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STO TECHNICAL REPORT **TR-HFM-292**

Skill Fade and Competence Retention: A Contemporary Review

(Érosion et maintien des compétences : une revue contemporaine)

This report documents the findings of Task Group HFM-292, including a review of factors influencing skill fade, underlying psychological mechanisms, and management approaches.

Published January 2023

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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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Skill Fade and Competence Retention: A Contemporary Review

(STO-TR-HFM-292)

Executive Summary

Military training often involves individuals or teams acquiring knowledge and skills that they may not be required to use immediately post-training or for extended periods of time throughout their career. Where this occurs, skill and knowledge fade may arise due to a lack of practice or limited opportunities for refresher training. Skill fade, if not addressed, can have serious implications for the safety of personnel, operational effectiveness as well as the efficiency and cost-effectiveness of training. The issue of skill fade and competence retention is likely to become increasingly important for NATO nations as they face a future operating environment that will be complex, unstable, and unpredictable. With the uncertainty surrounding the nature of future threats, military personnel will need to be trained to undertake a wider range of tasks and to adapt rapidly to changing demands. Military personnel will need to learn and retain a greater number of skills across a career and adapt their existing skills for use in new contexts. To ensure that training and education can keep pace with these changes in skill and knowledge requirements, it is important to identify and understand the factors that influence skill fade as well as the strategies to mitigate its detrimental effects and promote competence retention.

The aims of the HFM-292 "Understanding and Reducing Skill Decay" Research Task Group (RTG) were to:

1) Provide a contemporary framework for identifying and understanding the factors that influence skill fade; and
2) Identify models, technologies and learning approaches that could be used to either reduce skill fade or manage it more effectively through the efficient scheduling of refresher training.

To achieve these aims the RTG conducted a literature review and drew on the research conducted in their respective nations. The contributing researchers were eight Subject Matter Experts (SMEs) with significant experience in the study of competence retention in a military, medical, aviation and/or safety context.

The contemporary review of the literature led to the identification of 38 factors that influence skill fade. These factors fell into three broad categories: person-related factors (e.g., cognitive ability, age, motivation, experience), task-related factors (e.g., physical vs. cognitive tasks, open vs. closed loop tasks, the number of steps in a task) and training and education-related factors (e.g., the spacing of learning, mastery training, retrieval practice and test-enhanced learning, the use of learning technologies). The report provides a detailed description of each factor, the direction of its effect on skill acquisition and retention, and the supporting evidence from existing scientific literature. It is likely that, over time, the factors that influence skill fade will evolve due to changes in work practices and approaches to learning. Therefore, it becomes useful to consider the comparatively smaller and more stable set of psychological mechanisms that underpin the effects of the influencing factors. To this end, the report identifies the psychological mechanisms that are likely to underpin each influencing factor. Nine psychological mechanisms were identified by the SMEs based on their expertise and the review of the literature: automaticity, cortical plasticity, boredom/mind-wandering, distribution of processing among channels, information processing rate, perception of fidelity, embodied cognition, role of emotion in memory consolidation, and the need for cognition.

The report identifies three key approaches in the management of skill fade. The first approach is to use existing quantitative/statistical models to predict the rate of skill decay and specify appropriate refresher training intervals at the level of a military unit. The second approach is to use technologies and analytics to understand the personalised learning and competence retention profile of an individual such that refresher training (or job aids) can be delivered to that person just in time. The third approach is to utilise virtual training experiences (e.g., in virtual or augmented reality) as these can provide high-fidelity, multimodal, and engaging learning environments that have been shown to facilitate competence retention.

The HFM-292 RTG outline a number of recommendations in the report. Three of the key recommendations are that future research in this area should consider the need to:

1) Transition from laboratory-based research on the retention of simple procedural skills to field-based research in operational environments focusing on real-world complex skills;
2) Create a common standard for the categorisation and reporting of Knowledge, Skills and Attitudes (KSA) to enable meaningful comparisons to be drawn across competence retention research;
3) Increase the quantity of competence retention data by collecting it as a business-as-usual activity at initial and refresher training events using valid and reliable performance metrics.

