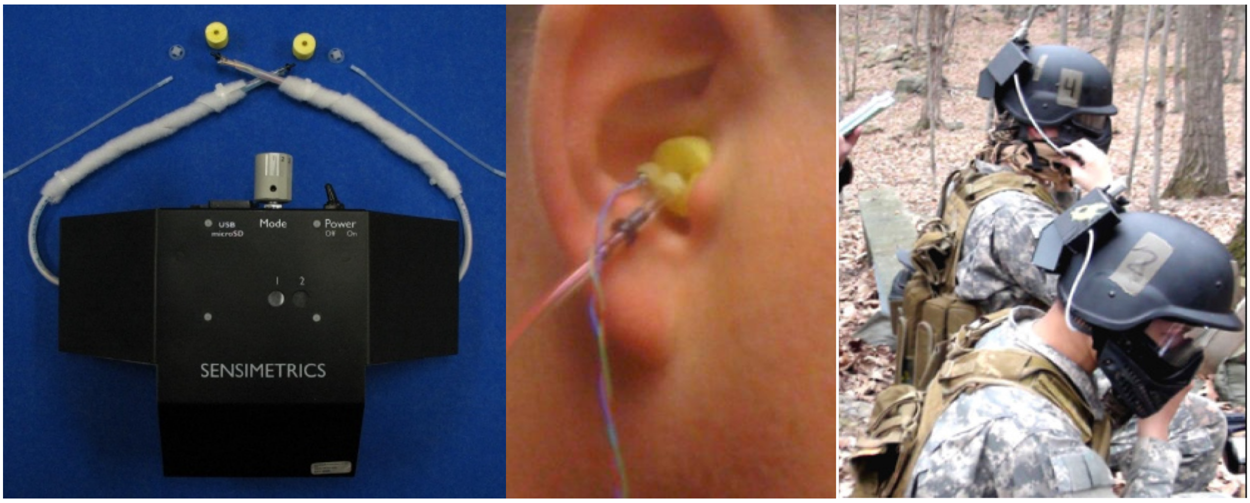

Figure 2-2: *HLSim* System.

The *HLSim* has a USB software interface that allows any desired hearing threshold to be programmed into the system (Figure 2-3, left panel). This allows the system to be used to evaluate the impact of hearing impairment on operational effectiveness in virtually any simulated combat environment.

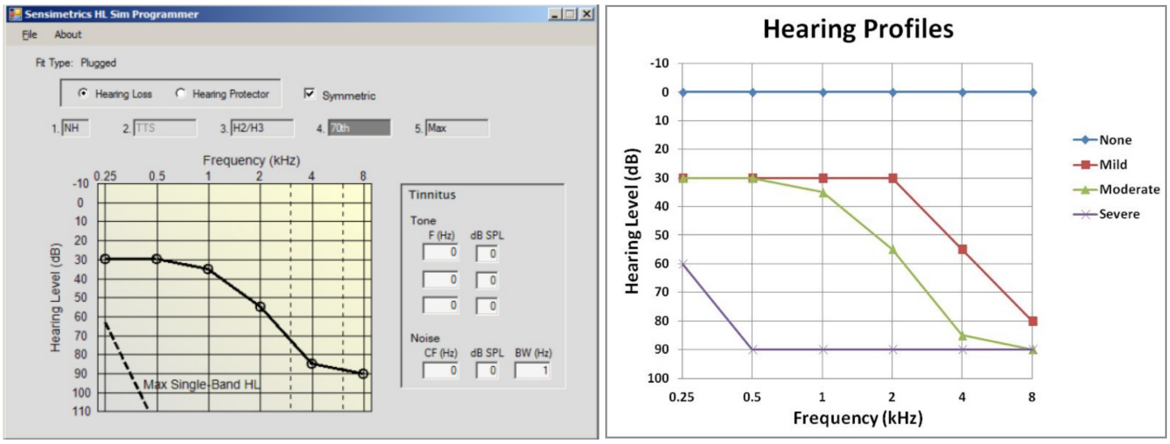

Figure 2-3: Programming of Hearing Loss Profiles in the *HLSim*.

In a recent pilot experiment conducted at the U.S. Military Academy at West Point, the *HLSim* was used to evaluate the impact that different levels of hearing loss had on a "last-man-standing" combat exercise where 4 – 6 players were placed a random locations on a wooded field of play and instructed to use a paintball marker to eliminate all of the other players from the exercise. The players conducted the exercise in a round-robin fashion where each player participated with each of four different levels of simulated hearing loss (None, Mild, Moderate and Severe; Figure 2-3, right panel). Performance in the exercise was evaluated in terms of Survivability, defined as the sequential order in which the players with each level of hearing loss were eliminated from the exercise (Figure 2-4, left panel); Lethality, defined as the percentage of the opponents on the field of play eliminated by the players with each level of hearing loss (Figure 2-4, middle panel); and overall wins, defined as the percentage of trials where the players at each level of hearing loss was the last remaining survivor on the battlefield (Figure 2-4, right panel).

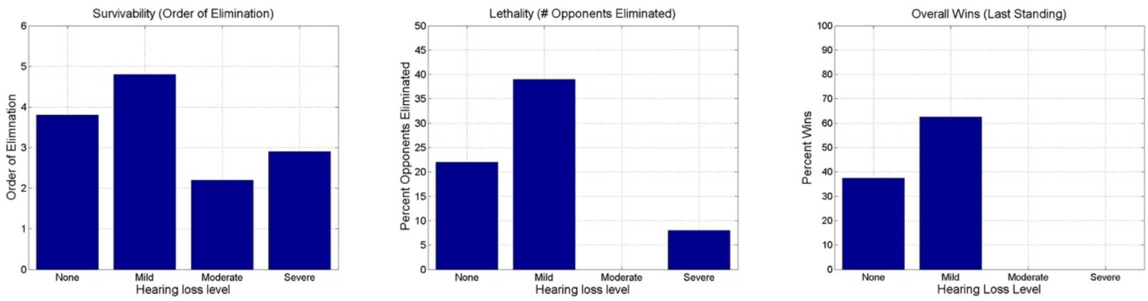

Figure 2-4: Effect of Simulated Hearing Loss on Survivability and Lethality in a Paintball Exercise.

Although somewhat preliminary, the results of the exercise suggest that hearing impairment had a modest effect on survivability, but a severe impact both on lethality and the probability of overall mission success. In part, at least, this appears to reflect a tendency for participants with hearing loss to adopt a more conservative strategy of finding a place to hide rather than aggressively pursuing the other players on the field. When only modest levels of hearing impairment were present, this shift from an offensive strategy to a more defensive strategy may have actually slightly helped the players in this exercise: the data show that listeners with mild hearing impairment performed as well or better than those with no impairment, perhaps because the players with no impairment were adopted an extremely aggressive strategy that was not optimal in this type of Military operation. However, the data strongly suggest that players with more than mild hearing loss had a very challenging time eliminating other opponents, and that this made overall victory in the exercise quite difficult. Further experiments are now planned to more precisely determine the amount of hearing loss required to severely impact the survivability and lethality of an individual in a dismounted combat environment.

2.3.3 The Adaptive Intelligibility Modification System (AIMS)

The Adaptive Intelligibility Modification System (AIMS) is a hearing loss simulation system designed to evaluate the impact of impaired speech intelligibility on collaborative Military tasks. The system consists of two or more wireless headsets (Logitech G930) connected to a custom software interface that allows speech intelligibility to be systematically varied from a very high level to near 0%. The intelligibility-modification processing worked as follows. The input signal is bandpass filtered into three bands with logarithmically-equal bandwidth over the range from 100 to 8000 Hz. An Automatic Gain Control (AGC) is then applied to each band independently to restrict the level to L_{in} = 30 dB below the peak output level of the system. The purpose of the AGC is to ensure that both conversational and shouted speech are presented at approximately the same level to the end listener and to prevent the use of shouting to overcome the intelligibility-modification processing. The AGC gain also has roll-off for low input levels to prevent amplification of background noise. Bandpass-filtered white noise is then injected into each of the three input bands at a specified SNR with respect to the input AGC limit of L_{in} as specified above. The reason for choosing L_{in} = 30 dB below the maximum output level of the system was due to this injected white noise. The output could accommodate white noises with RMS levels of L_{in}+10 dB and peak levels of L_{in}+30 dB. Thus, the SNR was adjustable from -10 dB (i.e., noise 10 dB louder than the signal) to infinity (i.e., no noise), where an SNR of +10 dB is generally intelligible while an SNR of -10 dB is generally unintelligible.

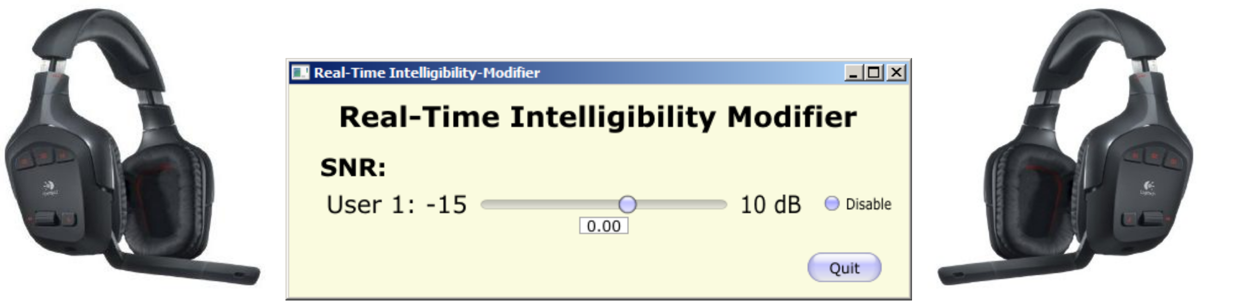

Figure 2-5: The Adaptive Intelligibility Modification System (AIMS).

One advantage of the AIMS system relative to other methods that have been used to adaptively adjust intelligibility in Military environments is that the system is designed to be suitable for simulating impaired intelligibility both over simulated radio or intercom systems *and* in face-to-face communication situations where the listener is able to take advantage of visual cues obtained by reading the lips of the talker. Figure 2-6 shows intelligibility data from 8 listeners using the Modified Rhyme Test (MRT). The MRT consists of a series of six-word lists of similar (or rhyming) sounds in single-syllable English words. The words are constructed as consonant-vowel-consonant with variability only in the initial or final sound (in each group of 6 words). A carrier sentence is used to present the word and the listener selects the word heard from a list (e.g., “you will mark hit, please”, where the choices in the list are bit, fit, hit, kit, sit, wit). The red and green symbols show performance in the case where the listeners were seated next to one another in the same room. The red symbols show the situation where they were able to see one another (Face-to-Face), and the green symbols show the case where they were unable to see one another (Back-to-Back). These results clearly show that the AIMS system is able to degrade the quality of the auditory channel without depriving the listeners of the useful cues they would ordinarily be able to obtain from seeing the movements of the talker’s lips. The blue symbols show performance for the listeners when they were attending to MRT phrases spoken by a different group of talkers located in an adjacent room. The very similar levels of performance obtained for the different sets of talkers used in the same room and different room conditions suggest that the AIMS system is able to robustly control the intelligibility obtained in a communication signal across a range of different talkers and a range of different listening environments.

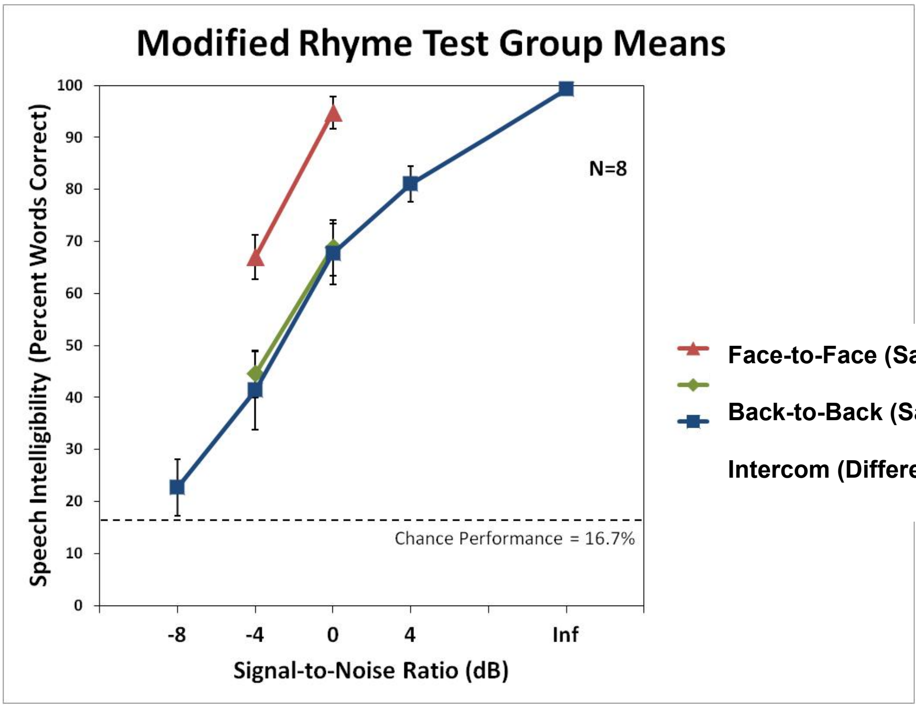

Figure 2-6: Intelligibility as a Function of SNR in the AIMS System.

The goal of using the AIMS in operational tasks is to measure the effects of speech intelligibility on overall performance without interference from the acoustic factors (noise, room reverberation, etc.) that influence intelligibility in the actual auditory environment. This methodology makes it possible to determine the impact that improved or degraded speech intelligibility might have on performance in the task without actually conducting the task in all the different acoustic conditions that might lead to improved or degraded speech intelligibility. The utility of this approach is most obvious in the case where our goal is to evaluate the impact of hearing impairment in an operational task such as a command and control task. The ideal approach might be to bring in trained operators with various levels of hearing impairment and have them conduct the task in the actual acoustic environment where the task occurs in order to directly determine the relationship between hearing impairment and task performance. However, it is very unlikely that it would be possible to find enough trained operators with hearing impairment to conduct this study, and even if it were possible, the results would be contaminated by differences in skill across the different trained operators.

However, with the AIMS system, it is possible to use trained operators with normal hearing to isolate the effect that variations in speech intelligibility (defined as percent correct responses on the MRT) has on performance in the task. Then, at a later time, it will be possible to simulate the actual acoustic environment that occurs in the task with recorded noise, and to use that recorded noise to evaluate speech intelligibility on the MRT task with *untrained* listeners with various levels of hearing loss. A fitness-for-duty standard can then be established by determining the maximum level of hearing loss that can be tolerated before the MRT score degrades to the point that performance in the operational task falls below the minimum acceptable level. A similar approach can be used for evaluating the impact of different communication systems, or of reduced or increased ambient noise, on performance in the operational task. In all cases, the approach is the same, as illustrated in Figure 2-7. The AIMS system is used to evaluate performance in the operational task as a function of SNR. Then the MRT test is used on the same talkers and listeners to determine the relationship between SNR on the AIMS system and percent intelligibility in the MRT task. These two curves can then be used to develop a curve relating operational performance to MRT speech intelligibility. Once the function relating operational performance to MRT speech intelligibility has been established, it will be possible to estimate operational performance in any possible acoustic environment either by simulating that environment with recorded noise and running relatively inexpensive listening tests on untrained listeners or by making mathematical predictions of speech intelligibility on the basis of the acoustic properties of the noise using analytical speech intelligibility prediction algorithms such as the Speech Transmission Index (STI) [50] or the Speech Intelligibility Index (SII) [51].

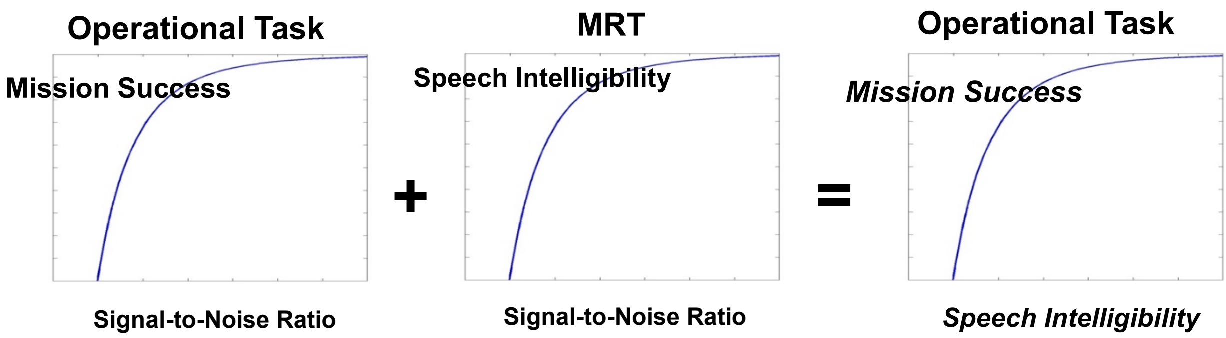

Figure 2-7: Approach for Isolating Impact of Speech Intelligibility on Operational Performance.

The overall approach used in the AIMS is not new. Similar experiments have been conducted to evaluate the impact of impaired speech intelligibility both in an M1 combat tank simulator [52] and in a UH60 Blackhawk simulator [53]. However, these previous experiments have been limited to situations involving a highly controlled environment where all speech communications originate from an electronic intercom system connected to a headset. The AIMS allows this approach to be extended to environments where operators are able to communicate to some team members via electronic intercom systems and other team members via face-to-face communication. We are now using the AIMS devices to conduct studies that will evaluate the impact of speech intelligibility on the overall operational performance of a squad-level unit during a simulated fire-fight and of a naval commander during command and control operations on a guided missile cruiser. These are both examples of complicated situations that involve a combination of face-to-face and electronic voice communications.

2.3.4 Conclusions

In this chapter, we have outlined an approach for evaluating the operational impact of impaired hearing that uses real-time, wearable hearing loss simulation systems to systematically degrade the hearing abilities of trained normal-hearing listeners in realistic operational environments. We have also outlined a strategy for using the results of these experiments to help develop improved auditory fitness-for-duty standards and performance-based requirements for hearing protection devices and communications systems. Although this project is still in its early stages, the results obtained to this point are promising. However, we should make it clear that this approach represents only one part of a comprehensive strategy to develop improved auditory fitness-for-duty standards for Military personnel. Additional research is also needed to:

1) Develop better methods for rapidly and efficiently measuring the hearing abilities of Service members in a clinical environment; and

2) To evaluate how well hearing impaired listeners are able to detect and identify actual hearing-critical auditory signals recorded in realistic Military environments.

Although the problem is a challenging one, we are confident that this multi-faceted approach to the development of auditory fitness-for-duty standards will allow us to make recommendations for a much more robust and defensible set of hearing requirements for Military service than is currently available.

2.4 IMPACT OF HEARING LOSS ON A SOLDIER'S LIFE

The ability to hear and communicate is critical for Service members themselves as well as for their teams, squads, and units. The sense of hearing impacts the safety of each warrior and unit, and is central to effective command and control, as well as for efficiency and precision when performing their mission. Our ears offer the ability to identify and localize auditory threats, focus on auditory cues that are critical to the mission, and recognize alarms and auditory safety cues that impact how Military members perform. Hearing readiness is tied to the function of these sensors, and enhances survivability and accuracy in communication through focused discernment of various sound signals and sources.

The previous sections documented the paradoxical noise environment in which Military members are called upon to work. It is easy to see how crucial signal-to-noise ratios can be degraded creating extremely difficult listening environments. The inability to decode appropriate signals causes confusion and inefficiency delaying task, and compromising efficiency [52]. Compounding the effect of steady-state noise and hearing loss related to noise, exposure to Improvised Explosive Devices (IEDs) in Afghanistan and Iraq randomly increase the threat and damage to the auditory-vestibular system. These weapons are a noise threat that cannot be anticipated, and require constant vigilance and protection.

The epidemiology of injuries to the auditory system are also detailed in prior sections, but the effect of hearing loss, tinnitus and auditory system injury can be profound on many levels. The effect on performance and Total Force management is described related to auditory fitness for duty, but much is still to be determined. The analytical process to identify the economic burden of noise exposure, hearing loss, and auditory injury encumbering Military programs is underway in the USA. Disability compensation for Veterans continues to grow in the United States and is estimated to cost over two billion dollars annually (understanding that compensation calculations are complicated, based on all connected disabilities, and direct cost analysis related to a specific injury is impossible). Hearing loss is also noted to be anecdotally responsible for significant program costs, education and training, protective equipment, equipment losses, lost man hours, retraining and recruiting costs. More dedicated analysis is underway in the DoD HCE as an analysis entitled the Defense Epidemiology and Economic Burden of Hearing Loss which is scheduled to conclude and reported in FY 2015.

Auditory injuries related to blast can result in symptoms of pain, hearing loss, tinnitus, dizziness and disorientation, any of which can be counterproductive to personal and unit effectiveness on the battlefield. While some of these injuries are transient and resolve spontaneously, most cause some degree of permanent disability, and each ear-related injury can act as an indicator of deeper, more ominous injury such as Traumatic Brain Injury (TBI). Acute traumatic hearing loss can affect the medical evaluation of other injuries as well. Trauma management protocols assume and rely on hearing ability in the assessment of brain function and to guide immediate triage and care. The Glasgow Coma Scale (GCS) uses patient responses in three categories, vision, motor, and verbal to assess brain function, determine care, and predict prognosis. If a patient has difficulty hearing, they may be less responsive and their scores could theoretically be degraded by 2 – 3 points, which in turn could potentially lead to unnecessary utilization of provider time and limited resources, or worse, delay expedient care.

Polytraumatic injuries require team care and multiple consultations. Inability to engage in these interactions can slow information exchange, or cause misunderstanding and lead to various unintended consequences. The energy required to compensate for losses can detract from energy needed to participate in other rehabilitative endeavors. Appropriate rehabilitation for auditory deficits can optimize rehabilitation and support from care teams and families. Still, hearing aids and Assistive Listening Devices (ALDs) are primarily developed for individuals without visual loss, amputation/s, chronic pain or other comorbid injuries affecting dexterity and maintenance of the devices. Hearing aids, assistive technologies and implantable devices are small for cosmetic and functional reasons and other injuries can inhibit or limit use or satisfaction of these devices. Patients with multi-sensory deficits, traumatic brain injury, and post-traumatic stress symptoms bring about additive interactions of problems that compound each injury above the effect of that injury on its own.

While hearing damage from combat can be acutely traumatic, the impact of occupational exposure is more often silent, insidious and incremental – largely unapparent even to the member impaired. In fact, Service members and Veterans may not realize they have a hearing loss until later in life when their vision or other senses begin to decline, or they are unable to register conversations and natural sounds, or when they are unable to engage in desired social interactions. Many times family members and friends are the first to comment on the degraded ability. Attempts by individuals with hearing loss to maintain concentration, attention and focus in conversation and educational exchanges is accommodated by further taxing cognitive, visual and other compensatory mechanisms. Although hearing aids and implantable devices can compensate hearing loss to some degree, there is no cure for hearing loss, and no standard remedy for tinnitus.

Tinnitus most often is a subtle nuisance that interferes with the normal activities of daily life, conversations, and relations (http://www.ncrar.research.va.gov/Education/Documents/TinnitusDocuments/Index.asp). At the other end of the spectrum, however, it can manifest as a debilitating intrusion on all thoughts, interactions, and activities; isolating an individual from hobbies, vocations, friends, and families; distracting sleep and concentration; exacerbating depression; and, in the extreme, inciting suicidal ideation and intention. The association of hearing loss, tinnitus, and/or altered balance function in polytrauma is common. Management of these injuries are often delayed until the more visible injuries are treated. Delay can alter and delay rehabilitation for other injuries by limiting interaction with care and support.

On an individual level, hearing injuries degrade quality of life, limit career choices, and create dependency on rehabilitative/assistive devices and technologies to accommodate for the loss. On an enterprise level, these injuries hinder effective communication, and thereby impair quality of unit/squad/team/crew performance and safety. Invisible hearing losses may not be apparent to individuals but can impact performance and siphon vigilance by diverting cognitive load and energy to accommodate for loss [23].

Consequences of hearing impairment include the inability to interpret speech sounds, often producing a reduced ability to communicate, delay in language acquisition, economic and educational disadvantage, social isolation and stigmatization. In multi-national coalition settings, it can deter ability to understand multi-national speakers communicating in a common, but secondary language.

The possible relationships and treatments for TBI, tinnitus, hearing loss, and post-traumatic stress disorder are very important and a great deal of research is being done, including strategies for treating polytrauma and multi-sensory impairment. Each factor can greatly decrease quality of life for the patient and the juxtaposition of multiple factors, causes, and relationships (including central auditory processing disorders) can increase the difficulty of treatment [63].

Not only does multi-sensory injury manifest in physical dysfunction and scarring, it is also associated with neurobehavioral and psychopathological dysfunction. Brenner and colleagues correlated a significantly higher incidence of post concussive syndrome when mTBI and PTSD co-occurred than when they were unassociated. With prolonged rehabilitation, chronic pain management, multiple consultations, and a new life focus on rehabilitation, psychosocial factors permeate multi-sensory injuries and recovery. Even though psychological assessments are not routine in non-TBI polytrauma, those injured exhibit neurobehavioral and psychopathological disorders and should be considered throughout rehabilitation [23]. In a cohort of immediate evacuees sustaining body wide injuries, TBI incidence was 54%, with 14% documented by abnormal neuroimaging findings [24]. In this analysis, a higher Injury Severity Score (ISS; anatomical scoring system for patients with multiple injuries) was significantly associated with abnormal neuroimaging, longer hospitalization, and more severe brain injury.

Blast-related TBI produces significantly greater rates of hearing loss and tinnitus compared with non-blast-related TBI, affecting up to 60% of blast TBI patients [41]. Dizziness has been reported in 98% and vertigo in 47% of these patients [42]. A high co-morbidity between TBI and visual dysfunction is apparent in up to 76% of soldiers with polytrauma [38]. In a study attempting to assess the co-occurrence of self-reported multi-sensory (auditory, visual, and vestibular) impairment after TBI, 17.4% of Veterans with a history of mild TBI reported such injuries. Post-Traumatic Stress Disorder (PTSD) and depression were also correlated strongly with reported multi-sensory impairment [40]. Thirty-four percent of patients with the perception of auditory stimuli when none were present – or tinnitus – had a diagnosis of PTSD and their tinnitus severity worsened with PTSD-related anxiety [27]. Such bi-directional relationships between tinnitus also exist with depression, anxiety, anger, and other auditory hallucinations.

Insults to the auditory system may not be fully appreciated by a patient until they interfere with a patient's ability to engage in a standard neurological evaluation. Strained communication can lead to miscommunication, misunderstanding, delayed diagnosis, misdiagnosis, and delayed or inappropriate therapy. Communication difficulty can introduce stress and frustration that may compound physiologic responses and diminish a patient's resolve. Patients who feel helpless and uninformed may experience increased anxiety, depression, and isolation. These responses can manifest physically as hypertension, dizziness, gastrointestinal distress, and headache. In short, patients with undiagnosed auditory deficits are vulnerable to a cascade of additional difficulties that further confuse the clinical picture and may lead to unhelpful medication, self-medication, and potential side effects.

Furthermore, an auditory injury can impair psychiatric evaluation in nearly every component of a mental status exam. Auditory system damage that disrupts the speech-motor feedback loop, for example, can elicit a Lombard effect in which the speaker involuntarily modifies speech rate, volume, and rhythm characteristics. Individuals with hearing loss may incorrectly perceive aggression from a speaker who is trying to accommodate by speaking more loudly. Hearing loss often manifests as requests to repeat instructions and this may be misinterpreted as cognitive or mental dysfunction. Patterns and characteristics of speech and communication are often noted on psychiatric examination, so it is important to recognize that they may be altered due solely to neurosensory injury.

Multiple sensory system injuries and chronic effects may also alter a patient's general appearance and behavior (e.g., motor movements, agitation), affect (blunted due to lack of engagement), sensorium, intellect, insight, and judgment (from injury side effects such as tinnitus, persistent central processing dysfunction, and/or cognitive deficits) [22], [23]. Central compensation for multiple neurosensory impairments can be mentally and physically fatiguing, leading in turn to decreased interest and ability in former activities and hobbies, which can compound depression and anxiety. Patients may also find it burdensome to manage various assistive devices, medications, and prostheses.

Another important challenge is the need for coordination among specialists. A patient who presents with TBI, PTSD, and vertigo, for example, will need to see multiple specialists for assessment and therapy. Therapy for vertigo may exacerbate TBI-related symptoms of fatigue, inattention, and memory deficits. Likewise, strategies for treating PTSD, such as exposure therapy, may exhaust the patient's mental resources, induce stress and fatigue, and thus compromise cognitive or vestibular therapy. Uncoordinated treatment regimens may leave a patient feeling helpless, observing that progress toward recovery in one domain may cause increased difficulty in another. The effect on the health care system may also be underappreciated. For example commonly associated symptoms of hearing loss such as isolation, anxiety and depression could theoretically lead to increased visits for other somatic complaints, drive up costs through increased use of prescription medicines, possibly lead to utilization of ancillary imaging services, and even add to use of surgical services. Potential clinical, system of care, and business assessment and analysis could not only add to individual treatment and care, but also point to enterprise improvements and cost savings adding value on broad levels. For example, comparative analysis of hearing and poor hearing cohort's utilization of pharmaceutical patterns for anti-depressant or anti-anxiety medications, or other services, may show trends that can lead to more focused and effective therapy. Treating the root cause as opposed to an associated symptom may prove cost effective.

Likewise, assistive devices and exercises that speed recovery and rehabilitation for patients with single sensory injuries can be difficult for polytrauma/TBI patients to manage without frustration and fatigue. For example, an upper extremity amputee who also suffers from blast-related vision and hearing dysfunction and mild TBI may not have the dexterity required to change the battery in a hearing aid, secure prostheses, or manage remote control devices. Current accommodations could benefit by further development and individualization of these necessary tools. The cumulative effect of polytrauma on an already burdened physical, cognitive, and psycho-social human system is likely far greater than the sum of its multiple underlying injuries.

2.5 EXISTING HEARING LOSS PREVENTION PROGRAMS

2.5.1 Estonia

Although there have been no large-scale scientific projects to study Military hearing loss in Estonia since the restoration of Estonia independence, attempts have been made to improve hearing loss prevention. Locations where higher risk of hearing loss may occur are regularly monitored every two years. New and improved safety regulations have been implemented. The selection of hearing protection and their suitability to noise levels are regulated. An electronic database of audiometric and medical data has been in use since 2002. Medical surveillance and audiometric examination of all active members are carried out before active Military service, periodically every 3 years during service, and after discharge from Military service. A new "Regulations of Health for Conscripts and Active Members" was enforced on 1 April 2013.

2.5.2 Germany

In Germany, intensive research has been done to develop technical hearing protection devices with the intent to reduce both impulse and steady-state noise. Currently, there are a range of devices available which enable hearing protection as well as speech understanding. The mean achievable noise reduction is currently about 35 dB. There are strong regulations for when and how to use hearing protection devices in the German forces. The program started in 1985 and led to a significant reduction in noise-induced hearing loss. As participation in NATO missions started in 2000, the incidence and prevalence of noise-induced hearing loss has increased. It became clear that hearing protection contradicted communication tasks. It also became evident that no protective solution is available to adequately protect against blast trauma to the ear.

Studies in soldiers with blast trauma show that post-traumatic stress is associated with the likelihood of progressive hearing loss in both ears over time. It is also apparent that hearing loss itself endangers compensation of post-traumatic distress order. These findings need further investigation to improve rehabilitation outcomes of traumatic injuries, as well is to reduce the burden of compensation claims.

Since 2012, research related to soldier's hearing function and hearing loss became one (out of 8) of the main focuses for Military medical research. The implementation of a hearing screening program for all soldiers based on the results of this report is underway.

2.5.3 Netherlands

The Dutch Military has historically suffered from loud noise exposure. Starting in the 1960's and 1970's, increased attention has been paid to hearing protection. Currently, several different types of hearing protection (plugs and muffs) are used according to the different functions of the Military personnel.

During the last decade, special focus has developed to detect hearing loss in blast injured patients.

The newest uniform for the Military is being designed to enhance optimal use of hearing equipment and hearing protection. Optimal fitting of hearing plugs is thought to be essential to extend the wear of these devices for longer periods of time. Furthermore, use of protective devices should not hinder communication or situational awareness.

In the Netherlands, employers are required by law to offer protection to personnel that work in environmental risk. One instrument to measure the health of Military personnel is a periodic work-related health assessment (PAGO). These evaluations are still voluntary. In 2006 a new PAGO for noise and hearing was implemented. However, the data collected from PAGO evaluations is not centrally stored. Individual bases identify personnel at higher risk, based on extensive Risk Inventory and Evaluations (RIEs); however, there is no Military-wide program for identifying and protecting individual Service members.

In 2012, the Dutch army medical authorities implemented a new program to inform soldiers about hearing protection, screen the ear and hearing function, and enforce hearing protection for all Military personnel. The purpose was to detect persons at risks at earlier stages so that more extensive protection and more timely treatment can be rendered.

There is an expectation that participation in a NATO database collaboration will lead to the development of Dutch army guidelines and improve and speed up worthwhile research projects for all participants. Through these process improvements and knowledge sharing opportunities, advocacy and education can be generalized that will facilitate the necessary hearing protection and medical treatment and rehabilitation for timely patient care of those exposed to loud noise or who suffer from noise-induced hearing loss.

2.5.4 Portugal

Measures to reduce noise exposure have been implemented in Portuguese Military units in the last two decades by soundproofing the working place, reducing noise emissions and providing personnel with hearing protection devices. Problems have arisen because these measures are sometimes impossible and/or are dangerous in duty and in Military combat.

The mandatory use of hearing protection devices in the workplace is covered by law. However, it is important to promote an awareness program for Military personal to address the concept of noise-induced hearing loss and its prevention.

The regular audiometric evaluation is performed before ingressing the Military forces and in specific Military groups (Special Forces, aviation operatives) because of operational requirements and exposures. By the end of 2015 it is intended to extend such surveillance to all those who are subject to noise levels considered in alarm or distress ranges, using the database proposed in this document. Nevertheless, the military ENT specialists continue to promote lectures about this issue to all Military personnel in order to enhance awareness of this problem and to increase prevention measures.

2.5.5 United States

The ability to hear and communicate is related to job safety and performance in the Military. Effective communication is significant at individual, squad and command levels. Noise is the most prevalent occupational hazard present in both operational and support functions of Military systems. At some point, Service members will be exposed to high-intensity noise and be expected to operate and communicate in those settings. The United Sates Armed Forces instituted hearing conservation programs in 1978 due to the noise hazard and the effect of hearing loss on Military operations. Aside from Military occupational exposure, off-duty exposure to noise is recognized as a growing threat. Doctrine and policy establish requirements for hearing conservation programs across the service components. Still, efforts to mitigate and remove noise sources and to protect Service members through administrative regulations, education, and provision of hearing protection need continued assessment to adapt to changing environmental threats and to identify and implement best practices.

Even though the services monitor hearing and provide, educate and train with hearing protection, the effect of noise on hearing continues to burden Military Service members with tinnitus and hearing loss as the two most prevalent service connected injuries. The United States Congress has directed several recent analyses to evaluate this effect, and improve hearing conservation efforts. The National Institute of Medicine (IOM) reported on, "Noise and Military Service: implications for hearing loss and tinnitus." [64]. The Department of Defense Hearing Center of Excellence (HCE) was established in 2010 to improve prevention, diagnosis, treatment, mitigation, and rehabilitation of auditory system injuries. The U.S. Government Accountability Office published an audit of Military service's hearing conservation programs [55], [56], [57]. The National IOM assessed the long-term effect of blast exposure [65]. NATO Human Factors in Medicine Panel evaluated the damage risk from impulse noise [58] prior to this current effort looking at optimizing reintegration of members with hearing loss.

Department of Defense Instruction (DoDI) 6055.12 for "Hearing Conservation Programs" states, "Engineering controls shall be the primary means of eliminating personnel exposure to potentially hazardous noise. All practical design approaches to reduce noise levels to below hazardous levels by engineering principles shall be explored." Understanding that the primary means for prevention are to remove or mitigate noise, this is not always achievable or practical. Recognizing this, U.S. hearing conservation programs work with acquisitions and weapons system developers, systems engineers, and industrial hygiene teams to identify and mitigate source noise, but also to outline personal and enterprise prevention strategies through a Comprehensive Hearing Health Program (CHHP).

Common elements of the above reports and analyses have been combined as best practices that are incorporated into the standardized DoD HCE CHHP. The goal of such a program is to modify Service members' behavior to protect and preserve their hearing. Such change is institutionalized in policy which documents the requirements and governance for program support, and is enabled through development of tools necessary to make change happen. Along with concerted effort to mitigate noise at the source [59], the three elements of CHHP are briefly described below:

1) **EDUCATE –** Education and awareness of exposure risk empowers individuals to participate actively in the program. Hearing monitoring programs provide CHHP administrators access to members to implement training, but equally important is global outreach through other health and readiness programs. Training ancillary teams to observe CHHP practices can be established by teaching leaders the importance of hearing and communication, and encouraging their promotion and advocacy of hearing health. Downloadable materials are available through the World Wide Web at www.hearing.health.mil.

2) **PROTECT –** Protection is an effective means of hearing preservation when noise cannot be mitigated or removed. Individualized protection can be set up through hearing monitoring programs which identify needs based on operational job requirements and personal hearing status. Prioritization of appropriate hearing protection should be maintained at a high level and augmented through identification of qualified protection devices for acquisition.

   A variety of hearing protection devices which span the technological limits exist and are employed by user communities based on their operational activities, budgeted priorities, and awareness of devices. These devices range from simple foam plugs to electronic tactical communication and protection devices with features such as level dependent function, active noise cancelation, blast protection, radio connectivity and vehicle-based communication system compatibility. Some occupations and activities require double ear protection with inserts and muffs. Best fit, double protection attenuation approaches 50 dB. Even with maximal protection, some noise intensities peak above levels where prolonged exposure is safe. Moreover, some environments do not have noise free locations where members can observe noise free periods in obeyance of 3 dB exchange requirements. These pose continued challenges to CHHP implementation.

3) **MONITOR** – Monitoring through structured surveillance of member's hearing status is the backbone of CHHP which also recommends periodic assessment of noise environments. Monitoring sets up encounters for education, and opportunities to reinforce protective techniques. It enables early detection of individual loss, as well as identifying regions of increased exposure or better protective practices. It allows customizable, agile intervention, standardization of best practices, and application of resources to individuals and regions of highest need.

   Industrial hygiene technicians conduct periodic noise surveys to document steady-state occupational noise risk areas. From these surveys, CHHP guidelines are established that limit approved exposure to noise in these known conditions based on a 3 dB exchange (see Table 2-2 above). Site supervisors enforce limits and protection, and job mates reinforce personal accountability. Many wartime noise threats are not routine or steady state. Exposure to IED, gunfire, and other weapons systems can occur without warning. Such exposures are best compensated for by wearing hearing protection whenever battle dress is required. Level dependent hearing protection is useful to allow for situational awareness and communication while still providing protection from gunfire and other random events.

   Off duty exposures are common and potentially cumulative with noise exposure encountered on the job. Advocacy and awareness campaigns developed under CHHP aim at educating members towards protecting against these often self-induced exposures. Hearing loss effects warrior survivability and lethality whether encountered on or off duty.

Elements of CHHP need acceptance and advocacy at high levels of Military command with leaders who understand the importance that hearing, as a sense, adds to the efficiency and objectives of the Military mission. Hearing is vital to communication, and protecting that capability is critical to operating at full capacity. Only with that understanding and advocacy will appropriate priority be able to overcome some of the inherent cultural biases that challenge individual accountability. Ultimately, vigilant and consistent individual actions are what will bring about success against an invisible, insidious, cumulative noise threat.

2.6 REFERENCES

[1] NIH, National Institute on Deafness and Other Communication Disorders, 2010, Quick Statistics, http://www.nidcd.nih.gov/health/statistics/Pages/quick.aspx.

[2] Hearing Health Foundation, Hearing Loss & Tinnitus Statistics, https://hearinghealthfoundation.org/statistics.

[3] Shargorodsky J., Curhan S., Curhan G. and Eavey R. Change in Prevalence of Hearing Loss in US Adolescents. The Journal of the American Medical Association, Volume 304, No. 7, August 18, 2010.

[4] Gilles A., Van Hal G., De Ridder D., Wouters K. and Van de Heyning P. Epidemiology of Noise-Induced Tinnitus and the Attitudes and Beliefs towards Noise and Hearing Protection in Adolescents. PLoS ONE 8(7): e70297, July 24, 2013.

[5] NIH, Department of Health and Human Services: Dealing with Hearing Loss. News in Health, December 2007, pp. 3.

[6] U.S. Department of Labor, Occupational Safety & Health Administration, Occupational Noise Exposure, https://www.osha.gov/SLTC/noisehearingconservation/.

[7] U.S. Department of Veterans Affairs, Veterans Benefits Administration, Annual Benefits Report Fiscal Year 2011.

[8] U.S. Department of Veterans Affairs, Veterans Benefits Administration, Annual Benefits Report Fiscal Year 2013.

[9] Hoffer M.E., Balaban C., Gottshall K., Balough B.J., Maddox M.R. and Penta J.R. Blast Exposure: Vestibular Consequences. Otology & Neurotology, Volume 31, Issue 2, pp. 232-236, February 2010.

[10] American Tinnitus Association, ADV Master Packet, February 2013.

[11] U.S. Army Health Command, Army Hearing Program: Hearing Loss Prevention for the Solider Presentation.

[12] NIH, National Institute on Deafness and Other Communication Disorders, Noise-Induced Hearing Loss, http://www.nidcd.nih.gov/health/hearing/pages/noise.aspx.

[13] NIH, Department of Health and Human Services: Dealing with Hearing Loss. News in Health, December 2008.

[14] U.S. Army Center for Health Promotion and Preventative Medicine: Readiness Through Hearing Conversation, Technical Guide 250 (2004), pp. 3.

[15] Hearing Loss Association of America, Basic Facts About Hearing Loss, http://www.hearingloss.org/content/basic-facts-about-hearing-loss.

[16] Hearing People Better: hearing Loss Affects Income, July 11, 2012.

[17] News-Medical.net, Hearing Loss Linked to Several Chronic Diseases, May 25, 2012.

[18] Bakalar N. Hearing Loss Takes a Toll on Health. New York Times, June 12, 2013.

[19] Kochkin S. Commentary: The Dollars and Sense of Addressing Hearing Loss in the Workplace. McClatchy Newspaper, June 18, 2012.

[20] Department of the Army: Army Hearing Program Special Text 4-01.501, February 2008.

[21] Kochkin S. and Rogin C. The Impact of Hearing Instruments on the Quality of Life. The Hearing Review, January 2000.

[22] U.S. Navy Flight Deck hearing Protection Use Trends: Survey Results American Speech-Language-Hearing Association, Untreated Hearing Loss in Adults – A Growing National Epidemic, http://www.asha.org/Aud/Articles/Untreated-Hearing-Loss-in-Adults/, 2012.

[23] Fausti S.A., Wilmington D.J., Gallun F.J., Myers P.J. and Henry J.A. 2009. Auditory and vestibular dysfunction associated with blast-related traumatic brain injury. J Rehabil Res Dev. 2009;46(6):797-810.

[24] Institute of Medicine, Gulf War and Health, Volume 9: Long-Term Effects of Blast Exposures, February 2014.

[25] Horton R. 2010 Global Burden of Disease Study, Understanding Disease, Injury, and Risk. The Lancet, Vol 380, No 9859, p. 2053-2054, 15 December 2012.

[26] OSHA, 2011a. Hearing Conservation Program. US Dept. Labor; Occupational Noise Exposure [Online]. Available by Occupational Safety and Health Administration. http://www.osha.gov/SLTC/noisehearingconservation/index.html (accessed 01.11.11).

[27] Yankaskas K. Prelude: Noise-induced tinnitus and hearing loss in the military. Hearing Research. (2012), doi:10.1016/j.heares, 2012.04.016.

[28] Stephenson M.R. and Stephenson C.M. 2000. Application of health communication theories. Proceedings of the 3rd Annual United States Army Force Health Protection Conference, Baltimore, MD, USA.

[29] Mazurek B., Olze H., Haupt H. and Szczepek A.J. 2010. The more the worse: the grade of noise-induced hearing loss associates with the severity of tinnitus. Int. J. Environ. Res. Public Health 7, 3071e3079.

[30] Groenwold M.R., Sangwoo T. and Masterson E. Severe hearing impairment among military Veterans – United States, 2010. Morbidity and Mortality Weekly Report; July 22, 2011 / 60(28):955-958.

[31] http://www.benefits.va.gov/reports/abr/2013_abr.pdf, Website accessed 10 June 2014.

[32] Scherer M.R. and Schubert M.C. Traumatic brain injury and vestibular pathology as a comorbidity after blast exposure. Physical Therapy. 2009; 89(9):980-992.

[33] Jagade M.V., Patil R.A., Suhail I.S., Kelkar P., et al. 2008. Bomb blast injury: Effect on middle and inner ear. Indian Journal of Otolaryngology and Head and Neck Surgery 60(4):324-330.

[34] Phillips Y.Y. and Richmond D.R. 1991. Primary blast injury and basic research: A brief history. In Conventional Warfare: Ballistic, Blast, and Burn Injuries. Washington, DC, USA: Office of the Surgeon General at TMM Publications.

[35] Xydakis M.S., Bebarta V.S., Harrison C.D., Conner J.C., et al. Tympanic-membrane perforation as a marker of concussive brain injury in Iraq. N Engl J Med. 2007 August 23;357(8):830-1.

[36] Ritenour A.E., Wickley A., Ritenour J.S. et al. Tympanic membrane perforation and hearing loss from blast overpressure in operation enduring freedom and operation Iraqi freedom wounded. Journal of Trauma. 2008 February; 64 (2 suppl):S174-8.

[37] Cave K.M., Cornish E.M. and Chandler D.W. Blast injury of the ear: clinical update from the global war on terror. Military Medicine. 2007 July; 172(2):726-30.

[38] Helfer T.M., Jordan N.N., Lee R.B., Pietruskiak P. et al. Noise-induced hearing injury and comorbidities among postdeployed UNITED STATES Army soldiers: April 2003 – June 2009. American Journal of Audiology. 2011 June;20(1):33-41.

[39] Walsh R.M., Pracy J.P., Huggon A.M. and Gleeson M.J. 1995. Bomb blast injuries to the ear: The London Bridge incident series. Journal of Accident & Emergency Medicine 12(3):194-198.

[40] Finlay S.E., Earby M., Baker D.J. and Murray V.S.G. 2012. Explosions and human health: The longterm effects of blast injury. Prehospital and Disaster Medicine 27(4):385-391.

[41] Cohen J.T., Ziv G., Bloom J., et al. Blast injury of the ear in a confined space explosion: auditory and vestibular evaluation. Isr Med Assc J. 2002 July; 4(7):559-62.

[42] Hoffer M.E., Balaban, C., Gottshall K., Balough B.J., Maddox M.R. and Penta J.R. Blast Exposure: Vestibular consequences and Associated Characteristics. Otology & Neurotology 31:232-236, 2010.

[43] DePalma R.G., Burris D.G., Champion H.R. and Hodgson M.J. Blast Injuries. N Engl J Med. 2005; 352(13):1335-42.

[44] Smith T. Linking Exposures and Health Outcomes to a Large Population-Based Longitudinal Study: The Millennium Cohort Study. Military Medicine, 176, 7:56, 2011.

[45] Dancer A. and Buck K. (2005). Noise: A Limiting Factor for the Use of Modern Weapon Systems? In New Directions for Improving Audio. Effectiveness (pp. KN1-1 – KN1-14). Meeting Proceedings RTO-MP-HFM-123, Keynote 1. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.aps.

[46] Zurek P.M. and Delhorne L.A. (1987). Consonant reception in noise by listeners with mild and moderate hearing impairment, J. Acoust. Soc. Am. 82, 1548-1559.

[47] Humes L.E., Dirks D.D., Bell T.S. and Kincaid G.E. (1987). Recognition of nonsense syllables by hearing-impaired listeners and by noise-masked normal. J. Acoust. Soc. Am. 81, 765-773.

[48] Dubno J.R. and Dirks D.D. (1992). Factors affecting performance of psychoacoustic and speech-recognition tasks in the presence of hearing loss, in Acoustical Factors Affecting Hearing Aid Performance, Second Edition, G.A. Studebaker and I. Hochberg (Eds.), Allyn and Bacon, Boston, MA, USA.

[49] Bonewitz L.B. and Ryan M.R. (2012). Effects of Differential Hearing Loss on Soldier Survivability and Lethality in Simulated Combat. Final report for senior class project, United States Military Academy, West Point, NY, USA.

[50] Ansi, A. 1997. S3. 5-1997, Methods for the calculation of the speech intelligibility index. New York: American National Standards Institute.

[51] Larm P. and Hongisto V. (2006). Experimental comparison between speech transmission index, rapid speech transmission index, and speech intelligibility index. The Journal of the Acoustical Society of America, 119, 1106.

[52] Garinther G. and Peters L. (1990). Impact of communications on armor crew performance, Army Research, Development and Acquisition Bulletin, 1-5.

[53] Casto L.K.L. and Casali J.G. (2010, September). Effect of Communications Headset, Hearing Ability, Flight Workload, and Communications Signal Quality on Pilot Performance in an Army Black Hawk Helicopter Simulator. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 54, No. 1, pp. 80-84). SAGE Publications.

[54] Humes L.E., Joellenbeck L.M. and Durch J.S. Noise and Military Service: implications for hearing loss and tinnitus. The National Academies Press, Washington, DC, USA, 22 September 2005.

[55] Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, P.L., No. 110-417, Section 721.

[56] Government Accountability Office Report to Congress, Hearing Loss Prevention, GAO 11-114, January 2011.

[57] Hauser S.L. Institute of Medicine Chair, Committee on Gulf War and Health: Long-Term Effects of Blast Exposures. Volume 9, Board on the Health of Select Populations, 2014.

[58] RTO Lecture Series 219 Damage Risk from Impulse Noise. RTO-EN-11 ISBN 92-837-1042-8 UNCLASSIFIED; AC/323(HFM)TP/31 September 2000.

[59] Defense Safety Oversight Committee: High Noise Source Reduction Working Group. Acoustical Engineering Controls and Estimated Return on Investment for DoD Selected High Noise Sources: A Roadmap for Future Noise Control in Acquisition – Draft report 2012-012.

[60] Scherer M.R. and Schubert M.C. (2009). Traumatic brain injury and vestibular pathology as a comorbidity after blast exposure. Physical therapy.

[61] Remenschneider A.K., et al. Otologic outcomes after blast injury: the Boston Marathon experience. Otology & Neurotology 35.10 (2014):1825-1834.

[62] Zurek P.M. and Desloge J.G., Hearing loss and prosthesis simulation in audiology. The Hearing Journal 60.7 (2007): 32-33.

[63] Rubovitch, V., et al. (2011). A mouse model of blast-induced mild traumatic brain injury. Experimental neurology, 232(2): 280-289.

[64] Noise and Military Service: Implications for Hearing Loss and Tinnitus. 2006. Paperback ISBN: 978-0-309-09949-3, DOI: 10.17226/11443.

[65] Gulf War and Health: Long-Term Effects of Blast Exposures. 2014. Paperback ISBN: 978-0-309-26764-9, DOI: 10.17226/18253.

Chapter 3 – SCREENING AND SURVEILLANCE METHODS

3.1 GENERAL ASPECTS

Good and healthy hearing is of major importance for any activity of soldiers in the field, e.g., Ref. [11]. Therefore, the hearing status of soldiers should be assessed on a regular basis. Reasons for periodic hearing testing of soldiers are:

- Oversight of the hearing status of the whole army:
  - Timely intervention as soon as a hearing loss starts to develop.
  - Maintaining a record of hearing status for each individual that can be used for tracking a hearing loss to its presumable origins.
- Surveillance of affected individuals:
  - Identifying areas of work that are especially prone to causing hearing loss and identifying best and worst effects of hearing conservation practices.

Typical diagnostic hearing tests are expensive especially in terms of human resources. Hearing testing for hearing conservation purposes does not have to be as precise as tests for diagnostics or rehabilitation, but they should still result in relevant, reproducible, and valid data [15]. A certain reduction of precision can be accepted if this means faster testing and cheaper or sturdier test equipment. For example, when measuring audiograms, bone conduction does not necessarily have to be assessed because the most prevalent types of hearing loss due to noise exposure will be evident from the air conduction audiogram alone. Additional bone conduction testing would take additional time and need additional equipment. Based on this premise, frequency specific threshold audiograms to identify air conducted tones will be referred to as "screening audiometry" so as not to confuse such testing with "hearing screening", which often refers to in-school testing of children where a reasonably low threshold sound is presented in a soundfield or to each ear and conclusive if the subject is able to identify that bench mark.

Screening audiometry should include the following requirements:

- Automation should be possible (i.e., reduced workload);
- Minimal maintenance needs;
- Inclusion of different aspects of hearing (i.e., speech in noise testing);
- Reliable identification of hearing problems;
- Reproducible for longitudinal assessment; and
- Comparable across different Nations.

If a potential hearing loss is detected in the hearing screening procedure, this should trigger further diagnostic testing, as well as the possibility for suitable intervention. Such interventions are discussed in the section "Hearing Diagnostics and Rehabilitation". The recommended questionnaires (Section 3.2.3) are internationally comparable and were developed to a large extent by partners of the international project HearCom [20].

In addition to assessing the hearing status of the tested individuals, the appointment for hearing tests should be used for educating the soldiers about the implications of noise (potential damage to the ears and adverse impact on communications).

3.2 HEARING SCREENING METHODS

3.2.1 Audiogram (Air Conduction)

As the most widely used audiometric test, the pure tone air conduction audiogram gives basic insight into an individual's hearing. The pure tone audiogram evaluates the individual hearing threshold levels for defined frequencies, i.e., the lowest level of a pure tone which can be perceived. An audiogram can be measured automatically following the procedure described by Hughson & Westlake [10]. For the automation procedure, see Bisitz & Silzle [2]. In order to be consistent with the U.S. DOEHRS-HC hearing conservation database, the audiogram should include the frequencies 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz for each ear. In a recent report, the Institute of Medicine on the effect of noise on Military service recommended including 8 kHz in addition to the six frequencies in the current standard, or possibly as a substitute for 6 kHz. If only air conduction is used, this can be done within five minutes per ear (see Ref. [1]). The implemented adaptive procedure allows fast standard audiogram measurements including high frequencies up to 16 kHz. Also very short screening measurements with a few frequencies are possible. Included in the procedure is functionality in order to avoid errors by accident or any attempt of deception.

The additional measurement of bone conduction thresholds could yield insights into the kind of hearing loss (conductive, sensorineural, or mixed), but this kind of diagnostics is something that needs to be done by an ENT specialist or Audiologist, so for hearing conservation testing, air conduction thresholds are sufficient. The high frequencies 8 kHz and 10 kHz are recommended for screening audiometry measures in order to identify as early as possible a potentially developing hearing loss due to noise exposure. Noise-induced hearing loss can result in a “noise notch” in the audiogram at frequencies around 3 kHz to 6 kHz, often most pronounced at 4 kHz (e.g., Refs. [9] and [11]).

In addition to storing the individual data points collected by the automatic audiogram measurement, a classification of the audiograms can be performed in order to decide if a referral to a specialist is necessary. Classification may be done according to WHO guidelines[1]. The WHO defined grades of hearing impairment based on the pure tone average at the frequencies 500 Hz, 1 kHz, 2 kHz and 4 kHz. Although the WHO classification is done for the better ear only, we propose to classify each ear separately. Individuals should be referred to further examination by an ENT specialist or Audiologist if the PTA is larger than 25 dB in one ear and if this is the first time the condition is detected (PTA of 25 dB is the boundary between the WHO categories “no impairment” and “slight impairment”).

Table 3-1: Audiogram – Resulting Data Points and Units.

		500 Hz		1 kHz		2 kHz	3 kHz	4 kHz	8 kHz		PTA
Left Ear	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	PTA (dB HL)
Right Ear	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	ACT (dB HL)	PTA (dB HL)

ACT: Air Conduction Threshold; PTA: Pure Tone Average.

[1] http://www.who.int/pbd/deafness/hearing_impairment_grades/en/index.html.