Érosion et maintien des compétences : une revue contemporaine

(STO-TR-HFM-292)

Synthèse

La formation militaire implique souvent que les individus ou les équipes acquièrent des connaissances et des compétences qu'ils n'ont pas besoin d'utiliser immédiatement après la formation ou pendant de longues périodes tout au long de leur carrière. Lorsque cela se produit, les compétences et les connaissances peuvent s'éroder en raison d'un manque de pratique ou d'opportunités limitées de remise à niveau. L'érosion des compétences, si elle n'est pas traitée, peut avoir de graves conséquences sur la sécurité du personnel, l'efficacité opérationnelle, ainsi que sur l'efficience et la rentabilité de la formation. La question de l'érosion et du maintien des compétences prendra probablement de plus en plus d'importance dans les pays de l'OTAN, qui seront confrontés à un environnement opérationnel complexe, instable et imprévisible. Compte tenu de l'incertitude liée à la nature des menaces futures, le personnel militaire devra être formé pour effectuer un plus large éventail de tâches et s'adapter rapidement à l'évolution des demandes. Le personnel militaire devra acquérir et conserver un plus grand nombre de compétences tout au long de sa carrière et adapter ses compétences existantes à de nouveaux contextes. Pour s'assurer que la formation et l'éducation peuvent suivre le rythme de ces changements d'exigences en matière de compétences et de connaissances, il est important d'identifier et de comprendre les facteurs qui influencent le déclin des compétences, tout comme les stratégies permettant d'atténuer ses effets néfastes et de promouvoir le maintien des compétences.

Les objectifs du groupe de recherche (RTG) HFM-292 « Comprendre et réduire le déclin des compétences » étaient :

1) de fournir un cadre contemporain d'identification et de compréhension des facteurs qui influencent l'érosion des compétences, et

2) d'identifier les modèles, technologies et démarches d'apprentissage qui pourraient servir soit à réduire l'érosion des compétences, soit à la gérer plus efficacement grâce à une planification efficace de la remise à niveau.

Pour atteindre ces objectifs, le RTG a mené une revue de la littérature et s'est appuyé sur les recherches menées dans ses pays respectifs. Les chercheurs qui y ont contribué étaient huit experts chevronnés dans l'étude du maintien des compétences dans un contexte militaire, médical, aéronautique et/ou de sécurité.

La revue contemporaine de la littérature a conduit à l'identification de 38 facteurs qui influencent l'érosion des compétences. Ces facteurs relevaient de trois grandes catégories : les facteurs liés à la personne (p. ex. capacités cognitives, âge, motivation, expérience), les facteurs liés aux tâches (p. ex. tâches physiques ou cognitives, tâches en boucle ouverte ou fermée, nombre d'étapes d'une tâche) et les facteurs liés à la formation et à l'éducation (p. ex. espacement de l'apprentissage, formation graduelle, récupération en mémoire, apprentissage amélioré par les tests, utilisation de technologies d'apprentissage). Le rapport fournit une description détaillée de chaque facteur, l'orientation de son effet sur l'acquisition et la conservation des compétences et les éléments probants issus de la littérature scientifique. Il est probable qu'au fil du temps, les facteurs qui influencent l'érosion des compétences évolueront en raison des changements de pratiques professionnelles et de démarches d'apprentissage. Par conséquent, il devient utile de considérer l'ensemble des mécanismes psychologiques comparativement plus petits et plus stables qui sous-tendent les effets des facteurs déterminants. Dans ce but, le rapport identifie les mécanismes psychologiques susceptibles de sous-tendre chaque facteur déterminant. Les experts ont identifié neuf mécanismes psychologiques, sur la base de leur expérience et de la littérature : l'automaticité, la plasticité corticale, l'ennui/la rêverie, la répartition du traitement entre les canaux, la vitesse de traitement de l'information, la perception de la fidélité, la cognition incarnée, le rôle de l'émotion dans la consolidation de la mémoire et le besoin de cognition.

Le rapport identifie trois approches essentielles de gestion de l'érosion des compétences. La première approche consiste à utiliser les modèles quantitatifs/statistiques existants pour prédire le rythme du déclin des compétences et spécifier des intervalles appropriés de remise à niveau d'une unité militaire. La deuxième approche consiste à utiliser des technologies et des analyses pour comprendre le profil personnalisé d'apprentissage et de conservation des compétences d'un individu, de sorte qu'une remise à niveau (ou des outils de travail) puisse lui être dispensée juste à temps. La troisième approche consiste à utiliser les expériences de formation virtuelle (par exemple, en réalité virtuelle ou augmentée), car elles peuvent fournir des environnements d'apprentissage multimodaux et stimulants à haute fidélité, qui ont fait leurs preuves pour faciliter le maintien des compétences.

Le RTG HFM-292 présente un certain nombre de recommandations dans le rapport. Trois d'entre elles, essentielles, portent sur le fait que les futures recherches dans ce domaine doivent tenir compte de la nécessité de :

1) passer de la recherche en laboratoire sur le maintien des compétences procédurales simples à la recherche en environnements opérationnels et axée sur des compétences complexes en situation réelle ;
2) créer une norme commune de catégorisation et compte rendu des connaissances, compétences et attitudes (KSA) afin de permettre des comparaisons significatives entre les différentes recherches sur le maintien des compétences ;
3) augmenter la quantité de données sur le maintien des compétences en faisant de leur collecte une activité normale lors des événements de formation initiale et de remise à niveau, à l'aide de mesures de performance valides et fiables.

Chapter 1 – INTRODUCTION

1.1 OVERVIEW AND SCOPE

Military personnel are repeatedly trained in specific knowledge and skills that they often may not use in their immediate post-training future or execute for extended periods of time throughout their career. Consider, for example:

1) Army reservists who may only receive formal training once or twice a year but who are expected to deploy with minimal refresher training (Wisher, Sabol et al., 1991);
2) Military surgical team members on low workload deployments who are rarely exposed to casualties and who experience a decline in surgical skills (Gerhardt, Mabry et al., 2012);
3) Military officers who have completed their basic training, but are delayed in starting their aircrew training (Arthur, Bennett et al., 2002); and
4) Medical doctors who are switching between the military combat casualty care and the civil national care context, both require different types of skills and thoughts in action (Gerhardt, Mabry et al., 2012; Siu, Best et al., 2016).

In each of these examples, skill and knowledge fade may arise due to a lack of practice or opportunities to refresh and reinvigorate.

In the literature, skill fade or skill loss refers to "the loss of trained or acquired skills or knowledge after periods of non-use" (Arthur, Bennett et al., 1998, p. 58). As indicated by several authors, it becomes particularly salient and problematic in situations where individuals received an initial training that could not be used afterwards for extended periods of time (e.g., Wisher, Sabol et al., 1991; Arthur, Bennett et al., 1998; Henik, Brain et al., 1999). Skill retention is instead "the maintenance or sustainment of learned behaviours without practice" (Schendel and Hagman, 1991; as cited in Bryant and Angel, 2000, p. 194) and can be considered and expressed as "the degree of competence to which an acquired skill [or knowledge] is retained through the passage of time" (Ginzburg and Dar-El, 2000, p. 327). When considering the overall operational performance, one should take into account the general individual abilities, attitudes and experience as well as the competence or "the knowledge, skills and underpinning attitudinal dispositions that must be acquired and maintained by individuals and teams in order to effectively perform tasks to a pre-defined standard of proficiency" (Cahillane, MacLean et al., 2020).

According to Sabol and Wisher (2001), military skill retention has three crucial components that characterise most of the tasks involved, which are knowledge, decision, and execution. Knowledge can refer to the recognition and/or recall ability of certain tasks and procedures. Decision – such as a medical diagnosis, technical troubleshooting, tactical strategy choice – relies strongly on the cognitive associations that are consequently linked to retrieval. Execution may refer to the optimal performance output requiring a well-balanced psychomotor, perceptual-motor, and psychophysiological integration. Hence, retention is dependent on interaction effects between training aspects, individual cognitive abilities (Hagman and Rose, 1983) and a final integrated transfer to several output contexts (Hesketh, 1997; Van Merriënboer, Kester et al., 2006). Within this entire process of training, competence, optimal performance and the retention of knowledge and skills, every step or component is thus crucial and interdependent. Moreover, each component and/or interaction relies on different types of brain processing (Sabol and Wisher, 2001; Crowley, Bendor et al., 2019). This multiprocessing nature causes the co-action of different retention timeline curves along with a series of individual factors that may be of influence (e.g., Arthur, Bennett et al., 1998). Indeed, the investigation of skill retention demands a holistic, human-centred approach, considering physical, cognitive, social, organisational, environmental, and other relevant factors (Karwowski, 2005, Sanli and Carnahan, 2017) whilst embracing inter-individual differences (Vlasblom, Pennings et al., 2020). As a result, skill retention remains a puzzling and complex topic.