3.2.2 Speech Test

In addition to the audiogram, a functional test of the auditory system should be performed that gives insight into speech understanding in noisy situations. This is an aspect of hearing that is highly relevant to daily life, and it is stated by many hearing impaired people as one of the major handicaps related to their hearing loss (e.g., Ref. [16]). Speech intelligibility tests in noise provide a test procedure suited to assess this aspect of hearing (e.g., Ref. [14]). Additionally, speech intelligibility in noise is an early indicator of a potentially developing hearing loss. Understanding speech in noise is one of the most important aspects of hearing in Military environments, especially for soldiers. Unfortunately, the audiogram and speech tests in quiet do not seem to be good indicators of speech understanding in noise (e.g., Ref. [18] and [3]).

An adequate screening test for assessing speech intelligibility in noise is the digit triplet test (e.g., Ref. [6] and [25]). It uses spoken combinations of digit triplets as speech material and determines the speech reception threshold in noise, usually with an adaptive procedure. The digit triplet test is available in the languages Dutch, English, French, German, Greek, Polish, Russian, Spanish, and Swedish. Further languages are under development (Arabic, Finnish, Hebrew, Italian, Persian and Turkish). During the development of the different language versions of the test, special attention has been paid to make the tests highly comparable across languages (see Refs. [23] and [25]). Validation studies using the digit triplet test have been performed for different languages (see Refs. [17], [12], [7], [13] and [21].

The digit triplet test is designed as a hearing screening test that can be performed by the test subject alone. Depending on the language, up to 30 trials of the test are performed in order to determine the speech reception threshold for digits in noise (SRT). The test is performed monaurally and takes less than five minutes per ear. Due to the restricted speech material, the digit triplet test may even be performed with non-native listeners if they know the digits of the test language [24]. However, testing in an individual's native language is clearly preferred.

For each language, there are reference SRT values determined in normal hearing populations. Based on these values, boundaries for good, intermediate and poor test results were determined. Thus, based on the test result of the digit triplets test, it can be decided if a referral of the tested individual to an ENT specialist or Audiologist might be necessary.

Due to the fact that the digit triplet test determines the threshold signal to noise ratio at which 50% of the presented speech stimuli are intelligible, test subjects are not able to cheat during this test.

Table 3-2: Speech Test – Resulting Data Points and Units.

	SRT in Noise
Left Ear	SRT (dB SNR)
Right Ear	SRT (dB SNR)

SRT: Speech Reception Threshold.

3.2.3 Hearing Questionnaire

Not all hearing problems are equally detectable using pure tone or speech audiometry, and not every individual suffers the same handicap due to a certain hearing loss. Therefore, an automated questionnaire assessing the everyday hearing experience of the tested individual will give additional insights into his or her potential hearing deficits. Questionnaires can be generic or disease specific. To achieve a reasonable sensitivity, the disease specific scales are an advantage. For hearing the fields “Ability”, “Handicap”, “Quality of Life (QoL)” and duty related aspects should be covered. For practicability the time spend for filling in a questionnaire is very limited, especially in screening programs. For NATO it is important to use questionnaires that are available in several languages.

It was agreed to use the "The Hearing-Dependent Daily Activities" HDDA questionnaire with 12 items, added by Military-specific questions for screening.

The questions of the HDDA cover the areas:

- Speech perception in quiet;
- Speech perception in noise;
- Sound localization;
- Recognition of sounds; and
- Detection of sounds.

Risk factors for soldiers should be addressed in screening procedures (Yes/No):

1) Did you experience any hearing loss, severe dizziness, Tinnitus (> 24 h) within the last year / since the last hearing tests?
2) Have you been on missions?
3) Did you suffer noise trauma or explosions trauma?
4) Do you work regularly (> 2 h/day) in loud noise (unable to talk)?
5) Were you involved in combat battles?
6) Have you had any head injury?

For each question, one of five answers must be chosen. The questionnaire can be completed by the tested individual on their own using a computer interface. Depending on the answers to the different questions, an overall score is calculated. The questionnaire was optimized and validated with normal hearing and hearing impaired subjects. This development resulted in boundaries for the scores of the questionnaire, so that good, intermediate and poor test results can be categorized. Although a questionnaire is inherently prone to manipulation by the test takers, it can result in valuable information about the problems that an individual experiences in everyday life. Completing the questionnaire takes less than 5 minutes.

Table 3-3: Hearing Questionnaire – Resulting Data Points and Units.

	HQ Score
Questionnaire	Score (normalized to a value between 0 and 1)

HQ: HearCom Questionnaire.

For more detailed analysis, more questionnaires are necessary.

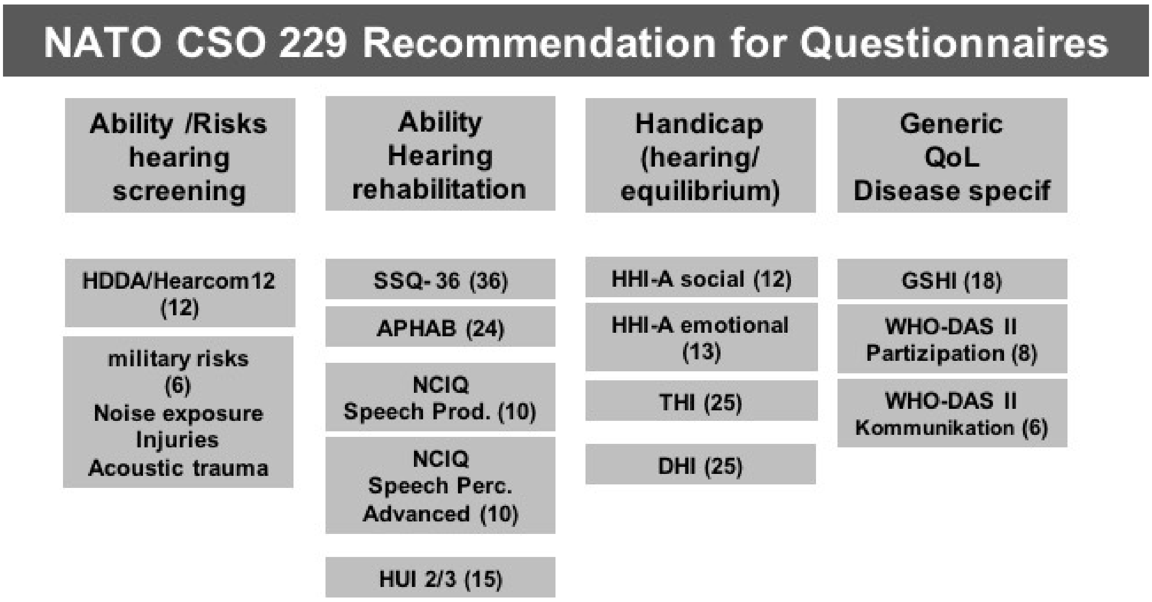

Figure 3-1: Internationally Approved Questionnaires for Hearing Assessment, Addressing Different Aspects of Hearing Function.

3.2.4 Ear Examination (Optional)

Examination of the ear (otoscopy) should only be performed if a trained ENT specialist or Audiologist is available, as findings are categorized as abnormal, normal or Nothing Abnormal Detected (NAD).

3.2.5 Ear History

The ear history of the tested individual will be assessed using an automated anamnesis questionnaire. Questions will be related to previous ear operations, grommets, discharge, otitis media, sudden hearing loss, etc.

3.3 HEARING DIAGNOSTICS AND REHABILITATION

For subjective hearing losses, or when screening exams are failed, soldiers should be referred for evaluation by an ENT specialist or Audiologist when possible so that test outcomes are maintained within the database. In the rare cases of emergency care that occurs outside of this system, provisions to recapture the information should be attempted. Standardized examinations should be performed that will yield comparable data for all soldiers and between participating countries. As a standardized measurement battery, the so-called Auditory Profile [8] has been proposed by the HearCom project [20]. The tests proposed here are based on the experiences with the Auditory Profile.

3.3.1 Ear Examination

The initial assessment of the patient should be an ear examination (otoscopy). This should be done at least annually.

3.3.2 Audiogram

As basic audiological information, the audiogram should be measured using air conduction (500 Hz; 1 kHz; 2 kHz; 3 kHz; 4 kHz; 6 kHz; 8 kHz) and bone conduction (500 Hz; 1 kHz; 2 kHz; 3 kHz; 4 kHz). Air conduction thresholds should be measured annually while bone conduction thresholds may be measured with less frequent intervals. In contrast to the audiogram measurement for hearing screening, an Audiologist or equivalent specialist should measure the audiogram.

3.3.3 Hearing/Ear History

The initial anamnesis should assess different aspects of hearing. At least noise exposure, otitis media, family history of hearing loss, tinnitus and noise-induced hearing loss should be assessed. Also balance problems or similar symptoms related to vestibular function should be assessed.

3.3.4 Speech Audiometry

Due to the fact that speech communication is one of the major functions of the auditory system, speech audiometry should be performed for any patient visiting an ENT specialist or Audiologist. Speech reception in quiet is an important aspect of speech audiometry. However, typically, speech reception performance in quiet is in most cases directly related to the pure tone audiogram and may therefore be omitted [18], [3]. As premise, any subject that cannot understand speech in quiet should not be considered for Military service. Therefore, the Speech Reception Threshold (SRT) in noise should be determined. This measure is more relevant for everyday listening performance (because speech is hardly ever listened to in absolute quiet) and cannot easily be predicted from the pure tone audiogram [19]. For assessing speech understanding in noise, typical single word tests (like, e.g., spondee tests or monosyllable tests) are insufficiently precise when using short test lists (e.g., Ref. [5]). Therefore, speech audiometry in noise should be performed using sentence tests (e.g., Ref. [14]). There are various sentence test procedures available in different languages (e.g., Ref. [7]). Clearly, speech audiometry for diagnostics and rehabilitation should be performed in the tested individual's native language. The test procedure that is most easily comparable between different languages is the so-called Matrix Test. Matrix Tests are available in the languages Danish, English, French, German, Polish, Spanish, and Swedish, and are currently being developed for the additional languages Dutch, Finnish, Italian, Persian, Russian and Turkish. The basic idea of Matrix Sentence Tests is to use a limited set of 50 words as basic speech material from which a large number of seemingly random sentences can be generated. Each sentence in one language always has the same syntactic structure (e.g., in English Name – Verb – Numeral – Adjective – Noun as in "Rachel prefers seven old rings"). The semantic content of each sentence is unpredictable because there are ten possible words for each position within a sentence that can be randomly chosen. This means that Matrix Tests can be used arbitrarily often with the same patient because the sentences cannot be learned by heart.

Due to the same basic structure and development of Matrix Tests in different languages, the test results of these tests are especially well comparable across different languages [22]. For diagnostics, unaided speech reception thresholds in noise should be determined with Matrix Tests for each ear individually. For rehabilitation purposes, a comparison of aided and unaided SRT can be used to assess the effect of a hearing device. Also, the SRT improvement between different hearing device settings can be used for fine-tuning.

An adaptive test may not always be feasible. When speech in noise testing varies between countries, attempts to correlate this test to indicate comparability should be considered. In some cases for diagnostic purposes it may be desirable to collect speech in noise performance data with some masker other than speech shaped noise (e.g., a speech masker or fluctuating noise masker). In such cases, attempts should also be made to collect speech reception data with a speech shaped noise masker to allow a point of comparison across patients.

3.3.5 Other Tests

Other ear examinations can be done on an as-needed based on the individual needs of the patient. The following list of tests is not exhaustive, but gives an overview of the most frequently performed tests.

3.3.5.1 Tympanometry

Tympanometry should be performed at least once for every patient.

3.3.5.2 Stapedius Reflex Measurement

The stapedius reflex threshold should be measured if necessary.

3.3.5.3 Otoacoustic Emissions

Distortion Product Otoacoustic Emissions (DPOAE) and/or Transitory Evoked Otoacoustic Emissions (TEOAE) should be assessed if necessary.

3.3.5.4 Loudness Scaling (ACALOS)

One of the major differences between conductive and sensorineural hearing loss is the recruitment effect. We propose to assess the recruitment effect by using Adaptive Categorical Loudness Scaling (ACALOS – see Ref. [4]. The ACALOS procedure not only yields insight into the presence or absence of recruitment, but also quickly and reliably determines the Most Comfortable Level (MCL) and the Uncomfortable Level (UCL). These measures can be used for diagnostic purposes as well as for rehabilitation (e.g., for prescribing hearing aids).

3.3.5.5 Auditory Brainstem Response

The Auditory Brainstem Response (ABR) will only be measured if clinically indicated.

3.3.5.6 Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) will only be performed if clinically indicated.

3.4 REFERENCES

[1] Bisitz T. 2012. Automated pure tone audiometry for screening purposes 2nd International Conference on Adult Hearing Screening. Cernobbio, Italy.

[2] Bisitz T. and Silzle A. 2011. Automated Pure-tone Audiometry Software Tool with Extended Frequency Range AES 130th Convention. London.

[3] Bosman A.J. and Smoorenburg G.F. 1995. Intelligibility of Dutch CVC syllables and sentences for listeners with normal hearing and with three types of hearing impairment. Audiology, 34, 260-284.

[4] Brand T. and Hohmann V. 2002. An adaptive procedure for categorical loudness scaling. J Acoust Soc Am, 112, 1597-1604.

[5] Brand T. and Wagener K.C. 2005. Wie lässt sich die maximale Verständlichkeit optimal bestimmen? 8. DGA-Jahrestagung 2005. Göttingen, Germany.

[6] Buschermöhle M., Wagener K.C., Berg D., Meis M. and Kollmeier B. 2012. Relation between screening test and audiological parameters in a clinical population - Statistical results from the digit triplet test in German (in preparation).

[7] Buschermöhle M., Zokoll M.A., Wagener K.C., Wardenga N., Warzybok A., et al. 2012. Multilingual Speech Audiometry and Diagnostics: Consistency of Speech Tests Across Languages XXXI World Congress for Audiology. Moscow, Russia.

[8] Dreschler W., Van Esch T., Larsby B., Hallgren M., Lutman M.E., et al. 2008. Charactering the individual ear by the "Auditory Profile" Acoustics'08. Paris, France, pp. 5017-5022.

[9] Gelfand S.A. 2001. Essentials of Audiology. New York: Thieme.

[10] Hughson W. and Westlake H. 1944. Manual for program outline for rehabilitation of aural casualties both military and civilian. Transactions of the American Academy of Ophthalmology and Otolaryngology.

[11] Humes L.E., Joellenbeck L.M. and Durch J.S. 2005. Noise And Military Service: Implications for Hearing Loss And Tinnitus: National Academies Press.

[12] Jansen S., Luts H., Wagener K.C., Frachet B. and Wouters J. 2010. The French digit triplet test: A hearing screening tool for speech intelligibility in noise. Int. J. Audiol., 49, 378-387.

[13] Jansen S., Luts H., Wagener K.C., Kollmeier B., Del Rio M., et al. 2012. Comparison of three types of French speech-in-noise tests: A multi-center study. Int. J. Audiol.

[14] Kollmeier B. and Wesselkamp M. 1997. Development and evaluation of a German sentence test for objective and subjective speech intelligibility assessment. J Acoust Soc Am, 102, 2412-2421.

[15] Koopman J., Davey E., Thomas N., Wittkop T. and Verschuure H. 2008. How should hearing screening tests be offered? Int. J. Audiol., 47, 230-237.

[16] Kramer S.E., Kapteyn T.S. and Festen J.M. 1998. The self-reported handicapping effect of hearing disabilities. Audiology, 37, 302-312.

[17] Smits C., Kramer S.E. and Houtgast T. 2006. Speech reception thresholds in noise and self-reported hearing disability in a general adult population. Ear and Hearing, 27, 538-549.

[18] Smoorenburg G.F. 1992. Speech reception in quiet and in noisy conditions by individuals with noise-induced hearing loss in relation to their tone audiogram. Journal of the Acoustical Society of America, 91, 421-437.

[19] Theunissen M., Swanepoel D. and Hanekom J. 2009. Sentence recognition in noise: Variables in compilation and interpretation of tests. Int J Audiol, 48, 743-757.

[20] Vlaming M.S., Kollmeier B., Dreschler W., Martin R., Wouters J., et al. 2011. HearCom: Hearing in the Communication Society. Acta Acust United Acustica, 97, 175-192.

[21] von Gablenz P., Holube I. and Buschermöhle M. 2012. Chances and limits of self-screening: Evaluation of the digit triplet test in noise (German telephone version) 2nd International Adult Hearing Screening Conference. Cernobbio, Italy.

[22] Wagener K.C., Brand T. and Kollmeier B. 2007. International cross-validation of sentence intelligibility tests 8th EFAS Congress. Heidelberg, Germany.

[23] Wagener K.C., Vormann M., Kollmeier B., Lyzenga J., Houtgast T., et al. 2008. HearCom Deliverable D-1-7: Report on normalization data and cross-language comparison for sentence tests: HearCom.

[24] Warzybok A., Wagener K.C. and Brand T. 2007. Intelligibility of German digit triplets test by non-native listeners 8th EFAS Congress / 10th Congress of the German Society of Audiology. Heidelberg, Germany.

[25] Zokoll M.A., Wagener K.C., Brand T., Buschermöhle M. and Kollmeier B. 2012. Internationally comparable screening tests for listening in noise in several European languages: The German digit triplet tests as an optimization prototype. Int. J. Audiol., 51, 697-707.

Chapter 4 – DATABASE CONCEPT

4.1 DATA SPECIFICATION

It is recommended that the required data be collected by automated systems to the extent practicable for efficiency and to maintain data integrity and quality. If possible, this should start with the transfer of audiological exam data directly from the diagnostic device to the database. When questionnaires can be filled in by Service members using touchscreen mobile devices they should be. These surveys may be directed or assisted as necessary by medical staff.

This concept includes eight dimensions of data acquisition, with a time conscious version designed to capture surveillance and exposure information for Service members with normal hearing documented by regular audiolometric screening, as well as a more detailed clinical dataset for members noted to have hearing loss.

4.1.1 STO HFM-229 Database

1 General Screening
- 1.1 Surveillance
- 1.2 Identification of hearing loss
- 1.3 Identification of risk areas

2 Prevention
- 2.1 Noise Mitigation
- 2.2 Ear Protection
- 2.3 Medical treatment prior to noise exposure
- 2.4 Others

3 Treatment
- 3.1 Audiological training
- 3.2 Medical treatment
- 3.3 Surgical treatment
- 3.4 Hearing aids
- 3.5 Implants

4 Rehabilitation long-term outcome
- 4.1 Compensation claims
- 4.2 Auditory outcome metrics
- 4.3 Tinnitus outcome measures
- 4.4 Rehabilitation methods
- 4.5 Others

5 Individual risk factors
- 5.1 Genetic risks
- 5.2 Behavioural risks
- 5.3 Pre-occupational hearing loss
- 5.4 Medical history
  - 5.4.1 Drugs
  - 5.4.2 Medication
  - 5.4.3 Middle and inner ear disease
  - 5.4.4 Others
- 5.5 Family history

6 Scientific Data
- 6.1 Noise exposure
- 6.2 Missions

6.3 Study Treatment Data
6.4 Other Interventions
7 Occupational Health
7.1 Fitness for duty criteria
7.2 Identification of occupational risk factors
7.3 Estimation of risk and sequelae
7.4 Preventive measures evaluation
8 Epidemiology
8.1 International comparison
8.2 Military hearing health and readiness
8.3 Military health measures
8.4 Hearing, hearing loss, and aging
8.5 Hearing and job
9 Others

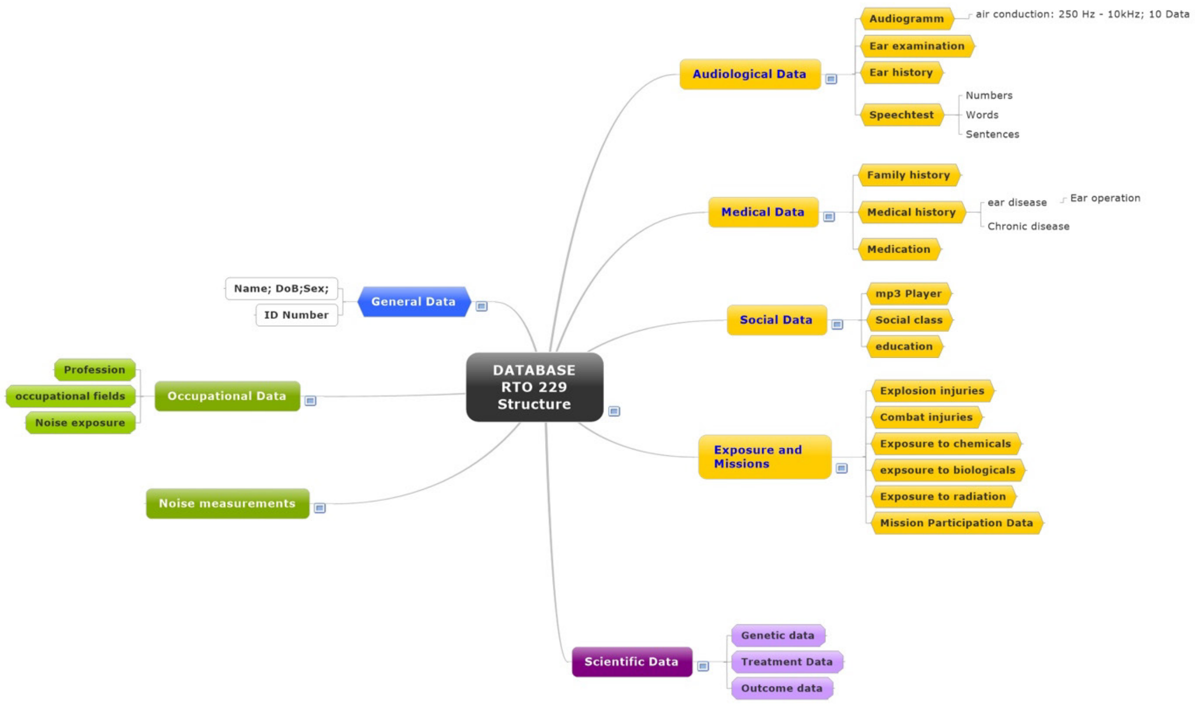

Figure 4-1: Description of Database Dimensions.

4.2 A CASE FOR AN INTERNATIONAL DATABASE

The Database enables commands or professionals to analyse the various aspects of health care concerning hearing and hearing loss. The figure points out possible fields of research, which are supported by the database.

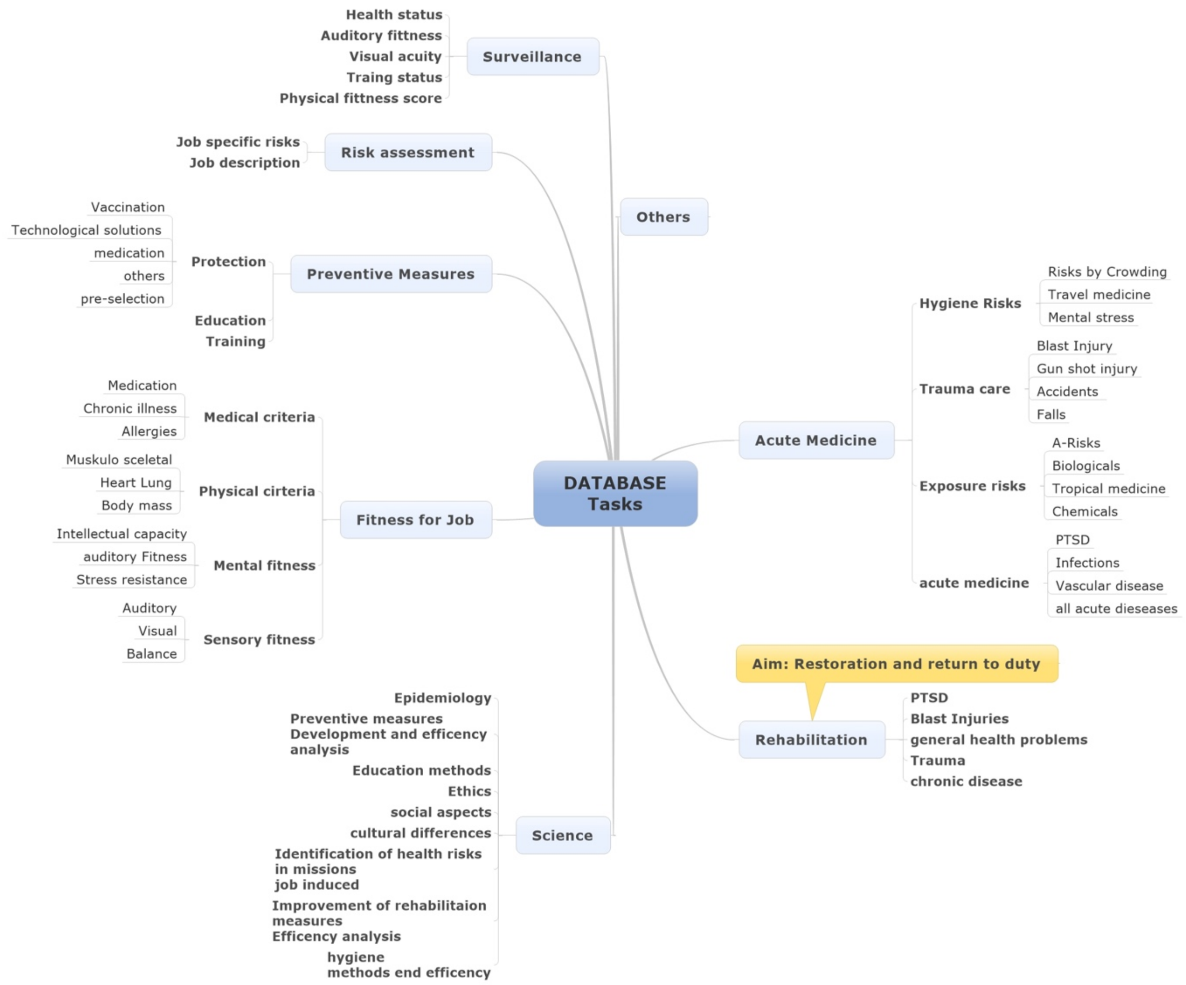

Figure 4-2: Field-Classification Within the Database.

4.2.1 Audiological Data

Automated systems can be used to obtain audiometric information. A set of subjective and objective tests, including speech understanding in noise and standardized questionnaires are recommended. For details, see Chapter 3.

4.2.2 Medical Data

4.2.2.1 Family History

Animal models and humans show different susceptibility to noise damage even under very carefully controlled exposure conditions. This difference in susceptibility may be related to unknown genetic components [2]. There are studies suggesting that a family history of hearing loss may be associated with molecular susceptibility at the enzyme or mitochondrial level [1]. However, as yet, there is limited but growing research related to this topic. Further research in this area may add significant information correlating family genetic history and noise-induced hearing loss which may identify resiliency and susceptibility patterns.

It is recommended that the questionnaire include the following questions:

- **Do you have family members who have had hearing loss, or who have worn hearing aids at an early age?**
- **If so, did they work in occupational noise?**
- **Did they participate in hobbies that exposed them to noise hazards?**

4.2.2.2 Medical History

4.2.2.2.1 Cancer

If patients are treated for cancer they often receive chemotherapy, radiation therapy or a combination of both. Chemotherapy consisting of platinum-derivates such as cisplatin and carboplatin are antitumor drugs with ototoxic side-effects [3], [5], [4]. The ototoxicity induced by platinum-derivates is characterized by loss of cochlear hair cells and cells of the spiral ganglion (agglomeration of nerve cell bodies in the cochlea) and degeneration of the stria vascularis [6]. Aminoglycosides are another class of ototoxic medications that, like platinum-derivates produces hearing loss that spreads from high to low frequencies [7]. Radiotherapy concentrated in the region of the petrous bone (i.e., for the treatment of nasopharyngeal or paranasal sinus cancer, cerebellopontine angle tumors and intracranial lymphoma) can cause direct cochlear damage, auditory nerve damage, or secondary damage as a result of the treatment [8], [9], [10].

4.2.2.2.2 Diabetes Mellitus

Patients with early onset Type 2 Diabetes Mellitus and poor glycemic control have an increased prevalence of sub-clinical hearing loss and impaired auditory brainstem responses. Hearing impairment may be an under-recognized complication of diabetes [11], [12].