In terms of cost-effectiveness and management, the investment in a well-balanced trade-off between available resources and operational requirements calls for important decisions to be made regarding the types of skills and knowledge that must be retained and what timeline to follow in order to plan retraining for the regain of skill proficiency (Bjork and Bjork, 1992; Richards and Deighton, 2019). Integral to this decision making is the requirement for evidence relating to:

1) What skills and knowledge types are likely to decay at a greater or lesser rate (without practice);
2) The factors that can change or moderate the rate of skill fade; and
3) Effective and efficient strategies that may be put in place to manage skill fade.

The military operational environment is increasingly volatile, uncertain, complex, and ambiguous (i.e., VUCA[1] -environment, Bennett and Lemoine, 2014), demanding a flexible mindset (Bowles, Feely et al., 2017) and the need for the rapid mobilisation of scarce or infrequently used skills when necessary (Richards and Deighton, 2019). Hence, skill and knowledge retention are even more important in the current military context.

For the above-described reasons, the current technical report aims at providing a reasoned review of the literature and a conceptual organisation of the factors associated with the individual, the task, and training, and education that may influence the retention of skills in the context of military operations. We will consider both the relevant literature in general and the literature specific to military populations. The review is contemporary with a focus, where possible, on evidence gathered from recent large-scale reviews of the skill fade literature, and a consideration of future-focused concepts. Unlike previous reviews, we will consider the growing evidence relating to the influence of a range of individual differences (e.g., motivation, experience, cognitive ability) on skill retention in Chapter 2. A second component in Chapter 2 will refer to task-related influences for which a competency perspective will be applied. From this perspective, we broaden the lens to include both simple and complex military training tasks that are characteristic of current and future military operational environments. As a third component in Chapter 2, the role of training and education will be discussed from a broad perspective that aims to reach out to future competence management perspectives. To do so, we will include an overview of the use of digital games for learning, education, and training from a military application perspective. Then, recognising the breadth of potential factors influencing skill fade, the report will add a new reflection frame in Chapter 3, proposing a greater consideration of those underlying reasons and psychological mechanisms that might explain why particular approaches to the design and delivery of training and education, or task-related characteristics, might influence the rate of skill fade. In the fourth Chapter, we will consider how to manage the retention of individual skills, extending the discussion to new and emerging approaches, including the personalisation of training and experiential training through virtual reality experiences. Chapter 5 will present a general discussion, listing the salient achievements and gaps in the field to conclude what challenges need to be addressed in future approaches. Chapter 6 aims to integrate these insights, identifying key challenges for future research as well as the major research gaps that are yet to be addressed. Finally, Chapter 7 offers four general considerations relating to:

1) The importance of continued international collaboration to drive the skill fade and competence retention field forward;
2) The need to consider the topic of skill fade and competence retention in relation to evolving operational environments and concepts (e.g., artificial intelligence, autonomous robotic systems) that are impacting the breadth and depth of skills demanded by future Defence personnel;

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[1] VUCA – Volatile, Uncertain, Complex, Ambiguous.

3) The design of more effective training experiences that promote competence retention and that capitalise on the growth in learning technology, learning analytics and innovation in this area; and
4) The need to translate existing research evidence into practical guidance for a range of communities, including individual practitioners, training managers, and regulators.

Chapter 2 – FACTORS INFLUENCING SKILL FADE AND COMPETENCE RETENTION

2.1 GENERAL OVERVIEW

In this chapter the range of factors moderating the rate at which skills and knowledge fade or retain, are discussed in relation to three areas: person-related factors, task-related factors, and training and education related factors. Each section provides an introduction to the breadth of factors to be discussed, followed by a focussed consideration of the reported research relating to each factor. In addition, within each section the reader is referred to particular elements of Annex B which presents a set of ‘look-up’ tables. These provide a short description of each skill fade factor, the particular effect reported by the literature, potential explanations for such effects (e.g., underlying psychological mechanisms) and scientific evidence. As an example, Table 2-1 provides an extract for the influencing factor titled “spacing of learning” included within the section training and education related factors.

Table 2-1: General Structure of Influencing Factor Tables.

Influencing Factor	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Spacing of learning	The length of the inter-study period which may be designed to be long (i.e., spaced) or by comparison, short (i.e., massed).	Spaced learning generally results in better skill retention than massed learning.	Greater spacing of learning increases the opportunity for mental rehearsal, information processing and retrieval practice and decreases fatigue arising from intensive practice periods.	Meta-analysis (Cepeda, Vul et al., 2008) and systematic literature review on spacing of training in surgical tasks (Cecilio-Fernandes, Cnossen et al., 2018); spaced learning and simple motor tasks (Donavan and Radosvich, 1999).

We would like to emphasise that the current report will discuss the influence of three main areas (i.e., person-related, task-related and training and education) on skill retention. As will be clear in both the section *person-related factors* and *training and education related factors*, the initial training-related conditions are often a prerequisite for later retention success or failure. In the current review, however, we will only discuss studies on retention where the initial training effect was part of the investigation. Studies that focus solely on initial training without consideration to the impact on skill fade or competence retention are excluded from this review. Moreover, since both initial training and experience can be considered as an individual feature as well as a training aspect, these aspects can occur in both sections. In addition to the three main areas of influence it is recognised that the organisation plays an essential role in terms of putting in place the structures, processes, procedures and supporting culture needed to manage the retention of required skills and knowledge among its personnel (e.g., Larouzee and Le Coze, 2020). However, a review of organisational related factors is outside the scope of this report.

2.2 PERSON-RELATED FACTORS

2.2.1 Introduction

Person-related factors are considered to be an important influencing component in the understanding of skill and competence retention, especially when considering more complex tasks (Day, Arthur et al., 2013). While there is a large amount of literature on individual differences in learning, the (direct) influence of individual differences specifically on retention of acquired competence over time is understudied. Individual differences have often been categorised into cognitive and non-cognitive abilities (e.g., Day, Arthur et al., 2013). At the forefront, as an innate ability, cognitive ability is finite and thus presents both an individual's limitations and their capacities (Campbell and Pritchard, 1976; Day, Arthur et al., 2013). Cognitive ability has been accepted to predict learning and training and therefore, also retention as a performance outcome (Boyd and Oswald, 2013; Day, Arthur et al., 2013; Jaeggi, Buschkuehl et al., 2014); and this over and above all other predictive constructs, across all jobs (e.g., personality; Colquitt, LePine et al., 2000; Converse and Oswald, 2014; Schmidt and Hunter, 1998). Particular cognitive abilities, which are often cited in the literature as important key components, are the ability to transfer training aspects (Baldwin and Ford, 1988; Blume, Ford et al., 2010; Colquitt, LePine et al., 2000) as well as the working memory one can rely on (e.g., Boyd and Oswald, 2013; Gronlund and Kimball, 2013). Hence, the cognitive component within the research domain of individual differences related to retention became an obvious differentiating factor from the other non-cognitive personal influencing factors (Day, Arthur et al., 2013).

In addition to what individuals are able to do (i.e., ability), one has to take into account what they are willing to do, in other words, their motivation. Motivation has been found to influence the choices one makes about the direction, persistence, and level of effort put forth (Locke and Latham, 2004). Naturally, one's motivation to learn has been positively associated with achieving certain goals (Diefendorff and Chandler, 2011; Locke and Latham, 2004). As one would expect, motivation to learn is said to have a positive effect on training performance and retention (Villado et al., 2013).

A concept related to motivation is self-efficacy or one's belief to successfully perform specific behaviours, (Wood and Bandura, 1989). Self-efficacy appears to be positively associated with learning, training motivation, and training performance (Noe and Colquitt, 2002) which are all factors that may be considered as a prerequisite for retention. Indeed, a pre-training that focuses on the trainee's belief in their ability to succeed in the specific course/training has been positively related to the learning requirements (Colquitt, LePine et al., 2000), the transfer of training (Ford, Sego, et al., 1991; Tziner, Fisher et al., 2007; Velada, Caetano et al., 2007), and the transfer of intentions (Machin and Fogarty, 2004). Nevertheless, although post-training self-efficacy has been related to the trainees' beliefs in their ability to learn and to transfer the training (Blume, Ford et al., 2010; Colquitt, LePine et al., 2000; Machin and Fogarty, 2004), we encountered no studies showing a direct impact on retention.