4.2.2.2.3 Auto-Immune Disease

An auto-immune Progressive Sensorineural Hearing Loss (PSNHL) can occur as one of the clinical features of systemic immune-mediated disorders, such as Cogan's syndrome, Behcet's disease, Wegener's granulomatosis, mixed cryoglobulinaemia, systemic sclerosis, systemic lupus erythematosus, giant cell arteritis, panarteritis nodosa, relapsing polychondritis, unclassified systemic vasculitides, etc., or as a distinct clinical entity, the so-called auto-immune inner ear disease [13], [14], [15].

4.2.2.2.4 Blast-Injury / PTSD / Ear Disease

A history of recurrent otitis media, grommet placement or chronic otitis media with or without cholesteatoma can be related to hearing loss (conductive or sensorineural). Therefore a thorough screening of ear diseases in the past is imperative when obtaining patient histories.

4.2.2.2.5 Tobacco

There is epidemiological research suggesting a positive association between smoking and hearing impairment [16], [17], [18], [19]. A few studies, however, have not found any association between smoking and hearing impairment [42], [20]. These studies suggest that smoking alone is not a risk factor of hearing impairment but can be when combined with other factors such as elevated blood pressure, use of painkillers or high cholesterol levels. A disturbance in the blood flow and a reduction in oxygen supply to the cochlea have been proposed as the mechanisms on which this may be based [18].

4.2.2.2.6 Alcohol

The current data suggest that low or moderate alcohol consumption does not influence the risk of hearing loss in older men [21], [22]. However data about the relation between alcohol and noise-induced hearing loss are scarce.

4.2.2.3 Medical Questionnaire

The questionnaire should contain the following questions:

- **Do you have, or have you ever been diagnosed with the following diseases or injuries?**
- **Cancer: Yes/No If yes, what type?**
- **Diabetes? Yes/No If yes, is it well controlled?**
- **Auto-immune disease? Yes/No**
- **Chronic headache? Yes/No**
- **Blast injury? Yes/No**
- **Post-traumatic stress disorder? Yes/No**
- **Chronic ear infections? Yes/No**
- **Grommet insertion? Yes/No**
- **Ear operations? Yes/No If yes: what kind of operation**
- **Do you use tobacco? Yes/No If yes: how much?**
- **Do you use alcohol? Yes/No If yes: how much?**

4.2.2.4 Medication

Many drugs are recognized for their potential ototoxic side effects. Among these, aminoglycosides, diuretics, NSAIDs are best known to enhance noise-induced damage.

It is clear that aminoglycosides such as gentamycin, kanamycin, streptomycin, amikacin, tobramycin, and neomycin have cochleotoxic effects with the sensory hair cells being particularly sensitive [24], [25], [26]. They enter the cochlea through the stria vascularis [25] before they reach the cochlear hair cells where they can be stored for several months [27], [28]. Aminoglycoside-induced hearing loss initially affects the high frequency and spreads to the lower frequencies [25] depending on the treatment duration and dosing.

Loop-diuretics like ethacrynic acid, furosemide and bumetanide inhibit sodium and chloride ion reabsorption. They are widely used in current clinical treatments. Their ototoxicity is a significant side-effect, which may last during treatment. Their cochleotoxic effect is characterized by a sudden high-frequency hearing loss due to dysfunctions of the stria vascularis [29], [23], [30]. Overall, ototoxicity attributed to this group of medications is usually self-limited and reversible in adult patients, although irreversible hearing loss has been reported in neonates [31].

The adverse effects of certain non-steroidal analgesic drugs on hearing are well documented in the literature. High doses of salicylate (> 2.5 g/d) induce an auditory temporary threshold shift and sometimes tinnitus [32]. In general the recovery to a normal auditory sensitivity occurs within two or three days from the last salicylate administration. The exact mechanism of salicylate-induced hearing impairments is still uncertain. It seems that the ototoxic effects result from a conjunction of several reversible disturbances at the level of the cochlea [33], [32].

Some studies indicate that the administration of ototoxic drugs such as aminoglycosides produces increased susceptibility to noise-induced damage [34], [35], [36].

Salicylate-induced temporary threshold shifts may exacerbate temporary noise effects due to the reduced comprehension of speech and difficulty to detect acoustic alarms in noisy environments [37]. So far, it is not known whether salicylates in combination with environmental noise would promote permanent noise-induced hearing loss [38].

In antitumor drugs, an exacerbation of cisplatin ototoxicity was observed in chinchilla and guinea pigs with concomitant moderate to high levels of noise exposure [39], [40], [41].

A comprehensive list of medications on a questionnaire is impractical. Addition of the following questions is recommended:

- **Do you use medication? Yes/No If yes: what kind?**
- **Have you ever been hospitalized and received IV antibiotics for an infection? Yes/No**
- **Was this associated with a sense of hearing loss or ringing in the ears (tinnitus)?**

4.2.2.5 Social Data

Demographic and socioeconomic data are important co-factors and variables when determining the chronic effects of hearing loss on individuals and society. Assessing off-duty noise exposure is an important epidemiological and population health consideration that may target advocacy, prevention and education campaigns at the right audiences. Associations between education and training level, career fields, age, time in the Military, genetic and family histories aside from showing trends and identifying potential risk can also uncover correlations between predispositions to hearing loss or hearing status and earning potential and/or other factors. The following questions may focus educational and protection efforts.

4.2.2.5.1 Social Class, Rank and Education

There may be significant differences in the access of educational information and environmental, occupational, and cultural noise exposures. Patients from a lower social class have an increased prevalence of sub-clinical hearing loss and impaired auditory brainstem responses [12].

4.2.2.5.2 Education

Education is also related to social class and an important demographical consideration. Furthermore it is interesting to find out what is the influence of education in the use of hearing protection (personal accountability), on the occurrence of noise exposure (occupational opportunity, risk-taking behavior), and, associations with rates of noise-induced hearing loss.

4.2.2.5.3 Social Questionnaire

The questionnaire should contain the following questions:

- **Do you frequently use an MP3 player with loud noise levels? Yes/No**
- **Do you have one of the following hobbies:**
  - **Hunting Yes/No**
  - **Motorsport Yes/No**
  - **Motor-biking Yes/No**
  - **Fireworks Yes/No**
- **If you answered yes to any of the above, do you use hearing protection during these activities?**
- **What is your current rank?**

- **What is your highest level of education?**
- **Have you ever been educated or trained in the use of hearing protection?**

4.3 REFERENCES

[1] Abreu-Silva R.S., Rincon D., Horimoto A.R., Sguillar A.P., Ricardo L.A., Kimura L., Batissoco A.C., Auricchio M.T., Otto P.A. and Mingroni-Netto R.C. The search of a genetic basis for noise-induced hearing loss (NIHL). Ann Hum Biol. 2011 March;38(2):210-8. Epub 2010 September 3.

[2] Davis R.R., Kozel P. and Erway L.C. Genetic influences in individual susceptibility to noise: a review. Noise Health. 2003 July – September;5(20):19-28.

[3] Fausti S.A., Schechter M.A., Rappaport B.Z., Frey R.H. and Mass R.E. Early detection of cisplatin ototoxicity: selected case reports, Cancer 53, 1984, pp. 224-231.

[4] Montaguti M., Brandolini C., Ferri G.G., Hatzopoulos S., Prete A. and Pession A. Cisplatin and carboplatin-induced ototoxicity in children: clinical aspects and perspectives for prevention, Acta Otorhinolaryngol. Ital. 22, 2002, pp. 14-18.

[5] Macdonald M.R., Harrison R.V., Wake M., Bliss B. and Macdonald R.E. Ototoxicity of carboplatin: comparing animal and clinical models at the hospital for sick children, J. Otolaryngol. 23, 1994, pp. 151-159.

[6] Hamers F.P., Wijbenga J., Wolters F.L., Klis S.F. and Sluyter S. and Smoorenburg, G.F. Cisplatin ototoxicity involves organ of Corti, stria vascularis and spiral ganglion: modulation by alphaMSH and ORG 2766, Audiol. Neurootol. 8, 2003, pp. 305-315.

[7] Van der Hulst R.J.A.M., Dreschler W.A. and Urbanus N.A.M. High-frequency audiometry in prospective clinical research of ototoxicity due to platinium derivates, Ann. Otol. Rhinol. Laryngol. 97, 1988, pp. 133-137.

[8] Petsuksiri J., Sermsree A., Thephamongkhol K., Keskool P., Thongyai K., Chansilpa Y. and Pattaranutaporn P. Sensorineural hearing loss after concurrent chemoradiotherapy in nasopharyngeal cancer patients. Radiat Oncol. 2011 February 20;6:19.

[9] Brown M., Ruckenstein M., Bigelow D., Judy K., Wilson V., Alonso-Basanta M. and Lee J.Y. Predictors of hearing loss after gamma knife radiosurgery for vestibular schwannomas: age, cochlear dose, and tumor coverage. Neurosurgery. 2011 September;69(3):605-13; Discussion 613-4.

[10] Fleury B. and Lapeyre M. Tolerance of normal tissues to radiation therapy: ear. Cancer Radiother. 2010 July;14(4-5):284-9. Epub 2010 June 4.

[11] Lerman-Garber I., Cuevas-Ramos D., Valdés S., Enríquez L., Lobato M., Osornio M., Escobedo A.R., Pascual-Ramos V., Mehta R., Ramírez-Anguiano J. and Gómez-Pérez F.J. Sensorineural hearing loss is a common finding in early onset type 2 diabetes. Endocr Pract. 2012 March 22:1-25. [Epub ahead of print].

[12] Mahboubi H., Zardouz S., Oliaei S., Pan D., Bazargan M. and Djalilian H.R. Noise-induced hearing threshold shift among US adults and implications for noise-induced hearing loss: National Health and Nutrition Examination Surveys. Eur Arch Otorhinolaryngol. 2013 Feb;270(2):461-7. doi: 10.1007/s00405-012-1979-6. Epub 2012 Mar 3.

[13] Berrettini S., Ravecca F., Forli F., Sellari-Franceschini S. and Piragine F. Diagnostic and therapeutic approach to progressive sensorineural hearing loss. Acta Otorhinolaryngol Ital. 1998 August; 18(4 Suppl 59):87-94.

[14] Moscicki R.A. Immune-mediated inner ear disorders. Baillieres Clin Neurol. 1994 November;3(3):547-63.

[15] Ruckenstein M.J. Autoimmune inner ear disease. Curr Opin Otolaryngol Head Neck Surg. 2004 October;12(5):426-30.

[16] Barone J.A., Peters J.M., Garabrant D.H., Bernstein L. and Krebsbach R. Smoking as a risk factor in noise-induced hearing loss, J. Occup. Med. 29, 1987, pp. 741-745.

[17] Cruickshanks K.J., Klein R., Klein B.E.K., Wiley T.L., Nondahl D.M. and Tweed T.S. Cigarette smoking and hearing loss, the epidemiology of hearing loss study, JAMA 279, 1998, pp. 1715-1719.

[18] Palmer K.T., Griffin M.J., Syddall H.E. and Coggon D. Cigarette smoking, occupational exposure to noise, and self reported hearing difficulties, Occup. Environ. Med. 61, 2004, pp. 340-344.

[19] Stanbury M., Rafferty A.P. and Rosenman K. Prevalence of hearing loss and work-related noise-induced hearing loss in Michigan, J. Occup. Environ. Med. 50, 2008, pp. 72-79.

[20] Starck J., Toppila E. and Pyykkö I. Smoking as a risk factor in sensory neural hearing loss among workers exposed to occupational noise, Acta Otolaryngol. (Stockh) 119, 1999, pp. 302-305.

[21] Curhan S.G., Eavey R., Shargorodsky J. and Curhan G.C. Prospective study of alcohol use and hearing loss in men. Ear Hear. 2011 February;32(1):46-52.

[22] Gopinath B., Flood V.M., McMahon C.M., Burlutsky G., Smith W. and Mitchell P. The effects of smoking and alcohol consumption on age-related hearing loss: the Blue Mountains Hearing Study. Ear Hear. 2010 April;31(2):277-82.

[23] Forge A. A tubulo-cisternal endoplasmic reticulum system in the potassium transporting marginal cells of the stria vascularis and effects of the ototoxic diuretic ethacrynic acid, Cell Tissue Res. 226, 1982, pp. 375-387.

[24] Forge A. and Schacht J. Aminoglycoside antibiotics, Audiol. Neurootol. 5, 2000, pp. 3-22.

[25] Govaerts P.J., Claes J., Van De Heyning P.H., Jorens P.G., Marquet J. and De Broe M.E. Aminoglycoside-induced ototoxicity, Toxicol. Lett. 52, 1990, pp. 227-251.

[26] Hashino E., Shero M. and Salvi R.J. Lysosomal targeting and accumulation of aminoglycoside in sensory hair cells, Brain Res. 777, 1997, pp. 75-85.

[27] Aran J.M., Erre J.P., Da Costa D.L., Debbarh I. and Dulon, D. Acute and chronic effects of aminoglycosides on cochlear hair cells, Ann. N.Y. Acad. Sci. 884, 1999, pp. 60-68.

[28] Dulon D., Hiel H., Aurousseau C., Erre J.P. and Aran J.M. Pharmacokinetics of gentamicin in the sensory hair cells of the organ of Corti: rapid uptake and long term persistence, C. R. Acad. Sci. III, 316 (7), 1993, pp. 682-687.

[29] Ding D., McFadden S.L., Woo J.M. and Salvi, R.J. Ethacrynic acid rapidly and selectively abolishes blood flow in vessels supplying the lateral wall of the cochlea, Hear. Res. 173, 2002, pp. 1-9.

[30] Martínez-Rodríguez R., García Lorenzo J., Bellido Peti J., Palou Redorta J., Gómez Ruiz J.J. and Villavicencio Mavrich H. Loop diuretics and ototoxicity, Actas Urol. Esp. 31, 2007, pp. 1189-1192.

[31] Mudd P.A., Edmunds A.L., Glatz F., Campbell K.C.M. and Rybak L.P. Inner ear, ototoxicity. emedicine, medscape’s continually updated clinical reference, updated: November 26, 2008. Available at: http://emedicine.medscape.com/article/857679-overview.

[32] Stypulkowski P.H. Mechanisms of salicylate ototoxicity, Hear. Res. 46, 1990, pp. 113-146.

[33] Cazals Y., Li X.Q., Aurousseau C. and Didier A. Acute effects of noradrenalin related vasoactive agents on the ototoxicity of aspirin: an experimental study in the guinea pig, Hear. Res. 36, 1988, pp. 89-96.

[34] Brown R.D., Penny J.E., Henley C.M., Hodges K.B., Kupetz S.A., Glenn D.W. and Jobe J.C. Ototoxic drugs and noise, Ciba Found. Symp. 85, 1981, pp. 151-171.

[35] Falk S. Combined effects of noise and ototoxic drugs, Environ. Health Perspect. 2, 1972, pp. 5-22.

[36] Mills J.H. and Going J.A. Review of environmental factors affecting hearing, Environ. Health Perspect. 44, 1982, pp. 119-127.

[37] Young L.L. and Wilson K.A. Effects of acetylsalicylate acid on speech discrimination, Audiology 21, 1982, pp. 342-349.

[38] Pyykkö I., Koskimies K., Starck J., Pekkarinen J., Färkkilä M. and Inaba R. Risk factors in the genesis of sensorineural hearing loss in Finnish forestry workers, Brit. J. Ind. Med. 46, 1989, pp. 439-446.

[39] Boettcher F.A., Henderson D., Gratton M.A., Danielson R.W. and Byrne C.D. Synergistic interactions of noise and other ototraumatic agents, Ear Hear. 8(4), 1987, pp. 192-212.

[40] Gratton M.A., Salvi R.J., Kamen B.A. and Saunders S.S. Interaction of cisplatin and noise on the peripheral auditory system, Hear. Res. 50(1-2), 1990, pp. 211-223.

[41] Laurell G. Combined effects of noise and cisplatin: short-and long-term follow-up, Ann. Otol. Rhinol. Laryngol. 101(12), 1992, pp. 969-976.

[42] Karlsmose B., Lauritzen T., Engberg M. and Parving A. A five-year longitudinal study of hearing in a Danish rural population aged 31–50 years. Br J Audiol. 2000;25:47-55.

Chapter 5 – PROPOSED FUTURE COMMON RESEARCH

The establishment of a multi-national hearing health and hearing conservation database will provide an immediately useful tool for Military hearing health specialists to track, diagnose and treat Military hearing problems. However, some of the greatest benefits that would occur once the database is established would be through its collaborative use to conduct wide-scale epidemiological analyses of hearing health problems and interventional impacts across multiple NATO Partner Nations. In this chapter, we outline some of the specific research problems the database could be used to address, as well as some areas for future collaborative research that could improve the effectiveness of the database and of Military hearing readiness programs in general.

5.1 DEVELOPMENT OF IMPROVED SCREENING TESTS

The greatest proportion of data in the database will come from periodic screenings of Military members used to identify those who have had significant noise exposures and those that may have developed hearing problems that will require further diagnosis and treatment. Although there are currently tests in place to accomplish these tasks, it is believed that hearing health could be greatly improved by the development of enhanced procedures to conduct these auditory screening tests. Any future tests should have the following characteristics:

1) The quality of the collected data should be sufficient to distinguish soldiers with normal hearing abilities from those who may be at risk of hearing impairment with a very low false negative rate (to ensure soldiers who have significant hearing loss are not missed) and a reasonably low false positive rate (to avoid the conduct of costly and unnecessary diagnostic hearing examinations).

2) The screening tests should be capable of being performed automatically, using adaptive audiometric procedures and closed-set speech materials.

3) Ideally, it would be possible to conduct the screening tests under austere (boothless) conditions, so they could be performed within the Military units. This will reduce costs for screening, as an Audiologist will not be necessary to perform hearing tests. By performing the tests within the units, travelling time and costs will also be reduced. And, perhaps most importantly, such testing introduces agility in testing enabling employment of testing closer to the actual exposure in time and space. Earlier diagnosis of injury opens a window of opportunity for early intervention that may restore or stabilize hearing.

4) At a minimum, the tests should contain pure tone audiometric data, occupational exposure information, and information on tinnitus. Ideally, the tests would also contain tests covering speech-in-noise perception, hearing quality aspects, middle and inner ear function and central auditory processing.

5) The development of diagnostic tests with sensitivities to the cellular and molecular level of injury that are missed by current audiometry is necessary. Such tests are necessary to understand and guide policy for those exposures that cause symptoms and sometimes temporary audiometric shifts that revert to what appears by normal audiometric sensitivities, but which may harbor sub-clinical damage.

On an aggregate level, information in the database will also be useful for identifying sites across the system that have higher incidence and prevalence rates. Such information will lead to closer assessment of the root causes of success and failures within the system. Improvements in education, training, protective equipment, and mitigation efforts identified could then be implemented on a wider basis and unproductive or inadequate efforts can be phased out.

5.2 RISK ANALYSIS: OCCUPATIONAL AND ENVIRONMENTAL RISKS

5.2.1 Occupational Risks

Militaries are broadly exposed to two kinds of noise, impulse noise and continuous noise, with probably different deleterious mechanisms on ear physiology, but with the same result: Noise-Induced Hearing Loss (NIHL).

5.2.2 Impulse Noise

Impulse noise is typically the sound of firearms. An impulse noise is characterized by a pressure peak time of less than 300 ms and a pressure wave below 1 bar (194 dB). The factors of harm are related to the spectral component of the noise (especially when components shift towards high frequencies, the shorter the rise time and the more application time there is, the more dangerous the factors become). The other factors affecting the aggressiveness of noise is distance to the noise source, the orientation of the head relative to the source, reverberation, the number of shots, and in particular, the recovery time between each shot or each burst. Figure 5-1 and Figure 5-2 show examples of the physical and spectrum of some firearms. In confined space (shot within a room or in a vehicle, etc.), the pressure signal is more complex. Reflections or reverberations of the original signal are important as sound levels can last much longer and consequently show different damaging effects of inner ear structures.

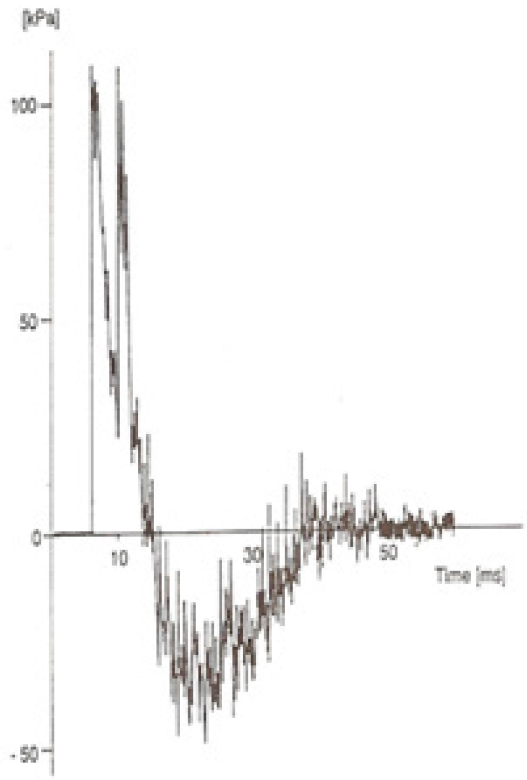

Figure 5-1: Acoustic Pressure of a 155 mm Cannon.

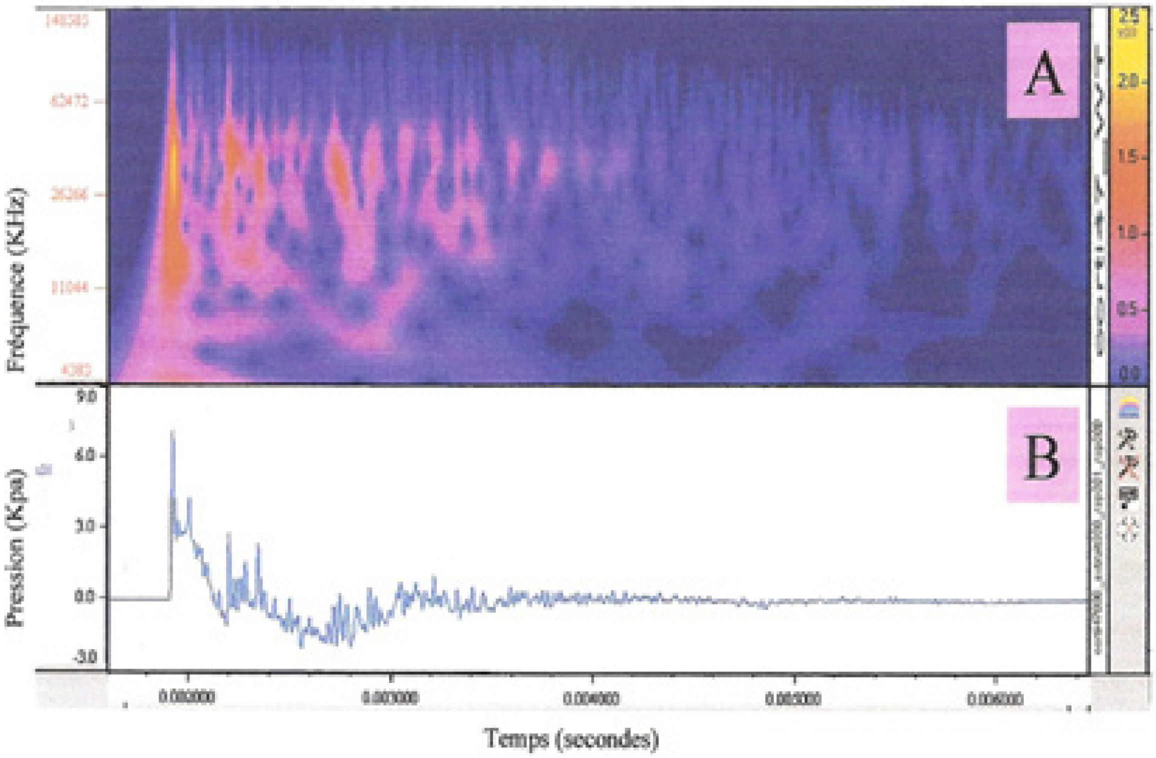

Figure 5-2: FAMAS French Firegun Spectra: A) Cross-Relation Frequency/Time; B) Cross-Relation Peak Pressure/Time.

Studies on the effects of impulse noise are difficult to achieve because these sounds are very difficult to calibrate, and even for the same weapon, variations could occur due to bullet weight or bullet manufacturing.

In free field, the use of artificial ears allows for the recording of the physical characteristics of sound depending on subject's activities (i.e., driver, gunner) is essential for studying of hearing protection efficiency.

For impulse noise, dB C is more relevant than dB A (for continuous noise) because it takes into account the level of overpressure in low frequency range. According to European safety regulations, there is a risk of hearing loss when acoustic pressure exceeds 135 dB C, even if the global acoustic dose doesn't exceed 85 dB A. Table 5-1 shows the theoretic number of shots a soldier could fire with maximum safety.

Table 5-1: Loudness Pressure and Decibel Values of Infantry Fire With or Without Protection.

Infantry fire arm without muffler	Delta P = 15,0 hPa = 157.6 dB (Lin) Laeq8 = 73;8 dB Max. number of shots allowance without ear protection for a 85 dBA Laeq8 : 13
Infantry fire arm with muffler	Delta P = 2.4 hPa = 141.6 dB (Lin) Laeq8 = 50.6 dB Max. number of shots allowance without ear protection for a 85 dBA Laeq8 : 2750

5.2.3 Continuous Noise

Continuous noise is the noise in all the vehicles, aircraft, or ships. It is also industrial noise found in various workshops. The level of noise depends on the type of vehicle or aircraft, and a sound cartography might be helpful to analyse noise induced risks factors. This can be used for job specific hearing protection recommendations. Noise deleterious effects to ears come from frequency spectrum (high frequencies are more dangerous than low frequencies), noise duration and intensity levels. There is a risk of hearing loss when the Laeq8 reaches 85 dB A, 8 hours per day, five days a week – also hearing protectors should be worn at the site of exposure. The decibel scales are being expressed in an exponential unit – when the acoustic pressure is doubled (+3 dB), the exposure time should be halved.

5.2.4 Environmental Risks

Combined exposure to noise and ototoxic agents is not a rare occurrence, since three-quarters of staff occupationally exposed to noise are also exposed to one or more chemicals [1]. Ototoxic chemical agents are present in the workplace – they are primarily solvents, aromatics (toluene and styrene) or chlorinated by carbon monoxide and hydrogen cyanide [2]. These ototoxic agents render the cochlea more vulnerable to noise disturbance and could thus potentiate the harmful effects of noise [169], [4], [5]. Thus, persons occupationally exposed to styrene have an increased risk of hearing loss, and combined exposure to noise and styrene seems more dangerous to the cochlea than noise exposure alone [6], [7]. There is a linear relationship between the level of exposure to styrene and hearing thresholds of 6 and 8 kHz [7]. Compared to a control group not exposed, the risk of hearing loss is 5 times higher in cases of combined exposure to noise and organic solvents, although this risk is only 3 times higher in the case of exposure to noise only [8]. Hearing loss observed in workers exposed to solvents and noise levels below 85 dB (A) is similar to that observed in workers exposed to noise only, but are significantly higher, between 92.5 and 107 dB [5]. In the aviation industry, the incidence of deafness observed among workers exposed simultaneously to noise and various solvents is 3 times greater than that observed among workers exposed to noise only [9]. For example, it has been demonstrated that JP-8 jet fuel steam enhances Noise-Induced Hearing Loss (NIHL). With exposure of both male and female Fischer 344 rats to fuel steam inhalations and simultaneous exposure to either continuous or intermittent noise over a 4-week period, a significant concentration-related impairment of auditory function was measured by Distortion Product Otoacoustic Emissions (DPOAE) and Compound Action Potential (CAP) threshold. Rats exposed to combined JP-8 (1500 mg/m^3) plus noise exposure had increased hearing impairment than exposure levels LP-8 (750 mg/m^3). JP-8 alone exerted no significant effect on auditory function [10].

Thus, multi-factorial exposures seem prone to premature aging of the inner ear, leading to early presbycusis. These co-factors for noise induced hearing loss raise the question of the relevance of exposure limits and in particular the level of noise exposure that could be tolerated in different workplaces when several risk factors of cochlear damage coexist.