Some of these person-related factors – such as self-efficacy – can be considered personality traits. Consequently, as traits tend to be stable across time, their potential to predict performance, including learning and retention, would not be surprising (e.g., adult learning; Hadziomerovic et al., 2014). For several decades, the Big Five personality theory has successfully predicted performance in many contexts (e.g., training, selection). With regard to training and job performance, for instance, conscientiousness (e.g., being dependable, persistent, detail orientated, and achievement striving) has demonstrated the highest prediction of the five (Barrick, Mount, et al., 2001). It is also positively related to the transfer of training (Blume, Ford et al., 2010; Colquitt, LePine et al., 2000; Tziner, Fisher et al., 2007); and thus, a potential candidate for retention. Moreover, one facet of Conscientiousness – achievement striving – has often been singled out due to its association with motivation (e.g., achievement motivation) and orientation (e.g., mastery, performance orientation; Day, Arthur et al., 2013).

Garnering the second highest ratings is emotional stability. Emotional stability (Gross, 2013) is a wide-ranged concept, it may be interpreted as the ability to remain calm and to work effectively under stressful conditions (Barrick, Mount et al., 2001). This ability to retain calmness and efficacy during a stressful operation is related to one's psychophysiological capability to self-regulate. The emotional and cognitive self-regulatory abilities are an outcome of top-down brain processes that succeed to give an appropriate response to bottom-up arousal processes evoked by the stressful condition (e.g., Thayer and Lane, 2000) and can be considered as an inter-individual differentiator (Van Puyvelde, Neyt et al., 2018). A well balanced psychophysiological regulated state provides an optimal readiness state to meet the necessary environmental challenges (Hancock-and Krueger, 2010; Van Puyvelde, Neyt et al., 2018). Emotional Stability is positively related to training transfer (Herold et al., 2002), training motivation and success across occupations (Barrick and Mount, 1991; Converse and Oswald, 2014), and job and training performance (Barrick and Mount, 1991), ergo are likely to facilitate competence retention.

As it becomes clear, the role of individual differences is still difficult to fully understand. Moreover, it is challenging to disentangle person-related differences from those aspects that are associated with initial learning processes and the initially obtained level of proficiency (Arthur, Bennett et al., 1998). That is, the degree of previous exposure and experience with any skill/knowledge may influence the steepness of a skill decay curve (Arthur, Bennett et al., 1998) and thus may also be related to retention outcomes (Bryant and Angel, 2000). For instance, it has been stated that persons with higher aptitude have a greater facility to over train and achieve better retention performances (Adams, Webb, et al., 2003). However, to identify the specific mechanism underlying these effects remains difficult. Firstly, built experience has the power to not only solidify knowledge and skills gained in training, but also to provide opportunities to gain new knowledge/skills in applied settings and to facilitate knowledge transfer (Yost and Plunkett, 2010). Hence, experience developed in previous domains may facilitate learning and retention in other domains. Secondly, prior knowledge has also been reported to facilitate retention by providing better organisational processing (e.g., memory retrieval) and superior memory (to aid retention; Gronlund and Kimball, 2013). Additionally, experience has been found to enhance the cognitive capacity to identify and attend to new knowledge, make decisions, and learn from mistakes (Baker, Robinson, et al., 2012). Hence, the role of experience clearly contributes to skill retention (Diaz Granadoes, Lazzara et al., 2013). However, it is only one component of a complex dynamic puzzle that has not yet been disentangled.

2.2.2 Influencing Factors Description and Evidence

Within this section eight key factors relating to individual differences are identified in relation to skill fade. Supporting evidence is provided, gathered from a review of the academic literature. This review is complementary to the information presented in Annex B, Table B-1.