5.2.5 Individual Susceptibility

It would be of great interest to find tests for the individual susceptibility for noise-induced hearing loss, in order to identify people at risk of cochlear damage. This goal was established a very long time ago – unfortunately to date it has still not been achieved. In 1965, Ward [11] analyzed 20 tests to determine susceptibility for hearing loss, but none proved significant.

Some individual susceptibility factors for noise-induced hearing loss are most probably genetic, but this is not sufficient to judge the risk.

Until now, it is clear that the static and dynamic characteristics of the middle and inner ear, such as the stiffness of the cochlear partition, thickness of the basilar and tectorial membrane, blood supply of the cochlea, rate of oxygen metabolism, and density of afferent and efferent innervation may be useful to calculate the amount of noise exposure to cause NIHL. Unfortunately one cannot measure these characteristics directly in the intact organism, so indirect measurement could be used to identify the more noise-susceptible individuals before NIHL occurs.

5.2.5.1 Genetics Aspects

Exposure to intense noise may produce either a temporary or permanent hearing loss depending upon multiple factors. Such factors involve the physical parameters of the noise stimulus including its intensity, duration, and frequency range, as well as an inherent, genetically determined susceptibility to Noise-Induced Hearing Loss (NIHL). For example, a great variability in susceptibility to NIHL reflecting differences in the underlying genetic background has been reported for both humans [12] and mice [13], [14] – but in reality, there is no genetic test available to determine the susceptibility. We have only studies on vulnerable mice and resistant mice to try to understand the molecular mechanism. One example is a significant induction of genes involved in cell-survival pathways such as the heat shock proteins HSP70 and HSP40, growth arrest and DNA damage inducible protein 45β (GADD45β), and CDK-interacting protein 1 (p21cip1) that was detected in the resistant mice. Moreover, in resistant mice, significant upregulation of HSP70, GADD45β, and p21cip1 was confirmed at the protein level. Since the functions of these proteins include roles in potent antiapoptotic cellular pathways, their upregulation may contribute to protection from NIHL in resistant mice [15].

Another study shows the possible association of the role of Glutathione S-Transferases (GST) genetic polymorphisms in susceptibility to NIHL [16]. The total plasma GST activity can be measured with a simple blood sample. Glutathione is an important cellular antioxidant that limits cell damage by the underlying NIHL-generation of reactive oxygen species, which is thought to be part of the mechanism.

5.2.6 Non-Auditory Test for Susceptibility

Role of Melanin: There is a correlation between the concentration of melanin in the stria vascularis and susceptibility to noise [17]. There is also a correlation between the concentration of melanin in the iris of the eyes and the concentration in the stria vascularis – so people with dark eyes are less susceptible to noise effect.

General Health: There is also a good correlation between general condition health and susceptibility. A good cardiovascular function, a low blood viscosity, a low rate of blood platelets aggregate, a low rate of cholesterol all decrease the risk of noise hearing loss [18], [19]. There seems to be a relation between diabetes [20] and vulnerability. The presence of repeated episodes of otitis media in childhood, even without otoscopic sequelae, seems to be strongly correlated with a high susceptibility to NIHL [21].

5.2.7 Auditory Test Limitations

All the auditory tests are able to predict individual susceptibility to TTS, but not to PTS. In fact, most of the tests deal with TTS in humans, and there is no ethical way to induce a PTS in humans for experimental purposes. So the problem for all tests is that there must be a correlation between sensitivity to TTS and sensitivity to PTS if they are to have any practical value. It is still uncertain, whether susceptibility to TTS predicts susceptibility to PTS. In acoustic trauma due to impulse noise, Dancer [22] supposed that the mechanisms of PTS and TTS are quite different: in PTS for example, more mechanical damage seems involved compared to in TTS, which seems to essentially rely on only metabolic disturbance.

Some authors tried to establish a correlation between the threshold of audibility and the susceptibility to noise [23].

Some tests are based on the study of the auditory fatigability, with a temporary increase of the thresholds after a white noise exposure in different conditions. The level of the increase and the recovery time might be the factor characterizing the susceptibility to noise. Chon [24] compares the TTS and the recovery time in workers with normal hearing and NIHL under Continuous Pure Tone (CPT), Continuous Band Noise (CBN), Continuous White Noise (CWN) and Intermittent White Noise (IWN) stimulation of 90 dB above threshold in normal hearing subjects and 70 dB in NIHL subjects.

The persons who have over 41 dB TTS after noise stimulation of 90 dB above threshold in normal hearing subjects and have over 25 dB TTS after noise stimulation of 70 dB suprathreshold in NIHL subjects are thought to be a high-risk group that is more susceptible to the noise. The recovery time from TTS to pre-stimulation level in NIHL subjects (11.6 minutes) was longer than that in normal subjects at each mode of stimulation (2.7 – 4.2 minutes).

The difference of TTS was statistically significant between the groups (NIHL vs. normal) when recovery time was above 10 minutes, suggesting that one key parameter of noise susceptibility could be the recovery time. Also, using speech audiometry (i e., increase of the discrimination score, discrimination at 40 dB above the speech reception threshold) and the recovery time, the authors found that normal individuals who have DS below 76% and a recovery time above six minutes after noise stimulation, could be at high risk for developing NIHL if they are exposed to noisy working environment. Another test was based on the determination of the “loudness discrimination index”. This test is based on “recruitment” (that means an over-proportional loudness perception of loud noise in hearing-impaired persons), usually observed after a noise exposure and was proposed as an early indicator of TTS [25].

Changes in the cochlea due to intense noise alter the slope of the temporal integration function. Thus, a “Speech Discrimination in Noise” test might be used to detect ears at risk, because frequency integration in the ear might be affected long before the TTS can be detected by pure tone audiometry [26].

5.2.8 Otoemissions Can Be Used to Evaluate the Susceptibility

A prospective study on occupational noise exposure (n = 100) by Shupak [27] shows that prediction of Noise-Induced Hearing Loss (NIHL) after 2 years could be done by measuring levels of transient evoked otoacoustic emissions after one year of exposure. In this study, the sensitivity was high (86 – 88 %), but specificity was low (33 – 35 %). Distortion Products of Otoacoustic Emissions (DPOAEs) and contralateral medial olivocochlear reflex strength were also studied. The authors concluded that: “DP-grams are not significantly correlated with Pure tone audiometry and could not be used as an objective measure of pure-tone thresholds in early NIHL. Medial olivocochlear reflex strength before chronic exposure to occupational noise (baseline) was not correlated to individual vulnerability to NIHL. Although TEOAEs changes after 1 year showed high sensitivity in predicting NIHL after 2 years of exposure, the authors estimated that they cannot be recommended as an efficient screening tool due to high false-positive rates.”

In contrast, in Job’s DPOAEs study [28], some parameters seem to be helpful for the evaluation of the vulnerability to the noise. The authors studied a population of 521 Air Force pilots over the last 3 years. Based on the measurement of distortion product otoacoustic emissions of a reference population with normal ears (n = 88), reference curves of normality have been established (i.e., mean, 1 and 2 Standard Deviations (SD)). DPOAEs values of each pilot were plotted on these curves, each value referring to a score for determining an index of otoacoustic abnormality (IaDPOAE). This index was calculated for each pilot at the beginning of follow up (Y0) and after 3 years (Y0+3). The authors showed that among pilots with normal audiograms at the beginning of the study, those having IaDPOAE greater than 15% had doubled the risk of developing early hearing loss visible on audiogram after 3 years of exposure. Consequently, the authors suggested that the IaDPOAE > 15% could be an indication of susceptibility to noise.

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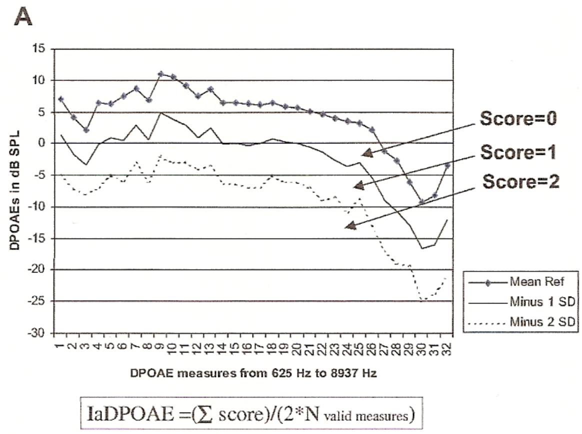

B

Hz	Mean Ref	Minus 1 SD	Minus 2 SD
625	7.44	2	-4
687	4.64	-1	-7
750	2.34	-3	-9
812	6.79	0	-6
875	6.48	1	-4
937	7.80	1	-6
1000	9.15	3	-2
1125	7.37	1	-5
1250	11.11	5	-1
1312	10.72	4	-2
1437	9.46	3	-3
1562	7.64	1	-5
1750	8.64	3	-3
1875	6.46	0	-6
2062	6.38	0	-6
2250	6.48	0	-6
2437	6.08	0	-6
2687	6.47	1	-4
2875	5.99	1	-5
3187	5.99	1	-5
3437	5.24	0	-6
3750	4.80	-1	-7
4125	4.27	-2	-9
4500	3.83	-3	-10
4875	3.80	-2	-9
5312	2.82	-5	-12
5812	-0.26	-8	-16
6312	-2.06	-11	-19
6875	-5.13	-12	-19
7500	-8.14	-16	-24
8187	-7.05	-15	-24
8937	-2.44	-11	-19

Fig. 1. The IaDPOAE calculation and formula. (A) 2F1-F2 DPOAEs reference DP-gram in normal ears ($n = 119$) without ENT antecedent and no noise exposure (Job and Nottet 2002). The graph represents the mean, minus 1 standard deviation (−1SD), minus 2 standard deviation (−2SD) and associated weighted scores. The reference DP-gram corresponded to a screening of frequencies from 625 to 8937 Hz (8 points/octave). (B) Values of reference curves that could be implement in a computer program.

Figure 5-3: Otoacoustic Emissions and Classification (from A. Jobs, Hearing Research).

It is worth noting that otoacoustic emissions indeed represent objective markers of cochlear Outer Hair Cells (OHC) dysfunctions [29], but slight disturbance of the middle ear functionality could also interfere with the results of otoacoustic emissions. Also susceptibility to noise could be found not only at the OHC level, but also possibly at the middle ear level. Indeed susceptibility to noise has been found to be more prevalent in subjects with a past history of otitis media [21], which was thought to prevent subjects from acoustic trauma.

5.3 EVALUATION OF FACTORS INFLUENCING HEARING LOSS

5.3.1 Epidemiological and Readiness Reports of Hearing Ability

Standardized reporting on hearing fitness and hearing loss rates will be a valuable result of the recommended database. Such reports would be important for hearing conservation program oversight, mission planning, resource allocation, planning for education and training of protective measures, identification of best practices in conservation and rehabilitation programs, and in guiding Military medical research.

The questionnaires will help to assess the quality of education related to hearing protection, the requirements for hearing skills in different Military specialties, the type and quality of noise exposure and hearing acuity. Audiometric screening will provide objective measures of hearing capability among Service members categorized by age, rank and specialty training. A similar report of speech understanding in noise can show correlation between audiometry and speech understanding.

Such reports would give an overview of hearing abilities and readiness as well as risk areas for potential hearing loss. They will show the effectiveness of education programs, the efficacy of hearing protection in use, and can be used to identify areas of high noise threat and to elevate the awareness for hearing protection campaigns.

5.3.2 Longitudinal Hearing Development

An intriguing aspect of the database will be its function to monitor individual hearing ability over the entire length of a member's Military lifecycle. This opens analysis to unprecedented cohort comparison to identify individuals and groups with increased risk of hearing loss, either due to their individual susceptibility or due to external events, mainly noise. Comprehensive data pinpointing hearing loss within the natural course of hearing over a service lifetime will enable adjudicators to quantify risks for hearing loss and make claims on an evidential basis. In the long term, hearing prevention measures can be directed to high-risk areas that will improve cost efficiency of hearing protection programs. The data will also help to define individual risks for hearing loss and can be correlated to prognostic factors. The evolving field of genetic risk for hearing loss in particular would benefit from longitudinal data. Surveillance and natural history data would be clinically useful guiding therapy and identifying best practices and standards. Finally, such data could be correlated with autopsy measures giving background to molecular and cellular studies of the temporal bone.

5.3.3 Hearing Protection and Hearing Loss Prevention

Protecting hearing and prevent hearing loss is the first goal of hearing healthcare. To support these goals, the development of targeted educational programs, technical protective equipment (active or passive), and medical interventions are necessary. It is important to measure the effectiveness of educational programs and other interventions and programs. Data acquired through the proposed questionnaires will help monitor the effectiveness of such programs. Longitudinal aggregation of data will display the effects of preventive measure enabling analyses to include the cost effectiveness of interventions. For this purpose, it is important to record the type of hearing protection utilized, the type and frequency of hearing conservation education, and whether fit testing of protective equipment has been available or used.

Hearing protection and prevention of hearing loss can be considered at two levels:

- Instrumental by the use of hearing protection; and
- Drug by the use of molecules that may have a protective effect in facilitating preventive or repair damage effect.

5.3.4 Natural Physiological Protection Against Noise

There is a poor protective reflex at the level of the middle ear; an acoustic reflex due to contraction of the muscles of the stapes and malleus in reaction of acoustic pressure > 80 dB SPL. This reflex stiffens the middle ear transmission system and limits the transfer of energy that enters into the inner ear. This reflex is not efficient enough to protect the inner ear from impulse noise for three reasons:

- First, attenuation is very low (about 10 dB) and concerned only frequencies below 2 kHz;
- Second, reflex latency is in average over 100 ms; and
- Third, the impulse noise high peak pressure duration is much shorter, so the soldier is not protected at least for the first shots.

In addition, in relation to inner ear, the median cochlear efferent system, which exerts a feedback control on the amplitude of contraction of the outer hair cells, could play a protective role for the inner ear [30], [31]

5.3.5 Instrumental Protection

There are numerous hearing protection devices available. None of them can provide protection for all conditions. They are divided due to forms (in ear canal devices; capsules), function (active – passive) type of protection (impulse or continuous noise) and so on. Modern developments are active noise suppression.

Nowadays the devices should not only protect, but must maintain communication and/or hearing of surrounding noise. These modern technologies also give the chance for augmented hearing or virtual hearing and information input.

5.3.6 What Kind of Hearing Protection, for Which Type of Noise?

The type of hearing protection depends on the type of noise against which we want to protect (continuous or impulse noise), the use that one wants to do (occasional or frequent use) and also the need to communicate (communication between the soldiers for example). A European directive (Noise 2003//10/CE) defines the sound limit for a daily exposure (8 h) at 87 dB(A) or a level of acoustic pressure max of 140 dB(C). When the sound level reaches 80 dB(A) or 135 dB(C) , information must be given and protection must be provided. When the level reaches 85 dB(A) or 135 dB(C), protection should be worn.

5.3.7 Protection “Standard” or “Molded”?

Standard protections are based on foam systems or fins. Standard protections are supposed to fit all ear canals conformations. They are not always easy to insert (the foam must be well compressed before being introduced in the ear canal) and does not always provided a perfect seal. Earplugs can sometimes be displaced and then no longer play their protective role. Caps made by molding do not have this disadvantage. The attenuation is about 10 dB for low frequencies, up to 40 dB on high frequencies. Some manufacturers modulate the mitigation of acoustic signals via a controllable valve (decreases while attenuation at all frequencies as the degree of opening of the valve) or through filters: the degree of attenuation changes little on the high frequencies (about 40 dB), but attenuation can be adjusted mainly at low and middle frequencies, which are important for speech (attenuation ranging from 7 to 25 dB depending on the filter) – these filters allows to communicate with preserving a good protection at high frequency (i.e., passive non-linear filters).

Helmets are standard protectors for some professionals and usually have integrated hearing protection. The degree of attenuation depends on the coating of the shell, and pressure of the capsule on the head. Their mitigation potential is higher than standard or molded plugs.

5.3.8 Linear or Non-Linear Attenuation?

A linear attenuation is constant regardless of the noise intensity. In the case of non-linear attenuation, the degree of attenuation increases as the intensity increases. This non-linear attenuation is more suitable for impulse noise, while the linear attenuation fits to continuous noise. The attenuation of non-linear systems is perforated and therefore the perception of surrounding noise is not disturbed.

5.3.9 Active or Passive Systems?

The principle of passive attenuation relies on the mask effect of the device. The passive attenuation systems are either linear (global attenuation in all frequency bands) or non-linear (different attenuation at special frequency band).

The principle of active attenuation is mixed: the active mitigation devices are mounted either on headphones or on molded protections, such as for hearing devices. There is therefore a passive role in mitigation. The active part varies depending on the type of protection you want:

- For protection against continuous noise: a processor analyzes ambient noise and a system generates a noise against phase reversal, with the sum of the two resulting in a cancellation of the IOP variation. These systems are particularly used in industry and aerospace.
- For protection against impulse noise: an amplifier obtained by the closure, canceling both the “cap effect”, does not cut the soldier from outside noise, but stabilizes the noise when the input noise is above 80 dB.

5.3.10 Pharmacologic Protection

Recent investigations into the cellular processes that underpin noise-induced cochlear damage and hearing loss have revealed two important mechanisms involved in noise-induced hair cell death. The first of these mechanisms is Reactive Oxygen Species (ROS) as a cause of cochlear pathology – they are cytotoxic and trigger inflammatory process leading to hair cell loss. ROS include oxygen-based molecules with an unpaired electron (free radicals, including superoxide, the hydroxyl radical and peroxynitrite), as well as oxygen-based molecules that will readily react to form free radicals (including hydrogen peroxide). Several studies have shown increases in ROS and ROS activity in the cochlea after noise exposure [32]. Pre-treatment of the cochlea with anti-oxidants (which scavenge ROS or convert them to less harmful molecules) or pro-anti-oxidant drugs can attenuate noise damage and hearing loss (for review, see Refs. [33] and [37]).

The second important mechanism in noise-induced cochlear damage is that noise-exposed hair cells die through apoptosis. Contrasted with necrotic cell death, which is a passive process, apoptosis is an active, regulated cell death process that consumes energy. Through the activation of a family of specific cysteine proteases called caspases, the cell systematically disassembles. Throughout the process of apoptosis, the cell membrane remains intact and the cell condenses and pulls away from neighboring cells, resulting in minimal damage to surrounding tissue. Apoptosis can be initiated by a number of triggers including mechanical stress and ROS, both of which occur in the cochlea as a result of noise exposure.

Pharmacological interruption of apoptotic cellular signaling pathways has been shown to reduce NIHL [35], [36], [34].

5.4 OFF-DUTY HEARING LOSS

With regard to compensation claims, it is important to differentiate between job-related and non-job-related hearing loss. Non-job-related hearing loss can either be due to intrinsic factors of the individuals, such as genetic predispositions or illnesses like otitis media, sudden hearing loss and other. In addition, leisure time exposure to hazardous noise or explosions may also affect hearing. Music players and other personal devices with in-ear hearing buds are more and more common, and many environmental venues and settings produce hazardous levels of noise such as sporting events, motor sports, concerts and others. It is important to address these problems by educating soldiers about the effect of off-duty noise which may exempt them from compensation claims. Slow progressive hearing loss will be detected by regular screening and requires validated screening methods. By using several tests (pure tone audiogram, optoacoustic emissions, and speech tests in noise), the reliability of screening will be sufficient to prove or disprove other than-job-related hearing loss. Educational programs should address off-duty exposure and promote awareness and safe hearing practices to counter off-duty hazards.

5.5 SURVEILLANCE

More comprehensive testing and data collecting will be performed on soldiers exposed to job-related risk factors for hearing loss or with established hearing loss. Various criteria can be implemented as inclusion criteria for more detailed analysis. RTG HFM-229 suggested the following criteria:

1) Hearing before and after deployment.
2) Known occupational exposures to hazardous noise.
3) Exposure to shooting or explosions.
4) Exposure to blast.
5) Surveillance of established hearing loss.

6) Sudden hearing loss or acute onset of auditory-vestibular symptoms.

7) Tinnitus.

Any soldier meeting any of these criteria will be tested in an audiology center for subjective and objective testing. Demographic information of the incident which caused the hearing loss will be included. Accessing other data sources (mission register, etc.) will be included and used for reports. Over time, the inclusion criteria will be adapted as needed, expanding and contracting based on feedback from ongoing analyses.

5.6 HEARING IN RISK AREAS

Detection of areas and activities that increase the risk of hearing loss are expected to consolidate as comprehensive hearing screening comes on line. Multi-variate statistical analysis will be possible once data is available. Stratification of risk based on injury patterns and trends can be associated with the Military activities and environments and outcomes associated with regional or nationally based hearing conservation programs can high light areas of success and concern. Association of cause and effect can then impact policy, education and training, and protection patterns as counter-measures to improve hearing loss prevention. Collaborative comparisons between NATO Nations will allow broad-scale application of best practices improving outcomes for all. All members of RTG HFM-229 agreed to start with the evaluation of areas of increased noise exposure, e.g., from engine noise or active shooting. Soldiers are usually exposed to these risk factors, but other unknown risk factors (intrinsic or extrinsic) may be present as well. Therefore the data must be analyzed for increased incidence of hearing loss, independent of noise exposure with further analyses developed to focus on such areas of interest or anomaly.

5.7 DEPLOYMENT AND HEARING LOSS

Injury risks during deployment add significant variability because the health of many organ systems may be affected. Soldiers are exposed to intense mental stress, environmental toxic substances, noise or explosions capable of blast injury, pollution, microbiological threats, tropical infections, dehydration, trauma, traumatic distress, epidemiological outbreaks, depression and anxiety disorders, sleep disorders and many more. All these factors can increase the risk for sudden hearing loss or ear injury. Therefore it is important to test hearing function prior to deployment to assess the functional status of hearing and ensure optimal communication abilities are met at baseline. Also, testing should be accomplished after mission completion to detect any hearing handicap or injury to the ear. These data points will be helpful in calculating the incidences of hearing damages, to identify specific deployment-related risk factors, to concentrate preventive measures, and to provide early identification and rehabilitation for amenable hearing problems.

5.8 BEST CLINICAL PRACTICES (SURGICAL; PROSTHETICS; TRAINING)

Military medicine must provide optimal and cost efficient treatment for all soldiers, both to meet the ethical obligation incurred from exposing Service members to environments with hazardous noise and to meet the expectations for excellence in care held by wounded Service members and their families. Treatment of hearing health problems is also a readiness issue. The complexity of modern Military operations require the Armed Forces to keep highly trained and experienced staff members in their job to the extent possible because retraining, recruitment, and replacement of these highly specialized experts in a timely fashion is often impossible and costly.

Technological advancements in the treatment of hearing loss have opened the door to maximizing retention. Excellent rehabilitation techniques are available and quickly emerging that offer specific solutions to niches of hearing loss which allow for significant customization of care across the spectrum of injury. Such specific treatment should maximize reintegration of Service members by reclaiming the sense of hearing that provides key performance related to Military operations and quality of life. It is important to validate and stratify treatment options to guide and optimize rehabilitation programs for maximum efficiency.

5.9 VALIDATION OF NEW TECHNOLOGIES

Many new technologies for hearing rehabilitation are in development and need validation for clinical use, for Military use, and their ability to impact the quality of rehabilitation. Advanced hearing technologies that are now under development include:

- Integration of communication techniques into hearing protection and hearing aids;
- Tissue engineering of inner ear structures;
- Cell cultures of hair cells;
- Directed neural regeneration;
- Drug development for the prevention and rescue of hearing loss;
- Bone conducting hearing aids and implants;
- Hybrid cochlear implants; and
- Implantable hearing aids.

The ability to model energy transfer within the ear, advancing development in imaging techniques, three-dimensional printing, micro-processing, advances in microphone and speaker technology, electromechanical simulation of biological systems, improvements in biocompatibility and compliant mechanisms, improvements in areas of brain stimulation, sound therapy, neuromodulation all have application in the field of auditory sciences. Capturing appropriate outcome measures within the database can serve as a valuable tool for evaluating the effectiveness of new technologies and the appropriateness of their use in the treatment of Service members. The occupational information in the database can also be used to develop appropriate criteria for the environments and occupations where these new technologies are likely to be most effective. [56]-[62]

5.10 BALANCE / VESTIBULAR FUNCTION

5.10.1 Vertigo and Blast Injury

Blast or improvised explosive devices are the most common mechanisms of injury in modern warfare. Primary blast injuries are caused by barotrauma attributable to either over-pressurization or under-pressurization relative to atmospheric pressure, creating a shock wave radiating from the point of detonation. Primary blast injuries affect the hollow organs in the chest, abdomen, middle-ear (tympanic membrane perforation, ossicular discontinuity), inner ear (cochlear and potentially vestibular cell damage), and the brain. Military Service members who have been exposed to blasts and who are returning from conflict zone complain of hearing loss, earache, and tinnitus, but also 15% to 40% complain of dizziness, gaze instability, motion intolerance and vertigo, symptoms consistent with peripheral vestibular pathology [38]-[40]. Peripheral vertigo can be described as rotatory or simply as an instability; but these symptoms can also manifest from the secondary or tertiary effects of blast (head trauma, brain injury or post-traumatic stress). Vestibular clinical examinations are usually found to be normal as the time from trauma increases [41], [42], but can symptoms have also been shown to increase with chronicity [43]. Some authors reported abnormal vestibular examination when observed shortly after the blast [44]-[47]. Injury patterns in survivors of blasts are typically complex and characterized by multi-system pathology and various degrees of severity. Traumatic Brain Injury (TBI), which often results from blast exposure, has been described as the “signature injury” of the wars in Afghanistan and Iraq [40]. Various neurological pathology is common following TBI

[48]. The summary of a recent review by the Institute of Medicine of the "Long-Term Effects of blast Exposures" was published by the National Academy Press in 2014 in a series on the Gulf War and Health [49]. The committee concluded, on the basis of its evaluation, that there is inadequate/insufficient evidence of an association between exposure to blast and long-term balance dysfunction and vertigo. These findings highlight the need for more concerted effort to study vestibular complaints.

5.10.2 Complex Origin of "Vestibular" Complaints in Blast Injury

The feeling that one is going to fall, the body illusion of movements or a non-specific sensation of dizziness is not necessarily a sign of vestibular involvement; anxiety and panic disorders could trigger sensations of unbalance [46], [50], [51]. In contrast, oscillopsia (perception that objects known to be stationary are moving) is a symptom associated with bilateral vestibular hypofunction, indicating inadequate gaze stabilization by the vestibulo-occular reflex as well as a clear rotational dizziness with indication of direction, strongly suggests a true vestibular problem. However, there is some evidence that anxiety arousal and mental stress could directly influence the slow phase of nystagmus [46] in the vestibulo-occular reflex. Thus, given the complexities of treating patients with polytrauma, it is essential to distinguish what is due purely to a peripheral vestibular pathology from other causes due to post-traumatic stress disorder or traumatic brain injury, and to characterize the constellation of comorbidities that often cloud both diagnosis and treatment. Blast injuries can impact vision, inner ear, proprioception and brain integrating functions, and is often associated acutely with hypovolemia. Longer-term chronic effects of dysfunction in multiple systems can be combined with polypharmacy, depression, sleep dysynchrony, headache, inactivity and deconditioning that may compound symptoms and the relationship between these variables is important to approaches to rehabilitation. [63]-[80]

5.11 DIRECTIONS FOR FURTHER COMMON RESEARCH

The incidence of vestibular and audiologic injury related to blast injury remains underreported [39]. To date, very few studies [52], [53] have addressed "vestibular complaints" in Service member's injures by blasts. There is an ongoing debate about whether these "vestibular symptoms" originate from pathophysiological process or are psychosomatic in nature. There is also suggestion that both were linked and consequently difficult to assess. There is a great need to build consensus on the clinical best practices for the assessment and management of blast-related dizziness, but also on how to carry out efficient vestibular surveillance. Consequently there is a need to characterize vestibular findings in detail.

A starting point may be to capture the symptoms at the earliest feasible encounter. Filling out a dizziness handicap inventory questionnaire provides a baseline function assessment. Clinical examination should involve:

- Gait analysis;
- Cerebellar test;
- Occulomotor examination;
- Head impulse testing; and
- A Gaze stabilization test.

In a surveillance program where possible electronystagmography should assess saccades (peripheral and central vestibular pathways), rotary chair and dynamic visual acuity test of the vestibulo-occular reflex, and Vestibulo Electoro-Myogenic Potential (VEMP), tests should be conducted. In the future, non-invasive functional explorations of intra-cranial pressure [54] should be used and developed for a deeper investigation of brain injury due to blasts. Such an investigation could help to indicate a concomitant factor (e.g., functional deficit in coordination and balance) at the origin of vestibular problems. Non-invasive testing for endolymphatic hydrops or Meniere's disease is available using distortion product otoacoustic emissions phase shift [55] as indirect measure of fluid pressure in the cochlea. Because cochlea fluid connects with cerebrospinal fluid, it could also reflect general intracranial fluid pressure, and could provide a cortical indicator of dysfunction, when standard vestibular examination is found normal. VEMP testing may also be useful in assessing endolymphatic hydrops and in combination with high-resolution CT imaging is helpful in identifying traumatically activated superior semi-circular canal dehiscence. In addition, magnetic resonance imagery such as Diffusion Tensor Imagery (DTI) has been used for interpreting the variation of intracerebral water flow and cortical tract dysfunction. DTI could help to quantify traumatic brain injury related cerebellar compression due to swelling. Multi-scale Electro-Mechanical Simulation (MEMS) modeling may help predict and focus applied energy to enhance the effect of brain stimulation techniques such as transcranial direct current stimulation and transcranial magnetic stimulation. Genetic analysis may target specific patterns of susceptibility or resilience to injury and blast and may offer insights for rehabilitation and treatment.

5.12 TINNITUS ASSESSMENT AND TREATMENT

5.12.1 Causes of Tinnitus

Tinnitus and hearing loss are frequent consequences of Acute Acoustic Trauma (AAT). Tinnitus is an auditory percept in the absence of any objective physical sound source. Tinnitus is often described by AAT subjects as a perception of a high-pitch continuous sound (such as whistling or ringing). Noise-induced tinnitus percept after an AAT is almost immediate or develops very rapidly. Repetitive exposure to noise usually increases the periodicity and/or the intensity of tinnitus, which can then be chronic. Tinnitus is a major occupational complaint in AAT patients, being often more debilitating than hearing loss. Tinnitus is a common feature of Military life, due to exposure to impulse noise associated with the use of firearms.

Tinnitus itself is not a disease, but rather a symptom of a variety of underlying pathology and consequently these processes may be confounding factors superimposed on what we could attribute exclusively to noise exposure. Otologic causes besides noise-induced hearing loss include:

- Presbycusis;
- Otosclerosis;
- Otitis;
- Impacted cerumen;
- Sudden deafness;
- Tympanic membrane perforation;
- Meniere's disease; and
- Other causes of hearing loss.

Neurologic causes include:

- Head injury;
- Headache;
- Whiplash;
- Multiple sclerosis;
- Vestibular schwannoma; and
- Other cerebellopontine-angle tumors.

Infectious causes include:

- Otitis media and sequelae of Lyme disease;
- Meningitis;
- Syphilis; and
- Other infectious or inflammatory processes that affect hearing.

Tinnitus is also a side effect of medications, such as:

- Salicylates;
- Non-steroidal anti-inflammatory drugs;
- Aminoglyco-side antibiotics;
- Loop diuretics; and
- Chemotherapy agents (e.g., platins and vincristine).

Temporomandibular-joint dysfunction and other dental disorders can also cause tinnitus. Pulsatile tinnitus can be objective and is often due to turbulence in carotid blood flow, dehiscense of the sigmoid sinus, arterio-venous malformation, hypertension and hypermetabolic conditions as well as vascular anomalies of the middle ear. This type of tinnitus may be amenable to surgery. For the other types of tinnitus the mechanistic origin of tinnitus is still a matter of debate.

5.12.2 Unsolved Origin for Tinnitus Mechanism

Cochlear cell damage is widely considered as a most likely origin for AAT tinnitus. It is widely assumed that cochlear cell damage triggers changes in the central auditory system, which is then interpreted as tinnitus by the higher processing stages in the brain [81], [82]. Thus, hyperactivity and synchronization of neural firing in the dorsal cochlear nucleus, inferior colliculus or the auditory cortex in acoustic trauma has been reported [83]-[87] and attributed to an imbalance of exitability between the cochlear Inner Hair Cells (IHC) and the Outer Hair Cells (OHC) [81], [88], [89]. Additionally, following damage of cochlear cells, central representations of intact lesion-edge frequencies have been found enlarged, and one theory of tinnitus holds that this process could be related to the tinnitus sensation [90]-[93]. Such data brought support for a cochlear origin for tinnitus, but alternative possibilities have been raised. Thus, it is unclear whether hyperactivity along the auditory pathway is a direct consequence of cochlear cell damage or results from hyperactivity in other neuronal pathways [94] and it has been argued that an auditory map reorganization cannot satisfactorily explain the emergence of tinnitus perception [95]. Additionally, not all available data fit with an exclusive role of cochlear damages. Several studies have shown that hearing loss, which is directly related to cochlear cell damage, is not tightly predictive of the occurrence and severity of tinnitus, despite the fact that tinnitus is more prevalent in subjects with hearing loss [96]-[98]. Also it is known that surgical section of the eighth cranial nerve in tinnitus patients is not successful in suppressing tinnitus in 38 to 85 % of the cases [99]- [100].

Somatosensory disturbances may be involved in tinnitus [101]-[102]. However, evidence for a somatosensory origin has been lacking in the case of AAT tinnitus. Tinnitus has also been proposed to have characteristics of a phantom pain [103]-[104]. Patients with tinnitus actually share similar emotional disturbances as chronic pain sufferers [105]-[106]. Finally, an influence of anxiety/mood states on noise-induced tinnitus onset after noise exposure has been demonstrated [107] suggesting a role for the autonomous sympathetic system [108].

In humans, the neural correlates of tinnitus have previously been determined using fMRI [109]-[112]. Almost all these studies converged on the hypothesized implication of non-auditory regions in tinnitus pathophysiology and suggest that various regions of the brain seem involved in the persistent awareness of the phenomenon as well as in the development of the associated distress leading to disabling chronic tinnitus (emotional networks). Recently another fMRI study on acute acoustic trauma tinnitus revealed that among cortical regions involved in emotional disturbance, a small region in the parietal operculum correlates with tinnitus periodicity and handicap [113]. This region is very close to a small area representing tympano-ossicular chain movements due to pressure variation [114]. These results for the first time could suggest that the middle-ear could be involved in the acute acoustic trauma tinnitus mechanism.

The Agency for Healthcare and Research Quality (AHRQ) provided a Clinical Evidence Review on a variety of tinnitus treatments between 1970 and 2012 [115]. Key Questions (KQs) to be answered were:

1) Measures used to assess patients for management needs (KQ1);
2) Effectiveness of treatments (KQ2); and
3) Identification of prognostic factors (KQ3).

The literature review identified 9,725 citations for tinnitus during this time span, of which only 52 publications met criteria for review. All were related to KQ2, and of these all showed low evidence of effectiveness in therapy. This suggests a strong need for structured research related to tinnitus, and the need for a consistent approach for identifying and characterizing the mechanisms against which therapies may be developed.

5.12.3 Directions for Further Common Tinnitus Research

The first scientific evidence concerning AAT tinnitus is that the estimation of the prevalence of this symptom among Infantry and Artillery is almost unknown, but certainly important. Effort should be encouraged to better capture and characterize the incidence and prevalence of tinnitus. Access to the common database should help fill in gaps in the paucity of information. Considering the imperfect knowledge associated with tinnitus mechanisms, various tinnitus treatments have emerged but none of them are totally successful. NATO members involved in this HFM Task Group wish to share their practice and knowledge. Thus, future common researches on tinnitus treatments could be organized around two categories:

1) Those aimed at directly alleviating or reducing the intensity of tinnitus; and
2) Those aimed at relieving the annoyance associated with tinnitus.

The former include pharmacotherapy and various types of stimulation (acoustic, mechanical, electrical, etc.), but requires more fundamental research on the mechanisms of tinnitus to be efficient. The latter include:

- Pharmacotherapy;
- Cognitive and behavioral therapy;
- Sound therapy;
- Habituation therapy;
- Massage/stretching; and
- Hearing aids.

The most efficient means of collaboration would be by standardizing the methods and outcomes metrics to be captured in any given study. The ability to compare therapies through multi-variate analyses is based on common methods of testing and points of follow up. Based on clinical data collected and on tinnitus qualities (localization, periodicity, duration, handicap (THI score), tonality, evident associated event), correlation studies could be conducted from the common database. For example, parsing out differences between noise-induced tinnitus and tinnitus related to middle ear dysfunction should include acoustic reflex measures; or the relationship of the noise-notch in noise-induced tinnitus should include assess speech in noise alterations. Also, the effect of emerging technologies such as hearing aids, implants, brain stimulation, and neuromodulation on noise-induced tinnitus could be assessed.

Multi-centric clinical research on new therapeutic agents could also be carried out through direct international collaboration to capitalize on resources available and exposure patterns.

New tools of investigation such as Magnetic Resonance Imaging (MRI), Magneto and Electro Encephalography (MEG/EEG) or new tools for treatments such as repetitive Transcranial Magnetic Stimulation (rTMS), Transcranial Direct Current Stimulation (TDCS), Cranial Nerve Neuromodulation (CNNM), and sound therapies in isolate or combination with other modalities should also be considered.

5.13 POST-TRAUMATIC STRESS DISORDER AND HEARING LOSS

Post-Traumatic Stress Disorder (PTSD) is a serious medical problem and interferes with the ability to cope with other health problems. Hearing impairment adds additional stress making it more difficult to treat PTSD. To analyze these interactions, it is important to have exact knowledge about the quality and quantity of hearing impairment, the presence of tinnitus, hearing rehabilitation and other comorbidities. It is important to obtain and compare metrics of the severity of PTSD and to quantify hearing loss, tinnitus and vestibulopathy and then to correlate disease severity between the conditions in the treated, untreated states, as well as to assess the effects over time. In this manner, it may be possible to identify factors predictive of outcome.

5.13.1 Blast Injury and Sequaelae

Many audiologists who deal with Military members and Veterans have noted that many individuals who have clinically normal audiometric thresholds but a history of deployment-related blast exposure report that they have greater than expected difficulties communicating in loud, noisy environments (e.g., bars and restaurants). Service members with a history of blast exposure or TBI (b/TBI) and relatively normal audiometric thresholds seem to experience greater than expected difficulty understanding speech in complicated auditory environments that involve multiple simultaneous talkers, rapid speech rates, or reverberant environments [116], [170], [121], [122]. Although the exact causes of this impairment are not completely understood, Military and VA Audiologists have generally accepted the convention of labeling this condition as a type of blast- or TBI-related Central Auditory Processing Disorder (CAPD) or b/TBI CAPD. In general, the diagnosis of b/TBI CAPD is given to patients with a history of blast exposure who have normal to near-normal audiometric thresholds, but have substantially greater than normal difficulty understanding speech in noisy real-world environments.

Normal audiometric threshold sensitivities can also be seen in cases with significant structural damage within the cochlea, and occurs even in cases where hair cell loss is not manifest. Aside from CAPD, other mechanisms may be involved as the basis for this so-called "hidden hearing loss". Recent research suggests that SNHL may result initially from degeneration of cochlear nerve synapses and their connectivity with hair cells, such that these changes precede hair cell loss and consequent auditory threshold shifts [119], [120]. If so, this identifies a critical opportunity for early identification of injury and introduction of therapeutic agents/interventions that could mitigate hearing loss by rescue/recovery of synapses and/or synaptic connectivity prior to hair cell loss. Research in diagnostics to identify cellular, molecular, central and genetic factors in auditory system injury are necessary to stimulate and guide improved preventative and rescue treatment research.

Studies are now underway to better understand the origin and impact of b/TBI CAPD and to determine its prevalence in blast-exposed SMs. Gallun et al. [121] found that b/TBI CAPD symptoms were equally common both in blast-exposed individuals who had been diagnosed with mTBI and those who had no history of blast exposure. Additionally, a recent study conducted in the laboratory at Walter Reed National Military Medical Center, (Bethesda, MD, USA) found that 40 – 45 % of normal hearing listeners with a history of deployment-related blast exposure fell in the bottom 5% of normal performance on tasks involving the detection of spatial cues and the comprehension of fast speech in reverberation [118]. When these findings are combined with reports that indicate that as many as 40% of all Military personnel returning from deployment have been exposed to a blast [123], it becomes apparent that b/TBI CAPD is a serious issue with a potentially large impact on the readiness and quality of life of our active duty SMs and Veterans.

Soldiers suffering blast injury need a long-term follow-up, especially for their hearing function. It was noted that about one third of cases will develop progressive hearing loss in the following years. Due to PTSD which is commonly present, soldiers need intensive attention to their rehabilitation process. Best hearing rehabilitation involves surgical procedures, the use of technical devices and intensive educational programs to achieve the best possible outcome. Soldiers with PTSD are usually depressed and less active with regards to rehabilitation. Therefore it was agreed that regular intensive hearing monitoring is necessary and should be compulsory for all soldiers suffering blast injury. Monitoring must take place over a time period of at least 10 years and be performed by audiological experts.

5.14 HEARING LOSS AND EARLY RETIREMENT / COMPENSATION CLAIMS

Hearing loss is a common cause for compensation claims in NATO forces and a common cause for early retirement. It is also known that explosions, shooting, blast and noise exposures can cause hearing loss, but it is still difficult to prove the correlation. Individual susceptibility, quantification of noise exposure, and other non-job-related risks for hearing loss or the delay between possible impact and detection of hearing loss makes it difficult to certify job-related damage. Regular screening makes it possible to reduce a time gap between the noise exposure and the detection of hearing loss and enables timely intervention before severe hearing loss is established. With the institutionalization of frequent routine screening along with early identification of losses within treatment windows, successful rescue from noise exposure may provide the motivation for Military members to self-identify for out of cycle testing based on exposures to noise that exceed safety limits or that cause symptoms of inner ear dysfunction. Longitudinal data basing of cohorts hearing status may also identify individuals with increased intrinsic risk for hearing loss which in turn enables focused education, protection and treatment options. The database will provide reliable data to define and quantify job-induced hearing loss.

5.15 HEARING LOSS AND QUALITY OF LIFE

The impact of hearing loss on the quality of life and professional satisfaction is under reported and should be analyzed. The cognitive effort needed to compensate for hearing loss reduces concentration, mental capabilities and leads to fatigue. These factors add to stress and other disability, limit quality of life and threaten fitness for duty. Validated questionnaires are available and serve to quantify quality of life aspects. These have been included in the database. Quantifying the effect of hearing loss, tinnitus, and vestibular dysfunction on the quality of life may provide the evidence base from which compensation claims can be established to adequately reflect the association. Many factors may be reflected in the quality of life assessment such as extent and severity of auditory vestibular dysfunction, the association with comorbid injuries, the effect of polypharmacy, the psychological health of the individual, the coping mechanisms and support systems available, and the valuation of a patients ability to re-assimilate or reintegrate into the Military/family/community/religious institutions with which they associate. Some people will be hardly affected by hearing loss, because they have little communication needs while others, who rely on acoustic information or communication are more affected. Tracking populations with QoL and hearing function metrics may show trends and associations that can be leveraged to improve quality of life and augment physical rehabilitation. Currently this is not addressed in any compensation claim judgments, but is a necessary future direction. The method of quantifying individual hearing needs is not established yet.

5.15.1 Impact of Hearing Skills on Military Fitness for Duty

Hearing is a very important function for fitness for duty. As shown above (Section 2.3.2), the survival rate of troops and soldiers depends on hearing function. Radio-transmitted communication, communications chains (Chinese whisper), non-native speakers and listeners endanger information transfer. Nevertheless, fast and precise information is necessary for military decisions and for successful operations.

The auditory fitness of the troop's state must be known at all times, in addition to their ability to hear in noisy surroundings. For the safety of the troops, for mission success and for soldiers to be able to function, hearing ability should be maximized – special jobs require excellent hearing abilities. It is the responsibility of the military leadership to provide precise and accurate communication, not only by technical means, but also by hearing and understanding abilities.

5.15.2 Hearing Requirements of the Job

Acoustic communication is mandatory for most jobs in Military service, but very limited information is available about the levels of hearing ability needed to safely and effectively fulfill specific duty requirements. Data availability from comprehensive screening will enable Military services to identify which soldiers meet the hearing requirements for their duties, and which need hearing rehabilitation to satisfy hearing demands. It can be expected that the data requirements promoted in this database will gather the necessary information for these determinations. This was the rationale for including various tests for screening purposes. Audiometry is a behavioural test that offers excellent information about hearing sensitivity in a very isolated idealized setting using tonal cues. Critical hearing tasks for the fulfillment of Military occupational requirements are rarely if ever similar to these settings. Because of this, we feel future research direction will be to develop functional testing utilizing operational environmental sounds and noise and speech cues that will offer a more valid representation of the members ability to function well in their working environment. Such testing would augment audiometry. Such testing could also quantify hearing ability in normal hearing individuals and in various states of rehabilitations and provide important prognostic information for Military Commanders. Currently generalized assumptions are made that Military members are able to hear and communicate unless otherwise identified as hearing impaired. The variability in hearing performance is high (i.e., the ability to identify a signal from the noisy surroundings or the ability to localize sounds); the knowledge on this individual performance level may be an indicator for job performance. It is expected that measures of these abilities will become crucial in future. [124]-[126]

5.16 HEARING TRAINING PROGRAMS

The performance of most body functions can be improved by training. This applies for hearing as well. The ability to locate sounds or understand speech in radio transmissions can be trained. Structured auditory training programs may be helpful for the improvement of communication standards and communication quality. This will reduce the risk of errors due to misunderstandings. Military specific auditory training programs are not yet available, but should be developed. Pertinent to NATO collaborative missions, non-native speakers and second language utilization are factors in effective communication. Here again, training in speech and radio etiquette improve the speed and accuracy of information transfer.

5.17 HEARING PROTECTION AND HEARING NEEDS

For more than 20 years, intensive research has been done to develop and improve hearing protective devices. This has successfully reduced the incidence of noise-induced hearing loss among soldiers. Modern hearing protection devices almost provide soldiers with normal hearing of speech. Those technologies use low pass filters, integrated communication signals, active noise reduction, and sound amplification to provide protection with very little interference to hearing function. Research in drug development for hearing protection or treatment of hearing loss is ongoing – trying hair cell preservation, directing neural regeneration, reducing secondary damage by reactive oygene species, or other genetic, metabolic or proteogenomic measurements. Sounds engineering and mitigation efforts to modify, cancel or reduce noise at its source are ongoing necessary efforts. [127]-[131]

Behavior change strategies for soldiers are necessary to prevent noise-induced hearing loss. These include building awareness and motivation to use protection, education and training to properly select and use hearing protection and accountability to report for testing when exposures incite auditory symptoms are all efforts to preserve hearing function.

Education addresses:

1) Proper use of hearing protective devices.
2) Awareness and avoidance of hazardous noise.
3) Knowledge of risk factors for hearing loss.
4) Knowledge of the importance of hearing on the quality of life.
5) Knowledge of early signs for hearing loss.
6) Explanation of the need for hearing screening.
7) Awareness of the significant off-duty noise sources.
8) Knowledge of the narrow window of treatment opportunity after exposure.

The effects of these training programs can be measured through regular screening programs and in the longitudinal analysis of hearing and hearing loss.

5.18 HEARING REHABILITATION EFFICIENCY

The main goal of hearing rehabilitation is to keep well-trained soldiers safely and effectively on duty. It is necessary to assess criteria and algorithms for various types of hearing losses, and to analyze rehabilitative effects following interventions. Treatment of hearing loss (reconstructive surgical techniques, technical devices or auditory training) will restore most hearing functions, but will not necessarily lead to normal hearing. It is possible that some functions are restored completely or will become even better than in normal hearing persons, while some hearing functions are still lacking. Analyzing how effective rehabilitation efforts are in returning Military members to duty needs to be a priority. Criteria to guide fitness for duty with hearing devices may differ from criteria for the normal hearing population. [132]-[142]

5.18.1 Impact on the Team

Hearing loss is a possible risk factor to safety and even for survival in combat situations. The handicap may not only endanger the affected soldier, but also the whole team. Communication errors, unheard warning signals and reduced situational awareness have a strong impact on soldier's performance. Therefore there is a strong need to establish hearing fitness criteria. Furthermore, it is necessary to be able to identify individuals who do not meet the requested fitness criteria. This does not mean that all hearing-impaired soldiers have to be dismissed. Solutions to hearing impairment can and should be individualized, and are increasingly available through currently available technologies – these range from medical treatments, training, support with technical devices, reclassification or reassignment of duties, redefining tasks and responsibilities, to many other potential solutions. Determining the ranges of capabilities for reintegration of troops with hearing impairments and hearing devices with the emphasis of improving function, supporting retention and avoiding dismissal is the priority line of future research. [143]-[156]

5.18.2 Others

Comprehensive health reports and databases on health issues are an important tool for mission planners. These reports drive efficiency improvements, reduction of survival risks, development of effective protection and health preservation for the Military service and for Service members. The individual soldier is still the most valuable resource of the force. More and more members are becoming highly specialized experts that cannot easily be replaced. As such, it is imperative to provide the best hearing health education, training, and protection to avoid hearing loss, as well as to continually improve the care options for the rescue, treatment, and rehabilitation of auditory-vestibular injuries, while enhancing reintegration potential for all Military Service members. These activities require diligent and vigilant collection of data, analysis of data, and utilization of data to improve troop readiness, as well as care that will achieve life-long quality of life. The proposed database and data management processes described herein will provide the ability to identify and provide the most up-to-date hearing health prevention and care today, and will fuel hearing research that will deliver the opportunities of tomorrow. In the end, hearing integrates people with each other and their environments, enhancing their lives, providing for safety, increasing performance, which ultimately enhances the culture and traditions that establish the corporate identity of our Military systems. [157]-[168]

5.19 SUMMARY

Hearing is a critical sense that allows Military member's to communicate, and hearing facilitates the effective performance of their duties. Auditory communication is the most effective form of information transfer. Oral communication is the fastest, surest and most effective way to communicate. Unfortunately, the noisy Military environment is not always conducive to soldier' communication and can be very difficult to overcome, i.e., very noisy environments with several simultaneous speakers, multiple concurrent actions, and significant cognitive requirements placed on soldiers who may be sleep deprived, fatigued and anxious are potential distractors from good communication. Hearing is important to collect relevant information, distinguish and locate critical events during the mission. Therefore it is essential to mitigate noise as much as possible, protect against the noise threat through education, training and appropriate hearing protection, to ensure availability of the most proper communication skills and equipment, with the first goals being to prevent hearing loss, as well as to identify those soldiers at risk for hearing loss, and to identify shifts in hearing early so that early restorative or rehabilitative intervention can be applied.

As evidence accumulates suggesting that the sense of hearing is a vital asset that enables the function of all soldiers, the need to focus on hearing, hearing readiness and hearing fitness for duty becomes more apparent. Intensive research will be necessary to optimize hearing performance, either by technical means or through auditory training. As many soldiers are highly trained and experienced specialists in their fields, it is important to keep them in their jobs to maintain the lessons learned through their experiences and to prevent the costly need to replace and retrain others to take their places. Therefore it is also important to rehabilitate hearing loss and auditory injuries as a way to create efficiency in manpower management and maximize the overall effectiveness of the Military strength.

Aside from the awareness of the high-risk noise environment, or the important role that communication and hearing play in Military survivability and job performance, it is also necessary to stress that noise is ubiquitous outside of Military venues, and that hearing is one of the most important aspects of social life, a significant contributor to emotional interaction, and a substantial effector of quality of life.

Because auditory system injuries (hearing loss and tinnitus) are the most prevalent disabilities in Veterans of Military service, the efforts of the Task Group HFM-229 are strongly supported by this sustained and growing historical need. Enacting the concept of an international standardized database as the basis of

NATO-wide actions to improve knowledge base, prevention programs, rehabilitative efforts and definition of hearing readiness criteria, will enable the comparison of current and future hearing conservation and care practices and promote a unified focus and effort to combine individual forces towards managing and improving the growing "workload" of improving hearing outcomes. In this time of limited resources, collaborative work to successfully implement common surveillance strategies and readiness programs stands out as the most efficient way to optimize hearing outcomes that will in turn improve professional performance in the Military.

5.20 REFERENCES

5.20.1 Sections 5.1, 5.2 and 5.3

[1] Magaud-Camus I., Floury M.-C., Vinck L. and Waltisperger D. Le bruit au travail en 2003 : une nuisance qui touche trois salariés sur dix. Dares, Ministère de l'emploi, du travail et de la cohésion sociale, Premières Informations et Premières Synthèses, juin 2005 ; n° 25-3 ; 6 p. http://www.travail.gouv.fr.

[2] Campo P. and Dornier G. Le point des connaissances sur bruit et agents ototoxiques, Institut National de Recherche et de Sécurité (INRS), février 2005 ; ED 5028 ; 4 p. http://www.inrs.fr.

[3] Avan P., Campo P., Lataye R. and Dancer A. Gêne et risques auditifs encourus selon les ambiances au travail, Acoustiques et techniques ; 1998 ; 12.

[4] Campo P. and Dornier G. Le point des connaissances sur bruit et agents ototoxiques, Institut National de Recherche et de Sécurité (INRS), février 2005 ; ED 5028 ; 4 p. http://www.inrs.fr.

[5] El-Shazly A. Toxic solvents in car paints increase the risk of hearing loss associated with occupational exposure to moderate noise intensity. B-ENT, 2006; 2(1):1-5.

[6] Morata T.C., Johnson A.C., Nylen P., et al. Audiometric findings in workers exposed to low levels of styrene and noise. J Occup Environ Med, 2002; 44(9):806-14.

[7] Sliwinska-Kowalska M., Zamyslowska-Szmytke E., Szymczak W., et al. Ototoxic effects of occupational exposure to styrene and co-exposure to styrene and noise. J Occup Environ Med, 2003; 45(1):15-24.

[8] Sliwinska-Kowalska M., Zamyslowska-Szmytke E., Szymczak W., et al. Effects of coexposure to noise and mixture of organic solvents on hearing in dockyard workers. J Occup Environ Med, 2004; 46(1):30-8.

[9] Kim J., Park H., Ha E., Jung T., Paik N. and Yang S. Combined effects of noise and mixed solvents exposure on the hearing function among workers in the aviation industry. Ind Health, 2005; 43(3): 567-73.

[10] Fechter L.D., Fisher J.W., Chapman G.D., Mokashi V.P., Ortiz P.A., Reboulet J.E., Stubbs J.E., Lear A.M., McInturf S.M., Prues S.L., Gearhart C.A., Fulton S. and Mattie D.R. Subchronic JP-8 jet fuel exposure enhances vulnerability to noise-induced hearing loss in rats. J Toxicol Environ Health A. 2012; 75(5):299-317.

[11] Ward, W.D. The concept of susceptibility to hearing loss. Journal of Occupational and Environmental Medicine 7.12 (1965):595-607.

[12] Davis R.R., Kozel P. and Erway L.C. Genetic influences in individual susceptibility to noise: a review. Noise Health. 2003; 5:19-28.

[13] Fortunato, M.E., Zarrilli F., Mazzaccara C., Intrieri M., Calcagno G., Vitale D.F., La Manna P., Saulino C., Marcelli V. and Sacchetti L. Paraoxonase and superoxide dismutase gene polymorphisms and noise-induced hearing loss. Clin Chem. 2004; 50:2012-8.

[14] Ohlemiller K.K. and Gagnon P.M. Genetic dependence of cochlear cells and structures injured by noise. Hear Res. 2007; 224:34-50, http://www.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&retmode=ref&cmd=prlinks&id=21187137.

[15] Gratton, M.A. and Schulte, B.A. Alterations in microvasculature are associated with atrophy of the stria vascularis in quiet-aged gerbils. Hearing research 82.1 (1995):44-52.

[16] Shen H., Huo X., Liu K., Li X., Gong W., Zhang H., Xu Y., Wang M., Li X., Zhang J., Zhang Z. and Zhu B. Genetic variation in GSTM1 is associated with susceptibility to noise-induced hearing loss in a Chinese population. J Occup Environ Med. 2012 September; 54(9):1157-62.

[17] Bonaccorsi P. U colore dell'iride cone "test" di Valutazione quantitativa, nell'nemo della concentratione di melamina nella striavasculare, Annali Lar. Otol. Rhinol Fraing., 64. 1965, 72.

[18] Jansen G. Relation between temporary threshold shift and peripheral circulatory effects of sound, in "Physiological Effects of Noise", Welch and Welch Eds., 1970, Plenum, New York, USA.

[19] Rosen S., Plester D., El-Mofty A. and Rosen H.V. Relation of hearing loss to cardiovascular disease. Trans. Am. Acad. Ophtalmo. Otolaryngol. 68, 1964, 433.

[20] Wu H.P., Hsu C.J., Cheng T.J. and Guo Y.L. N-acetylcysteine attenuates noise-induced permanent hearing loss in diabetic rats. Hear Res. 2010 August; 267(1-2):71-7.

[21] Job A., Raynal M. and Rondet Ph. Hearing loss and use of personal stereos in young adults with antecedents of otitis media. The Lancet, 353, 1999, 35.

[22] Dancer A. Individual Susceptibility to NIHL and New Perspective in Treatment of Acute Noise Trauma Puper presented at the RTO HFM Lecture Series on "Damage Risk from Impulse Noise I, held in Maryland, USA, 5-6 June 2000 and Meppen, Germany, 15-16 June 2000, both published in RTO-EN-11 AC/323(HFM)TP/31, ISBN 92-837-1042-8, Published September 2000.

[23] Botte M-C., Baruch C. and Dancer A. TTS as a function of exposure frequency. J. Acoustique, 3, 1990, 53.

[24] Chon K.M., Roh H.J., Goh E.K. and Wang S.G. Noise Induced Hearing Loss and the Individual Susceptibility to the Noise. Audiology, 1996, 2(1).

[25] Bienvenue G.R., Violin-Singer J.R. and Michael P.L. Loudness discrimination index (LDI): a test for early detection of noise susceptible individuals. Am. Ind. Hyg. Assoc. J., 38, 1977, 333.

[26] Humes L.E. Review of four new indices of Susceptibility to Noise-Induced-Hearing-Loss. J. Occup. Med., 19, 1977, 116.

[27] Shupak A., Tal D., Sharoni Z., Oren M., Ravid A. and Pratt H. Otoacoustic emissions in early noise-induced hearing loss. Otol Neurotol. 2007 September; 28(6):745-52.

[28] Job A., Raynal M., Kossowski M., Studler M., Ghernaouti C., Baffioni-Venturi A., Roux A., Darolles C. and Guelorget A. Otoacoustic detection of risk of early hearing loss in ears with normal audiograms: a 3-year follow-up study. Hear Res. 2009 May; 251(1-2):10-6.

[29] Kemp D.T., Ryan S., et al. (1990). A guide to the effective use of otoacoustic emissions. Ear Hear 11(2):93-105.

[30] Khalfa S., Morlet T., et al. (1997). Evidence of peripheral hearing asymmetry in humans: clinical implications. Acta Otolaryngol 117(2):192-6.

[31] Patuzzi R.B. and Thompson M.L. (1991). Cochlear efferent neurones and protection against acoustic trauma: protection of outer hair cell receptor current and interanimal variability. Hear Res 54(1): 45-58.

[32] Rajan R. and Patuzzi R.B. (1992). Additivity of threshold losses produced by acute acoustic trauma. Hear Res 60(2):216-30.

[33] Lynch E.D. and Kil J. (2005) Compounds for prevention and treatment of noise-induced hearing loss. DDT, 10 (19):1291-98.

[34] Abi-Hachem R N., Zine A., et al. (2010) The injured cochlea as a target for inflammatory processes, initiation of cell death pathways and application of related otoprotectives strategies. Recent Pat CNS Drug Discov 5(2):147-63.

[35] Cheng A.G., Cunningham, L.L., et al. (2005). Mechanisms of hair cell death and protection. Curr Opin Otolaryngol Head Neck Surg 13(6):343-8.

[36] Fetoni A.R., Mancuso C., et al. (2010) In vivo protective effect of ferulic acid against noise-induced hearing loss in the guinea-pig. Neuroscience 169(4):1575-88.

[37] Fetoni A.R., De Bartolo P., et al (2013). Noise-induced hearing loss (NIHL) as a target of oxidative stress-mediated damage: cochlear and cortical responses after an increase in antioxidant defense. J Neurosci. February 27; 33(9):4011-23.

5.20.2 Sections 5.3 to 5.19 – Screening

[38] Beswick R., Driscoll C., Kei J., Khan A. and Glennon S. (2013). Which risk factors predict postnatal hearing loss in children? Journal of the American Academy of Audiology, 24(3), 205-213.

[39] Bhatia P., Mintz S., Hecht B.F., Deavenport, A. and Kuo A.A. (2013). Early identification of young children with hearing loss in federally qualified health centers. Journal of Developmental and Behavioral Pediatrics: JDBP, 34(1), 15-21.

[40] De Raeve L. and Wouters A. (2013). Accessibility to cochlear implants in Belgium: State of the art on selection, reimbursement, habilitation, and outcomes in children and adults. Cochlear Implants International, 14 Suppl 1, 18-25.

[41] Morris A.E., Lutman M.E., Cook A.J. and Turner D. (2013). An economic evaluation of screening 60- to 70-year-old adults for hearing loss. Journal of Public Health (Oxford, England), 35(1), 139-146.

[42] Muñoz K., Blaiser K. and Barwick K. (2013). Parent hearing aid experiences in the United States. Journal of the American Academy of Audiology, 24(1), 5-16.

[43] Salvago P., Martines E. and Martines F. (2013). Prevalence and risk factors for sensorineural hearing loss: Western Sicily overview. European Archives of Oto-Rhino-Laryngology: Official Journal of the European Federation of Oto-Rhino-Laryngological Societies (EUFOS): Affiliated with the German Society for Oto-Rhino-Laryngology – Head and Neck Surgery.

[44] Sekhar D.L., Zalewski T.R. and Paul I.M. (2013). Variability of State School-Based Hearing Screening Protocols in the United States. Journal of Community Health.

[45] Van Kerschaver E., Boudewyns A.N., Declau F., Van de Heyning P.H. and Wuyts F.L. (2013). Socio-demographic determinants of hearing impairment studied in 103,835 term babies. European Journal of Public Health, 23(1), 55-60.

[46] Weichbold V., Holzer A., Newesely G., Zorowka P. and Stephan K. (2013). Results of hearing screenings in 14- to 15-year old adolescents. Hno, 61(1), 25-29.

[47] Wood S.A., Davis A.C. and Sutton G.J. (2013). Effectiveness of targeted surveillance to identify moderate to profound permanent childhood hearing impairment in babies with risk factors who pass newborn screening. International Journal of Audiology.

5.20.3 Sections 5.3 to 5.19 – Best Clinical Practices

5.20.3.1 Advanced Technologies

[48] Achar P. (2013). Hearing rehabilitation with middle ear implants: An overview. The Surgeon: Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland.

[49] Ajalloueyan M., Kouhi A., Asgari A., Salem M. and Hasanalifard M. (2013). Stem cell transplantation in noise induced hearing loss. International Journal of Pediatric Otorhinolaryngology.

[50] Clark J.H., Yeagle J., Arbaje A.I., Lin F.R., Niparko J.K. and Francis H.W. (2012). Cochlear implant rehabilitation in older adults: literature review and proposal of a conceptual framework. Journal of the American Geriatrics Society 60.10 (2012): 1936-1945.

[51] Cohen S. (2004). Quality of life in hearing-impaired adults: The role of cochlear implants and hearing aids. Otolaryngology - Head and Neck Surgery, 131(4), 413-422.

[52] Hassepass F., Aschendorff A., Wesarg T., Kröger S., Laszig R., Beck R.L., et al. (2013). Unilateral deafness in children: audiologic and subjective assessment of hearing ability after cochlear implantation. Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 34(1), 53-60.

[53] Hidalgo J.L.T., Gras C.B., Lapeira J.M.T., Martinez I.P., Verdejo M.A.L., Rabadan F.E. and Puime A.O. (2008). The Hearing-Dependent Daily Activities Scale to Evaluate Impact of Hearing Loss in Older People. The Annals of Family Medicine, 6(5), 441-447.

[54] Khwaja S., Mawman D., Nichani J., Bruce I., Green K. and Lloyd S. (2012). Cochlear implantation in patients profoundly deafened after head injury. Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 33(8), 1328-1332.

[55] Kohan D. and Levy L. (1999). Aural rehabilitation hearing aids and assistive listening devices. Amer Academy of Otolaryngology.

[56] Lew H.L.H., Jerger J.F.J., Guillory S.B.S. and Henry J.A.J. (2006). Auditory dysfunction in traumatic brain injury. Journal of Rehabilitation Research and Development, 44(7), 921-928.

[57] Olze H., Szczepek A.J., Haupt H., Förster U., Zirke N., Gräbel S. and Mazurek B. (2011). Cochlear implantation has a positive influence on quality of life, tinnitus, and psychological comorbidity. The Laryngoscope, 121(10), 2220-2227.

[58] Öberg M., Marcusson J., Nägga K. and Wressle E. (2012). Hearing difficulties, uptake, and outcomes of hearing aids in people 85 years of age. International Journal of Audiology, 51(2), 108-115.

[59] Phythyon M.J. and McConnell F. (1969). Notes on Theory, Research, and Practice Hearing Rehabilitation for Older People. The Gerontologist, 9(1), 66-68.

[60] Redfors Y.D., Hellgren J. and Möller C. (2013). Hearing-aid use and benefit: A long-term follow-up in patients undergoing surgery for otosclerosis. International Journal of Audiology, 52(3), 194-199.

[61] Semaan M.T., Gehani N.C., Tummala N., Coughlan C., Fares S.A., Hsu D.P., et al. (2012). Cochlear implantation outcomes in patients with far advanced otosclerosis. American Journal of Otolaryngology, 33(5), 608-614.

[62] Tye-Murray N., Spry J.L. and Mauzé E. (2009). Professionals with hearing loss: maintaining that competitive edge. Ear and Hearing, 30(4), 475-484.

5.20.3.2 Balance / Vestibular Function

[63] Kerr A.G. and Byrne J.E. Concussive effects of bomb blast on the ear. J Laryngol Otol, 1975. 89(2): p. 131-43.

[64] Scherer M., et al. Characterizing self-reported dizziness and otovestibular impairment among blast-injured traumatic amputees: a pilot study. Mil Med, 2007. 172(7): p. 731-7.

[65] Scherer M.R. and Schubert M.C. Traumatic brain injury and vestibular pathology as a comorbidity after blast exposure. Phys Ther, 2009. 89(9): p. 980-92.

[66] Van Campen L.E., et al. One-year vestibular and balance outcomes of Oklahoma City bombing survivors. J Am Acad Audiol, 1999. 10(9): p. 467-83.

[67] Cudennec Y.F., Buffe P. and Poncet J.L. Otologic features and teachings of a bombing attempt. Mil Med, 1995. 160(9): p. 467-70.

[68] Hoffer M.E., Balaban C., Gottshall K., et al. Blast Exposure: Vestibular consequences and associated characteristics. Otology Neurotology, 2010. 31(2):232-6.

[69] Mehlenbacher A., et al. Sound induced vertigo: superior canal dehiscence resulting from blast exposure. Arch Phys Med Rehabil, 2012. 93(4): p. 723-4.

[70] Shupak A., et al. Vestibular and audiometric consequences of blast injury to the ear. Arch Otolaryngol Head Neck Surg, 1993. 119(12): p. 1362-7.

[71] Yardley L., et al. Effects of anxiety arousal and mental stress on the vestibulo-ocular reflex. Acta Otolaryngol, 1995. 115(5): p. 597-602.

[72] Sylvia F.R., Drake A.I. and Wester D.C. Transient vestibular balance dysfunction after primary blast injury. Mil Med, 2001. 166(10): p. 918-20.

[73] Fausti S.A., et al. Auditory and vestibular dysfunction associated with blast-related traumatic brain injury. J Rehabil Res Dev, 2009. 46(6): p. 797-810.

[74] Katon W. Panic disorder: epidemiology, diagnosis, and treatment in primary care. J Clin Psychiatry, 1986. 47 Suppl: p. 21-30.

[75] Hauser S.L., et al. Gulf War and Health, Volume 9: Long-Term Effects of Blast Exposures. National Academies Press 2014. http://www.nap.edu/catalog.php?record_id=18253.

[76] Tevzadze N. and Shakarishvili R. Vertigo syndromes associated with earthquake in Georgia. Georgian Med News, 2007(148-149): p. 36-9.

[77] Tyagi I. and Taneja H.C. Acoustic biast trauma. Indian J Otolaryngol Head Neck Surg, 1997. 49(Suppl 1): p. 51-4.

[78] Cohen J.T., et al. Blast injury of the ear in a confined space explosion: auditory and vestibular evaluation. Isr Med Assoc J, 2002. 4(7): p. 559-62.

[79] Sakka L., et al. Electrophysiological monitoring of cochlear function as a non-invasive method to assess intracranial pressure variations. Acta Neurochir Suppl, 2012. 114: p. 131-4.

[80] Avan P., et al. Unstable distortion-product otoacoustic emission phase in Meniere’s disease. Hear Res, 2011. 277(1-2): p. 88-95.

5.20.3.3 Tinnitus Assessment and Treatment

[81] Jastreboff P.J. 1990. Phantom auditory perception (tinnitus): mechanisms of generation and perception. Neurosci Res 8:221-254.

[82] Roberts L.E., Eggermont J.J., Caspary D.M., Shore S.E., Melcher J.R. and Kaltenbach J.A. 2010. Ringing ears: the neuroscience of tinnitus. J Neurosci 30:14972-14979.

[83] Rajan R. and Irvine D.R. 1998. Neuronal responses across cortical field A1 in plasticity induced by peripheral auditory organ damage. Audiol Neurootol 3:123-144.

[84] Kaltenbach J.A. 2000. Neurophysiologic mechanisms of tinnitus. J Am Acad Audiol 11:125-137.

[85] Eggermont J.J. 2003. Central tinnitus. Auris Nasus Larynx 30 Suppl:S7-12.

[86] Norena A.J. and Eggermont J.J. 2003. Changes in spontaneous neural activity immediately after an acoustic trauma: implications for neural correlates of tinnitus. Hear Res 183:137-153.

[87] Eggermont J.J. 2006. Cortical tonotopic map reorganization and its implications for treatment of tinnitus. Acta Otolaryngol Suppl:9-12.

[88] Shiomi Y., Tsuji J., Naito Y., Fujiki N. and Yamamoto N. 1997. Characteristics of DPOAE audiogram in tinnitus patients. Hear Res 108:83-88.

[89] Job A., Raynal M. and Kossowski M. 2007. Susceptibility to tinnitus revealed at 2 kHz range by bilateral lower DPOAEs in normal hearing subjects with noise exposure. Audiol Neurootol 12:137-144.

[90] Muhlnickel W., Elbert T., Taub E. and Flor H. 1998. Reorganization of auditory cortex in tinnitus. Proc Natl Acad Sci U S A 95:10340-10343.

[91] Dietrich V., Nieschalk M., Stoll W., Rajan R. and Pantev C. 2001. Cortical reorganization in patients with high frequency cochlear hearing loss. Hear Res 158:95-101.

[92] Lockwood A.H., Salvi R.J. and Burkard R.F. 2002. Tinnitus. N Engl J Med 347:904-910.

[93] Moller A.R. 2003. Pathophysiology of tinnitus. Otolaryngol Clin North Am 36:249-266, v-vi.

[94] Shore S.E., Koehler S., Oldakowski M., Hughes L.F. and Syed S. 2008. Dorsal cochlear nucleus responses to somatosensory stimulation are enhanced after noise-induced hearing loss. Eur J Neurosci 27:155-168.

[95] Weisz N., Wienbruch C., Dohrmann K. and Elbert T. 2005. Neuromagnetic indicators of auditory cortical reorganization of tinnitus. Brain 128:2722-2731.

[96] Jastreboff P.J. and Hazell J.W.P. 2004. Tinnitus retraining therapy. Cambridge: Cambridge University Press.

[97] Verret C., Matras-Maslin V., Haus-Cheymol R., Berger F., Texier G., Decam C., Poncet J. and Spiegel A. 2005. Traumatismes sonores aigus dans les armées. Résultats de la surveillance épidémiologique de 2002 à 2004. In: Département d'épidémiologie et de santé publique nord. Ecole du Val de Grâce, p. 42.

[98] Nottet J.B., Moulin A., Brossard N., Suc B. and Job A. 2006. Otoacoustic emissions and persistent tinnitus after acute acoustic trauma. Laryngoscope 116:970-975.

[99] Barrs D. and Brackmann D. 1984. Translabyrinthine nerve section: effect on tinnitus. The Journal of Laryngology & Otology (Supplement), pp. 287-293.

[100] House J.W. and Brackmann D.E. 1981. Tinnitus: surgical treatment. Ciba Found Symp 85: 204-216.

[101] Sanchez T.G., Guerra G.C., Lorenzi M.C., Brandao A.L. and Bento R.F. 2002. The influence of voluntary muscle contractions upon the onset and modulation of tinnitus. Audiol Neurootol 7:370-375.

[102] Levine R.A., Nam E.C., Oron Y. and Melcher J.R. 2007. Evidence for a tinnitus subgroup responsive to somatosensory based treatment modalities. Prog Brain Res 166: 195-207.

[103] Folmer R.L., Griest S.E. and Martin W.H. 2001. Chronic tinnitus as phantom auditory pain. Otolaryngol Head Neck Surg 124:394-400.

[104] De Ridder D., De Mulder G., Menovsky T., Sunaert S. and Kovacs S. 2007. Electrical stimulation of auditory and somatosensory cortices for treatment of tinnitus and pain. Prog Brain Res 166:377-388.

[105] Axelsson A. and Ringdahl A. 1989. Tinnitus--a study of its prevalence and characteristics. Br J Audiol 23:53-62.

[106] Heller A.J. 2003. Classification and epidemiology of tinnitus. Otolaryngol Clin North Am 36:239-248.

[107] Job A., Cian C., Esquivie D., Leifflen D., Trousselard M., Charles C. and Nottet J.B. 2004. Moderate variations of mood/emotional states related to alterations in cochlear otoacoustic emissions and tinnitus onset in young normal hearing subjects exposed to gun impulse noise. Hear Res 193:31-38.

[108] Critchley H.D., Wiens S., Rotshtein P., Ohman A. and Dolan R.J. (2004) Neural systems supporting interoceptive awareness. Nat Neurosci 7:189-195.

[109] Kovacs S., Peeters R., Smits M., De Ridder D., Van Hecke P. and Sunaert S. 2006. Activation of cortical and subcortical auditory structures at 3 T by means of a functional magnetic resonance imaging paradigm suitable for clinical use. Invest Radiol 41:87-96.

[110] Smits M., Kovacs S., de Ridder D., Peeters R.R., van Hecke P. and Sunaert S. 2007. Lateralization of functional magnetic resonance imaging (fMRI) activation in the auditory pathway of patients with lateralized tinnitus. Neuroradiology 49:669-679.

[111] Leaver A.M., Renier L., Chevillet M.A., Morgan S., Kim H.J. and Rauschecker J.P. 2011. Dysregulation of limbic and auditory networks in tinnitus. Neuron 69:33-43.

[112] Maudoux A., Lefebvre P., Cabay J.E., Demertzi A., Vanhaudenhuyse A., Laureys S. and Soddu A. Auditory Resting-State Network Connectivity in Tinnitus: A Functional MRI Study; Plos One 2012; 7:e36222

[113] Job A., Pons Y., Lamalle L., Jaillard A., Buck K., Segebarth C. and Delon-Martin C. 2012 Abnormal cortical sensorimotor activity during “Target” sound detection in subjects with acute acoustic trauma sequelae: an fMRI study. Brain Behav 2:187-199.

[114] Job A., Paucod J.-C., O’Beirne G.A. and Delon-Martin C. 2011. Cortical representation of tympanic membrane movements due to pressure variation: A fMRI study. Hum brain mapp 32:744-749.

[115] Clancy C.M., Slutsky J., Chang S. and Janakiramen S. Evaluation and Treatment of Tinnitus: Comparative Effectiveness. Comparative effectiveness review 122, Effective Health Care Program, Agency for Healthcare Research and Quality, August 2013.

5.20.3.4 Blast-Related CAPD

[116] Ahissar M., Nahum M., Nelken I. and Hochstein S. (2009). Reverse hierarchies and sensory learning. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1515), 285-299.

[117] Brungart D., Kubli L., Sheffield B., Phatak S., Makashay M. and Grant K. (2014). Evaluating functional hearing deficits in blast-exposed personnel with normal audiometric thresholds. Poster presented at the 37th annual meeting of the Association for Research in Otolaryngology, Baltimore, MD, USA.

[118] Brungart D., Sheffield B. and Kubli L. (2014). Development of a test battery for evaluating speech perception in complex listening environments. The Journal of the Acoustical Society of America 136(2) 777-790. http://dx.doi.org/10.1121/1.4887440.

[119] Kujawa S.G. and Liberman M.C. Adding insult to injury: cochlear nerve degeneration after “temporary” noise-induced hearing loss. J Neurosci. 2009;29:14077-14085.

[120] Kujawa, S.G. and Liberman, M.C. Synaptopathy in the noise-exposed and aging cochlea: primary neural degeneration in acquired sensorineural hearing loss. Hearing Research, 11 Mar 2015, Epub ahead of print. http://www.ncbi.nlm.nih.gov/pubmed/25769437.

[121] Gallun F., Diedesch A., Kubli L., Walden T., Folmer R., Lewis M., McDermott D., Fausti S. and Leek M. (2012a). Performance on tests of central auditory processing by individuals exposed to high intensity blasts. Journal of Rehabilitation Research & Development, 49(7), 1000-1024.

[122] Gallun F., Lewis S., Folmer R., Diedesch A., Kubli L., McDermott D., Walden T., Fautsi S., Lew H. and Leek M. (2012b). Implications of blast exposure for central auditory function: A review. Journal of Rehabilitation Research & Development, 49(7), 1059-1074.

[123] London S. (2009). Sleep disturbances may provide entry into PTSD care. Clinical Psychiatry News / August 2009, http://findarticles.com/p/articles/mi_hb4345/is_8_37/ai_n35610745/.

5.20.3.5 Auditory Function

[124] McCreery R.W., Brennan M.A., Hoover B., Kopun J. and Stelmachowicz P.G. (2012). Maximizing Audibility and Speech Recognition with Nonlinear Frequency Compression by Estimating Audible Bandwidth. Ear and Hearing.

[125] Norin J.A., Emanuel D.C. and Letowski T.R. (2011). Speech intelligibility and passive, level-dependent earplugs. Ear and Hearing, 32(5), 642-649.

[126] Vaillancourt V., Laroche C., Giguère C., Beaulieu M.-A. and Legault J.-P. (2011). Evaluation of auditory functions for Royal Canadian Mounted Police officers. Journal of the American Academy of Audiology, 22(6), 313-331.

5.20.3.6 Inner-Ear Function

[127] de Souza Chelminski Barreto M.A.M., Costa C.S.A.C., de Souza Guarita L.K.L., Oliveira C.A.C.P.C. and Júnior F.B.F. (2009). Auditory monitoring by means of evaluation of the cochleain soldiers of the Brazilian Army exposed to impulse noise. The International Tinnitus Journal, 16(2), 123-129.

[128] Job A., Raynal M., Kossowski M., Studler M., Ghernaouti C., Baffioni-Venturi A., et al. (2009). Otoacoustic detection of risk of early hearing loss in ears with normal audiograms: A 3-year follow-up study. Hearing Research, 251(1-2), 10-16.

[129] Konopka W., Zalewski P. and Pietkiewicz P. (2001). Evaluation of transient and distortion product otoacoustic emissions before and after shooting practice. Noise & Health.

[130] Plinkert P.K., Hemmert W. and Wagner W. (1999). Monitoring noise susceptibility: sensitivity of otoacoustic emissions and subjective audiometry. British journal of audiology 33.6 (1999):367-382.

[131] Sliwinska-Kowalska M. and Kotylo P. (2001). Otoacoustic emissions in industrial hearing loss assessment. Noise & Health.

5.20.3.7 Implantable Devices

[132] Blamey P., Artières F., Başkent D., Bergeron F., Beynon A., Burke E., et al. (2013). Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants: an update with 2251 patients. Audiology and Neurotology, 18(1), 36-47.

[133] Cohen S. (2004). Quality of life in hearing-impaired adults: The role of cochlear implants and hearing aids. Otolaryngology - Head and Neck Surgery, 131(4), 413-422.

[134] Goswamy J., Bruce I.A., Green K.M.J. and O'Driscoll M.P. (2012). Cochlear implantation in a patient with sensori-neural deafness secondary to Charcot-Marie-Tooth disease. Cochlear Implants International, 13(3), 184-187.

[135] Helbig S., Rajan G.P., Stöver T., Lockley M., Kuthubutheen J. and Green K.M. (2013). Hearing preservation after cochlear reimplantation. Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 34(1), 61-65.

[136] Jacob R. and Stelzig Y. (2012). Cochlear implant Versorgung in Deutschland. HNO, 1-12.

[137] Kerber S. and Seeber B.U. (2012). Sound localization in noise by normal-hearing listeners and cochlear implant users. Ear and Hearing, 33(4), 445-457.

[138] Lazard D.S., Vincent C., Venail F., Van de Heyning P., Truy E., Sterkers O., et al. (2012). Pre-, Per- and Postoperative Factors Affecting Performance of Postlinguistically Deaf Adults Using Cochlear Implants: A New Conceptual Model over Time. (M.S. Malmierca, Ed.)PLoS ONE, 7(11), e48739.

[139] Litovsky R.Y., Goupell M.J., Godar S., Grieco-Calub T., Jones G.L., Garadat S.N., et al. (2012). Studies on bilateral cochlear implants at the University of Wisconsin's Binaural Hearing and Speech Laboratory. Journal of the American Academy of Audiology, 23(6), 476-494.

[140] McKay C.M., Lim H.H. and Lenarz T. (2012). Temporal Processing in the Auditory System: Insights from Cochlear and Auditory Midbrain Implantees. Journal of the Association for Research in Otolaryngology: JARO.

[141] Niedermeier K., Braun S., Fauser C., Kiefer J., Straubinger R.K. and Stark T. (2012). A safety evaluation of dexamethasone-releasing cochlear implants: Comparative study on the risk of otogenic meningitis after implantation. Acta Oto-Laryngologica, 132(12), 1252-1260.

[142] Zhang T., Dorman M.F., Fu Q.-J. and Spahr A.J. (2012). Auditory training in patients with unilateral cochlear implant and contralateral acoustic stimulation. Ear and Hearing, 33(6), e70-9.

5.20.3.8 Impact of Hearing Skills on Military Fitness for Duty

[143] Chan G., Tan V. and Koh D. (2000). Ageing and fitness to work. Occupational Medicine.

[144] Charness N. and Bosman E.A. (1994). Age-related changes in perceptual and psychomotor performance: implications for engineering design. Experimental Aging Research.

[145] Convery E., Keidser G., Caposecco A., Swanepoel D.W., Wong L.L. and Shen E. (2013). Hearing-aid assembly management among adults from culturally and linguistically diverse backgrounds: Toward the feasibility of self-fitting hearing aids. International journal of audiology, 52(6), 385-393.

[146] Daniel E. (2007). Noise and Hearing Loss: A Review. Journal of School Health, 77(5), 225-231.

[147] de Raad J., Nijhuis F.J.N. and Willems J.H.B.M. (2005). Difference in Fitness for Duty among Soldiers on a Mission: Can These Be Explained by a Difference in the Preemployment Assessment?

[148] Hancock K.E., Chung Y. and Delgutte B. (2013). Congenital and Prolonged Adult-Onset Deafness Cause Distinct Degradations in Neural ITD Coding with Bilateral Cochlear Implants. Journal of the Association for Research in Otolaryngology: JARO, 122-128.

[149] Hornsby B.W.Y. (2013). The Effects of Hearing Aid Use on Listening Effort and Mental Fatigue Associated With Sustained Speech Processing Demands. Ear and Hearing, 235-38.

[150] Hutchinson K.M., Alessio H. and Baiduc R.R. (2010). Association between cardiovascular health and hearing function: Pure-tone and distortion product otoacoustic emission measures. American Journal of Audiology.

[151] Kales S.N. and Christiani D.C. (1999). Fitness for Duty Evaluations of Firefighters. Journal of Occupational and Environmental Medicine.

[152] McCormack A. and Fortnum H. (2013). Why do people fitted with hearing aids not wear them? International Journal of Audiology, 23-28.

[153] Palmer K.T., Brown I. and Hobson J. (2013). Fitness for Work: The Medical Aspects. OUP Oxford.

[154] Picou E.M., Ricketts T.A. and Hornsby B.W.Y. (2013). How Hearing Aids, Background Noise, and Visual Cues Influence Objective Listening Effort. Ear and Hearing, 344-350.

[155] Roine I., Pelkonen T., Cruzeiro M.L., Kataja M., Peltola H. and Pitkäranta A. (2013). Hearing Impairment and its Predictors in Childhood Bacterial Meningitis in Angola. Pediatric Infectious Disease Journal.

[156] Tufts J.B., Vasil K.A. and Briggs S. (2009). Auditory fitness for duty: a review. Journal of the American Academy of Audiology, 20(9), 539-557.

5.20.3.9 Others

[157] Cadoni G., Cianfoni A., Agostino S., Scipione S., Tartaglione T., Galli J. and Colosimo C. (2006). Magnetic resonance imaging findings in sudden sensorineural hearing loss. The Journal of Otolaryngology, 35(5), 310-316.

[158] Domínguez-Punaro M.C., Koedel U., Hoegen T., Demel C., Klein M. and Gottschalk M. (2012). Severe cochlear inflammation and vestibular syndrome in an experimental model of Streptococcus suis infection in mice. European Journal of Clinical Microbiology & Infectious Diseases: Official Publication of the European Society of Clinical Microbiology, 31(9), 2391-2400.

[159] Harris J.P., Fukuda S. and Keithley E.M. (1990). Spiral modiolar vein: its importance in inner ear inflammation. Acta Oto-Laryngologica.

[160] Ichimiya I., Yoshida K., Hirano T., Suzuki M. and Mogi G. (2000). Significance of spiral ligament fibrocytes with cochlear inflammation. International Journal of Pediatric Otorhinolaryngology, 56(1), 45-51.

[161] Kuhn M., Heman-Ackah S.E., Shaikh J.A. and Roehm P.C. (2011). Sudden Sensorineural Hearing Loss: A Review of Diagnosis, Treatment, and Prognosis. Trends in Amplification, 15(3), 91-105.

[162] Levi J., Looney L., Murray R., Inverso Y., O'Reilly R.C. and Morlet T. (2012). Auditory nerve function following cochleitis. International Journal of Pediatric Otorhinolaryngology, 36-39.

[163] Menardo J.J., Tang Y.Y., Ladrech S.S., Lenoir M.M., Casas F.F., Michel C.C., et al. (2012). Oxidative stress, inflammation, and autophagic stress as the key mechanisms of premature age-related hearing loss in SAMP8 mouse Cochlea. Antioxidants and Redox Signaling, 16(3), 263-274.

[164] Mijovic T., Zeitouni A. and Colmegna I. (2013). Autoimmune sensorineural hearing loss: the otology-rheumatology interface. Rheumatology, 0(2013), 91-9.

[165] Ni D., Shepherd R.K., Seldon H.L., Xu S.A. and Clark G.M. (1992). Cochlear pathology following chronic electrical stimulation of the auditory nerve. I: Normal hearing kittens. Hearing Research.

[166] Stachler R.J., Chandrasekhar S.S., Archer S.M., Rosenfeld R.M., Schwartz S.R., Barrs D.M., et al. (2012). Clinical Practice Guideline: Sudden Hearing Loss. Otolaryngology - Head and Neck Surgery, 146(3_suppl), 1-35.

[167] Teissier N.N., Delezoide A.-L.A., Mas A.-E.A., Khung-Savatovsky S.S., Bessières B.B., Nardelli J.J., et al. (2011). Inner ear lesions in congenital cytomegalovirus infection of human fetuses. Acta Neuropathologica, 122(6), 763-774.

[168] Yang G.S., Song H.T., Keithley E.M. and Harris J.P. (2000). Intratympanic immunosuppressives for prevention of immune-mediated sensorineural hearing loss. The American Journal of Otology, 21(4), 499-504.

[169] Avan P. and Bonfils P. Distortion-product otoacoustic emission spectra and high-resolution audiometry in noise-induced hearing loss. Hearing research 209.1 (2005): 68-75.

[170] De Haan H.J. The relationship of estimated comprehensibility to the rate of connected speech. Perception & Psychophysics 32.1 (1982): 27-31.

Chapter 6 – HEARING FACTS IN THE MILITARY

6.1 HEARING LOSS AND TINNITUS IN THE UNITED STATES

- As of 2010, approximately 36 million Americans have hearing loss. An estimated one out of every three cases is caused by excess noise exposure (noise-induced hearing loss).
- An estimated 50 million Americans suffer from tinnitus (ringing in the ears). Of those, 16 million have sought medical attention for their tinnitus.
- An estimated one in five American teens suffers from the same degree of hearing loss found in older adults age 50 – 60.
- An estimated one in five high-schoolers suffer from ringing in the ears (tinnitus).
- Hearing loss, which is the third most common chronic condition in older adults after arthritis and heart disease, represents a pressing national public health issue.
- More than 30 million Americans are exposed to dangerous levels of noise in their workplaces and an additional nine million are exposed to ototoxic chemicals.

6.2 HEARING AND AUDITORY INJURY IN THE MILITARY

- The Department of Veterans Affairs (VA) spent an estimated $1.39 billion to compensate major auditory disabilities in FY 2010.
- The auditory system accounts for the second highest affected body system in VA-disabled veterans.
- **2.12 M** American Veterans have service-connected disability of the auditory body system.
- Over 764,000 are unique claims from the Gulf War Era (includes non-combat claims).
- Tinnitus (1,121,709) and hearing loss (854,855) account for the two most prevalent service-connected disabilities among veterans.
- Current trends suggest that the incidence of tinnitus and hearing loss is increasing 13 – 18 percent annually.
- At the current estimated rate of increase, VA costs for veterans with service-connected tinnitus is projected to increase to over $2.26 billion by 2014.
- Combined, tinnitus and hearing loss affected nearly 16 percent of veterans who began receiving VA disability compensation in FY 2012 and nearly 20 percent of veterans who began receiving VA disability in 2011.
- More than 350,000 Service members have reported tinnitus and more than 250,000 Service members have reported hearing loss following redeployment from the Gulf War conflicts.
- Noise-induced hearing loss is among the top disabilities associated with current conflicts (OEF/OIF veterans).

- 50 – 60 percent of one's situational awareness comes from hearing. With bad hearing, it takes approximately 90 seconds to identify a target that takes 40 seconds to acquire with good hearing. The 50-second difference could mean life or death or mission success or failure.

- Seven out of ten injuries in Theater are due to blasts; an estimated 50 percent of these blast wounded warriors experience permanent hearing loss.

- Sustained exposure to engine noise in a convoy can be just as damaging to hearing as exposure resulting from an Improvised Explosive Device (IED).

6.3 KNOW YOUR DECIBELS

- The loudness of sound is measured in units called decibels (dB). Prolonged or close-range exposure to levels above 85 dB (e.g., lawnmower or helicopter cockpit noise) can cause hearing loss.

- The impact of decibels increases rapidly. For example, 20 dB is 100 times more powerful than 1 dB – and 120 dB is 1,000,000,000,000 times more powerful than 1 dB.

- For each 10 dB increase in volume, the perceived volume of noise is doubled.

- An MP3 player at maximum level is roughly 105 dB. That's 100 times more intense than 85 dB (which is widely regarded as the safe sound threshold).

- Lawn and home tools and equipment can reach up to 104 dB.

- Rock concerts can reach up to 130 dB, sports arenas can reach up to 140 dB.

- The quietest DoD weapon is the M-16, which measures in at about 156 dB. One shot without hearing protection can potentially damage one's hearing.

- Exposure to sounds 160 dB or higher (e.g., noise from fireworks or a close-range handgun) can cause immediate physical damage to one's ears.

- If someone is three feet away from you and you cannot hear them, the noise levels in your surroundings are probably high enough to damage your hearing. This is often the situation in noisy restaurants, night clubs as well as rock concerts, sporting events, and crowded festivals/parades.

- To reduce NIHL, the U.S. Occupational Safety and Health Administration (OSHA) requires hearing protection for civilian workers exposed to eight hours of continuous noise at or above 85 dB.

- For more about the danger of everyday noise, see HCE's poster, "How Loud is Too Loud?".

6.4 UNDERSTAND AUDITORY INJURY

- Gradual hearing loss can affect people of all ages, varying from mild to profound. Depending on the cause, it can be mild or severe, temporary or permanent.

- Humans have approximately 17,000 – 20,000 sensory hair cells in their ears. Once damaged, the cells cannot grow back, leaving one with permanent hearing loss.

- Harmful noise triggers destructive molecules in the ear that contribute to hair cell damage and NIHL.

- NIHL can be caused by one-time exposure to an intense "impulse" sound, such as noise from a blast or explosion, or by continuous exposure to loud sounds over an extended period of time, such as noise generated by the roar of aircrafts or ship engines.
- Exposure to seemingly "routine" noises found in everyday circumstances, such as sporting events, night clubs or rock concerts, can gradually damage hearing over time.
- Hearing loss and tinnitus may be experienced in one or both ears. Also, the symptoms of tinnitus may be constant, or they may come and go (i.e., re-occur in periodic episodes).
- Severe tinnitus can accompany hearing loss and be just as debilitating as the hearing loss itself.
- Noise-Induced Hearing Loss (NIHL) is largely preventable. Hearing protection decreases the intensity of noise and helps preserve your hearing.

6.5 APPRECIATE THE IMPACT OF HEARING LOSS

- There is a correlation between untreated hearing loss and diminished income/earning potential.
- Hearing loss has been linked to chronic disease, dementia, depression, and anxiety.
- In older adults, hearing loss increases the risk of hospitalization and poor health.
- Effects of hearing loss by some estimates cost U.S. society approximately $26,000,000,000/year.
- Hearing loss and tinnitus cost the VA hundreds of millions of dollars each year in compensation.
- Studies suggest that the ability for a unit to accomplish its mission is directly proportional to its ability to communicate effectively.
- Hearing loss significantly impedes situational awareness and communication; in doing so, it interferes with a warrior's ability to recognize threats, exchange mission-critical information and give and receive commands.
- A warrior with an undiagnosed hearing impairment could endanger his/her own life as well as the safety and mission accomplishment of his/her unit as a whole.
- Good hearing is prerequisite for peak performance in both combat and non-combat environments.
- Untreated hearing loss can negatively affect one's quality of life and interpersonal relationships.

6.6 FUN FACTS

- No two ears are the same, which is important to keep in mind when ensuring proper fit for hearing protective devices. During hearing protection testing, there was a < 2 mm difference in insertion depth between 85 percent of subjects' left and right.
- Only one out of five who could benefit from a hearing aid actually wears one.
- On average, hearing aid users waited over 10 years after their initial diagnosis to be fitted with their first set of hearing aids.

Chapter 7 – FUTURE STO HFM PROJECTS RECOMMENDATIONS

Precise acoustic communication is a major factor for fitness for duty, as mentioned in previous chapters. In international Military operations, native and non-native speakers/listeners have to communicate important information. The reliability of this communication process is endangered when language knowledge, pronunciation or hearing deficits are present. Non-native listeners will especially have difficulties in understanding English in noisy surroundings.

To address this problem, it is important to develop and validate more realistic speech tests.

These tests will be developed by a proposed future STO HFM Task Group to:

- Enhance speech intelligibility in international Military environments.
- Identify factors endangering intelligibility.
- Identify suitable staff for missions.
- Develop methods of improving communication quality among Nations.
- Validate hearing rehabilitation devices: Do they fit in Military environment?
- Validate hearing protection devices: Do they endanger intelligibility?

In addition to the work carried out by this Task Group, more research in acoustic communication quality should be planned by NATO authorities to meet future needs. The Database concept is able to support these efforts and some NATO Nations have started to implement such a database.

The research fields in hearing and communication will cover:

1) Auditory readiness;
2) Fitness for duty criteria;
3) Hearing rehabilitation: Bringing soldiers back to work;
4) Communications quality and assessment in Military surrounding;
5) Assessing speech understanding in international context; and
6) Protection and epidemiology (Military specific).

Appendix 1 – STRUCTURE OF A DATABASE FOR HEARING SCREENING

Medical Data		
Sub-Registry	**Data Fields**	**Name of Field**
Diagnosis (Dx)	Pre-existing conditions	Pre-existing conditions
		Pre-existing hearing loss
Medical Data	Do you suffer from diabetes?	
Medical Data	Do you suffer from autoimmune disease?	
Medical Data	Do you suffer from blast injury?	
Medical Data	Do you suffer from PTSD?	
Medical Data	Do you use medication on a regular (daily) base?	
Medical Data	Do you use tobacco	
Medical Data		How much?
Medical Data	Do you use alcohol	
Medical Data		How much?
Medical Data	Were you treated for a malignancy?	
Medical Data		Did you receive chemotherapy?
Medical Data		Did you receive radiotherapy?

Ear Disease			
Sub-Registry	**Data Fields**	**Name of the Field**	**Data Value**
			Figure
			Predefined text
			Yes/No
			Free Text
Ear History		Was this early for age?	Yes/No?
Ear History		Was this noise induced?	Yes/No?
Ear History	Do you suffer from / have you suffered from:		Yes/No?
Ear History	Ear infections?		Yes/No?
Ear History	Ear operations?		Yes/No?
Ear History		What kind of operation?	Yes/No?
Ear History		What kind of medication?	Yes/No?

Ear Disease			
Sub-Registry	**Data Fields**	**Name of the Field**	**Data Value**
Ear History	Do you frequently use an MP3 player (other music system) with loud noise levels?		Yes/No?
Ear History	Do you have one of the following hobbies?		Yes/No?
Ear History		Hunting/shooting?	Yes/No?
Ear History		Motorsports?	Yes/No?
Tinnitus			
	tin	Experiencing tinnitus	Yes/No, if yes, carry on
	tinEAR	Laterality of tinnitus	Right
			Left
			Both
	tinWhen	Occurrence of tinnitus	After noise
			Anytime
			After or during stress
			Pressure variation
			Only at night
			Else
	tinPeriodicity	Periodicity of tinnitus	Occasional after noise
			Occasional anytime
			Frequent after noise
			Frequent anytime
			Permanent
	tinDuration	Tinnitus duration	In year (6 month = 0,5)
	tinhandicap	Tinnitus social handicap	Tinnitus Handicap Inventory (THI score)
	tintone	Tinnitus tonality categories	Low frequency (< 500 Hz)
			Medium frequency (500 – 2500 Hz)
			High frequency (3000 – 5000 Hz)
			Very high frequency (> 6000 Hz)
	tinlooklike	Open text	
	tinAssoEvent	Associated event	High noise or acoustic trauma
			Middle ear pressure problem
			Bruxism (jaw tension)
			Ear wax extraction

Ear Disease

Sub-Registry	Data Fields	Name of the Field	Data Value
			Meniere's disease
			Jaw/dentistry surgery
			Ear surgery
			Head injury
			Otitis media
			Otitis media in childhood
			Myringotomy
			Otosclerosis
Dizziness Vertigo			
Balance	Diz	Experience of dizziness	Yes/No
Only in blast injury	Dizposition	Positional test	Normal vs. abnormal
	Dizheadimp	Head impulse test	Normal vs. abnormal
	Dizdynapost	Dynamic posturography	Normal vs. abnormal
	DizTarget	Normal vs. abnormal	
	DizDVA	Dynamic visual acuity	Normal vs. abnormal
	Dizelectronys	Electronystagmography	Normal vs. abnormal
	Dizrotary	Rotary chair test	Normal vs. abnormal
	History short		
	Nystagmus		Spontaneous; Provocation None?
	Balance		
	Dizziness related to blast		Ear history

Social Data

Sub-Registry	Data Fields	Name of Field
Social Noise		MP3
		Disco rock concerts
		Shooting
		Fireworks
		Accidents
Education		School
		Degree
Others		

Noise Measurements

Sub-Registry	Data Fields	Name of Field
Job-Related Noise Exposure		Type of noise
Job-Related Noise Exposure		Duration
Job-Related Noise Exposure		Average dB
Job-Related Noise Exposure		Shooting
Job-Related Noise Exposure		Bombs (missiles)
Job-Related Noise Exposure		Headphone
Job-Related Noise Exposure		Ear protection

Exposure and Missions

Sub-Registry	Data Fields	Name of field	Screening	Data Value
			Monitoring	
				Figure
				Predefined Text
				Yes/No
				Free text
Service History	Specialty	Service Branch		Army/Navy/Air Force
	Specialty	Duty Status		Active/Reserve/Guard
	Specialty	Years of Service		Figure
	Exposure	Number of Deployments		Figure
	Exposure	# times Exposed to Blast		Figure
	Exposure	# times Traumatic brain injury TBI		Figure
	Exposure	Amount of noise exposure		Figure 0 – 10
	Exposure	Kinds of Noise Exposure		Predefined Text
	Protection	Kinds of Hearing Protection		Predefined Text
	Exposure	# times under fire		Figures
	Exposure	# months of deployment		Figures

Occupational Data		
	Every Two Years	**Sampling Frequency**
Sub-Registry	**Data Fields**	**Name of Field**
Rank		
Service Duty Occupational Code		
Mailing Address of Assignment		
Location – Place of Work		
Major Command		
Occupation	Main task in/with:	
Last year	Infantry	
	Armor	How to ask?
	Aircraft rotary	
	Aircraft fixed	
	Support	
	Administration	
	Office equivalent	
	Equipment Operator	
	Divers	
Noise exposure		
Last year	Need to wear hearing protection	
	Difficulties understanding	
	Quiet	
	Machinery	
	Ground vehicles	
	Aircraft	
	Artillery	
	Small arms	
	Radio communication	Left right both sides
	Shoulder-fired missiles	
	Demolition	
	Sirens/alarm	
	Other noise	
	Difficulties in hearing after noise exposure	TTS
Hearing protection	Type	Ear plug
		Covers
		Individual ear plug
		None
		Others

Appendix 2 – QUESTIONNAIRES

- **Impairment –** affects functioning at the level of the body and is defined as “a loss or abnormality of body structure or physiological or psychological function”. For example: hearing loss.
- **Activity Limitation –** defines “the nature or extent of functioning at the level of the person”. For example: difficulty hearing speech in background noise.
- **Participation Restriction –** is defined as “the nature or extent of a person’s involvement in life situations in relation to impairment, activities, health conditions, and contextual factors”. For example: limitation in participation in one’s own health care.
- **Satisfaction –** is the subjective assessment by the customer or patient that his/her needs or expectations have been met. It doesn’t matter how the good the care or how effective the treatment was if the patient was not satisfied with the outcome.
- **Health-Related Quality of Life –** is defined as “the functional effect of an illness and its consequent therapy upon the patient”. For example: the impact of hearing loss on family or depression.

Table A2-1: List of Validated International Hearing Questionnaires and Their Limitations.

Name of the Questionnaire / Scales	Authors / Origin	Languages†	License Fee
HDDA: Hearing-Dependent Daily Activities Scale 12 items (Screening)	López-Torres Hidalgo (2008)	DE, EN, FR	No
HQ: HearCom (Screening) 18 items	Vlaming et al. (2011)	DE, EN, NL	No
SSQ-49 (Three Scales: Speech, Spatial, Qualities), SSQ-12 (Clinic Short-form)	Jensen et al. (2009), Noble et al. (2013), Meis et al. (2010)	DE, DK, EN, NL, S	No
GP: Gothenburg Profile Scale 1, 10 Items, Speech Intelligibility, Localization	Ringdahl et al. (1998), Kießling (1996)	DE, EN, SE	No
Oldenburger Inventar, SF: 12 Items	Holube et al. (1994)	DE, NL	No
APHAB: Abbreviated Profile for Hearing Aid Performance, online analyses possible	Cox & Alexander (1995)	20 languages, such DE, EN	No
GHABP: Glasgow Hearing Aid Benefit Profile	Gatehouse (1999)	9 languages DE, EN	No
COSI: Client-Oriented Scale of Improvement	Dillon et al. (1997)	AR, DE, EN	No
SSQ-C: SSQ Comparative version of HA or CI, SSQ-B (Benefit pre-post HA/CI provision), 49 Items	Jensen et al. (2009)	EN, DE, DK, NL, S	No
SADL: Satisfaction with Amplification in Daily Life	Cox & Alexander (1999), Kießling et al. (2011)	DE, DK, EN,	No
IOI-HA: International Outcome Inventory for Hearing Aids, 7 Items	Cox et al. (2000), Noble (2002)	> 20, also DE, EN, NL	No
NCIQ: Nijmegen Cochlear Implant Questionnaire Physical scales: Sound Perception basic, and advanced, Speech prod. / CI domain!	Hinderink et al. (2000)	DE, EN, NL	No

Name of the Questionnaire / Scales	Authors / Origin	Languages[†]	License Fee
HDDA: Hearing-Dependent Daily Activities Scale 12 items (Screening)	López-Torres Hidalgo (2008)	DE, EN, FR	No
HQ: HearCom (Screening) 18 items	Vlaming et al. (2011)	DE, EN, NL	No
SSQ-49 (Three Scales: Speech, Spatial, Qualities), SSQ-12 (Clinic Short-form)	Jensen et al. (2009), Noble et al. (2013), Meis et al. (2010)	DK, DE, EN, NL, S	No
GP: Gothenburg Profile Scale 1, 10 Items, Speech Intelligibility, Localization	Ringdahl et al. (1998), Kießling (1996)	EN, DE, SE	No
Oldenburger Inventar, SF: 12 Items	Holube et al. (1994)	DE, NL	No
APHAB: Abbreviated Profile for Hearing Aid Performance, online analyses possible	Cox & Alexander (1995)	20 languages, such DE, EN	No
GHABP: Glasgow Hearing Aid Benefit Profile	Gatehouse (1999)	9 lang. DE, EN	No
COSI: Client-Oriented Scale of Improvement	Dillon et al. (1997)	AR, DE, EN	No
SSQ-C: SSQ Comparative version of HA or CI, SSQ-B (Benefit pre-post HA/CI provision), 49 Items	Jensen et al. (2009)	DK, DE, EN, NL, S	No
SADL: Satisfaction with Amplification in Daily Life	Cox & Alexander (1999), Kießling et al. (2011)	DE, DK, EN,	No
IOI-HA: International Outcome Inventory for Hearing Aids, 7 Items	Cox et al. (2000), Noble (2002)	> 20, also DE, EN, NL	No
NCIQ: Nijmegen Cochlear Implant Questionnaire Physical scales: Sound Perception basic, and advanced, Speech prod. / CI domain!	Hinderink et al. (2000)	DE, EN, NL	No
NHP: Nottingham Health Profile	Hunt & McEwan (1980), Kohlmann et al. (2000)	> 20 languages	Free
SF-36/-12: Short Form 36/12	Ware & Gandek (1994)	> 50 languages	Yes, 348 € / PC 350 €, + 1 – 2 € per Person
EQ 5-D (EURO-QOL): European Quality Of Life scale	Rabin & de Charro (2001)	> 100 languages	To clarify, by studies
GHSI/GBI: Glasgow Health Status Inventory, 18 items, generic form with specific contents	Robinson et al. (1996), Brodbeck (2010)	DE + 5, EN	No, © MRC IHR
HUI/HUI2-3: Health Utilities Index, important for clinical studies	Horsman et al. (2003)	> 20 languages	Yes, $5,000 CDN/ 3 years
IRES Questionnaire/Rehabilitation, based on ICF, scales psychological	Bührlen et al. (2005)	DE only	No
WHO-DAS II; International Classification of Functions (ICF), two sensitive scales Communication (6 Items), participation (8 Items)	WHO-DAS II (2001)		

[†] AR = Arabic; DE = German; DK = Danish; EN = English; FR = French; NL = Dutch; S = Swedish; SE/SP = Spanish

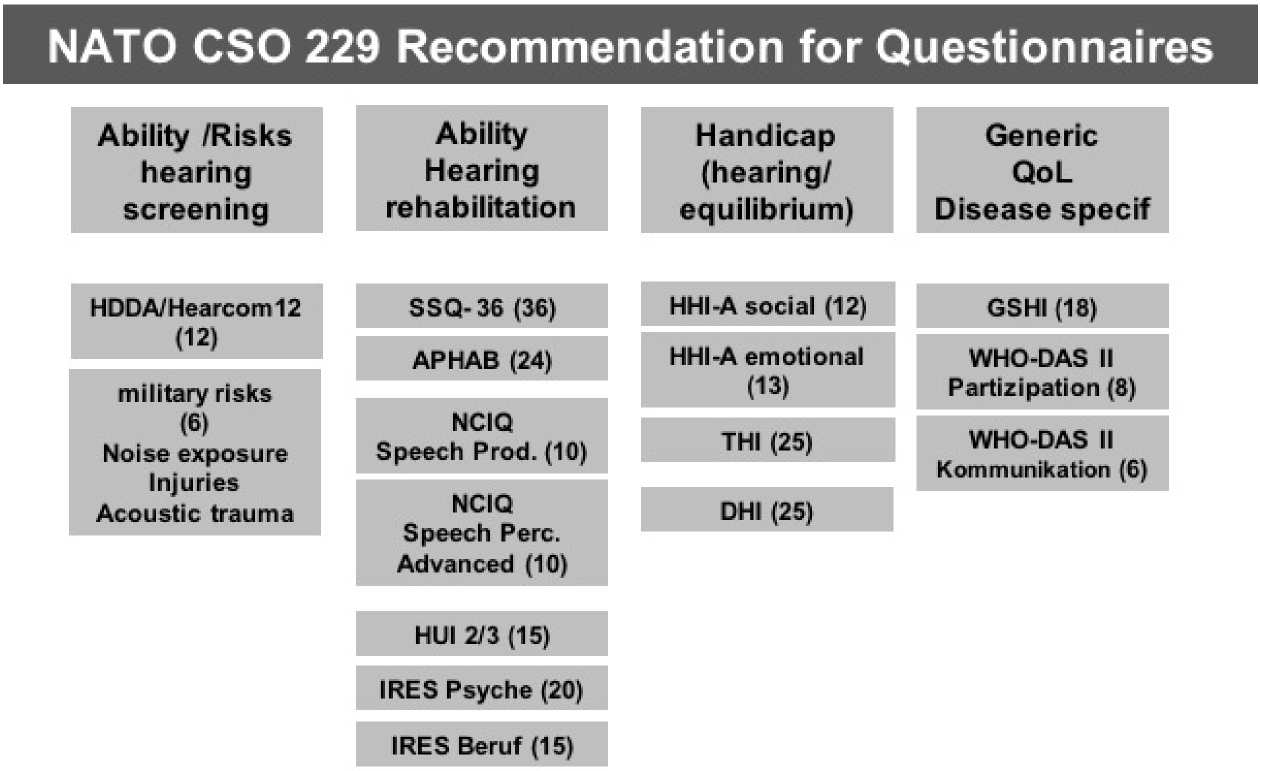

Figure A2-1: CSO 229 – Recommended Set of Questionnaires Useful for NATO Members.

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6. Title

Optimizing Hearing Loss Prevention and Treatment, Rehabilitation and Re-Integration of Soldiers with Hearing Impairment

7. Presented at/Sponsored by

This report documents the findings of Task Group HFM-229 (2012 – 2015), which analyzed the impact of hearing loss prevention, treatment and rehabilitation of soldiers with hearing impairment in the military. It proposes the structure of a database for hearing screening and surveillance of hearing loss developed by this group and indicates fields of possible common research to be performed in the future.

8. Author(s)/Editor(s)	9. Date
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14. Abstract

Hearing is a key function and critical sense for military performance. The ability to communicate is crucial for effective command and control, and personal and unit safety, and does affect survival. Hearing provides critical situational awareness, communication and sound localization information in combat and everyday operations. In order to identify hearing readiness criteria, ensure such criteria are met, identify soldiers at risk of hearing loss, and to judge the quality and timeliness of hearing rehabilitation and hearing prevention programs, a hearing health surveillance system and database is necessary. This report outlines the structure and classification criteria of hearing relevant data that can be implemented in almost all NATO Nations, despite language specific differences. The recommendation of automatic screening systems facilitates workload management, and reduces cost and time per soldier to optimize collection of data within resource constraints. The concept facilitates the ability of Military leaders to increase their Service members' effectiveness, safety, hearing health and quality of life by safeguarding the crucial sensory function of hearing. The modularity of the database concept will allow it to be integrated into other medical or fitness databases and expanded by other screening modules to maintain relevance and currency.

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