2.2.2.1 Motor and Cognitive Abilities

Early studies of personal factors potentially influencing skill retention examined the impact of cognitive ability on the degree of retention. In these basic studies, participants were divided into low-, medium-and high ability groups based on initial ability tests. High ability participants were more likely to show skill and/or knowledge retention than the low ability group. Carron and Marteniuk (1970) reported an interaction between motor ability (low or high ability) and the retention of balance skills on a stabilo meter after a retention interval of two weeks onwards (no effect was observed after one day or one week). Carron (1971) observed a marginal significant interaction effect for a retention interval of two years. Another study on the retention of gross motor skills was conducted by Purdy and Lockhart (1962) who observed that high ability was related to a better outcome in learning, retention after one year of no practice, and re-learning. In a study by Fox, Taylor, et al., (1969) on the impact of mental ability on the retention of army-related skills and knowledge, participants' ability assignment was first defined based on the results of the Armed Forces Qualification Test (AFQT). The results showed that high ability persons, in comparison to low ability persons, showed both higher skill and knowledge retention on various psychometric and operational army-related criteria that differed in complexity. Hall, Ford, et al., (1983) reported that Navy sailors who were trained to a level of mastery in basic electricity and electronics performed better, with retention intervals ranging from 18 to 34 days. Several hypothetical explanations have been offered in the literature. According to Hall, Ford, et al., (1983) and Farr (1987), the higher the ability the more effective strategies are available at the learning level to acquire knowledge and skills. Arthur, Bennett et al., (1998) suggested that high ability persons probably acquire a higher initial training efficiency because they need less time to acquire the required minimal level. A similar hypothesis was formulated by Vineberg (1975) who compared three ability groups (based on AFQT results) on performance in 13 basic training tasks for soldiers twice, with 6 weeks in between. The impact of cognitive ability was primarily observable in the first stage of initial learning. Afterwards, Vineberg (1975) observed that the retention curves declined in the three groups at the same rate regardless of ability.

Cognitive ability has been suggested to interact with the degree of structure present in the training such that higher ability persons would benefit from unstructured training whereas lower ability persons benefit from structured training (Kintsch, 1994). In more recent work, cognitive abilities (i.e., processing speed, working memory, and long-term memory) were indicated as an explaining factor between literacy and the retention of knowledge on health-related information about colorectal cancer screening in cancer patients (Wilson, Wolf et al., 2010). After one week, literacy significantly predicted knowledge but most of this relationship was explained by cognition (i.e., 46%, see Wilson, Wolf et al., 2010).

Hence, while there is evidence on the predictive value of cognitive abilities on learning, there is no clear answer on how the individual task, knowledge or general ability may aid in processes of retention, i.e., after learning has occurred. It is thus difficult to identify whether an observed advantage in performance is due to better retention or to advantages in the training process. If high ability individuals benefit more from the training, they receive a higher performance level at the end of their training giving them advantage for the subsequent period of potential decay. Hence, a measured difference in decay between high and low ability individuals after a period of no-use should be compared with an eventual difference at the end of the initial training.

2.2.2.2 Non-Cognitive and Non-Motor Abilities

Most non-cognitive abilities are linked to personality traits (e.g., conscientiousness, openness to experience), motivation and attitude-related factors such as motivation, self-efficacy, voluntary learning, overlearning (Arthur and Day, 2013), age and gender. In the following, we will present the current state-of-the art, depicting very mixed results.

2.2.2.3 Self-Efficacy

The concept of self-efficacy is based on the social cognitive theory of Bandura (1977) who defined self-efficacy as the belief one has in their ability to perform a specific task, emphasising the specificity of the task. When feeling self-efficacious, a person will act in a certain way to assure certain outcomes. Self-efficacy has been suggested to be an influencer on learning in that it may stimulate associations with other knowledge during an initial training process (Anderson, 1995), suggesting that it may work by mechanisms related to the transfer of skills (Arthur, Day et al., 2013).

With regard to self-efficacy, trained paramedics were studied to assess the impact of both self-efficacy and paediatric airway management skills retraining (Youngquist, Henderson et al., 2008). A voluntary group was retrained (retention test) and then compared with a control group. The retention interval varied considerably from one to 18 months. Those with the lowest self-efficacy baseline profited the most from both the self-efficacy and skills training. However, they also experienced the most decline between training events. Youngquist et al., (2008) described a gap between self-efficacy and skill retention. Even when self-efficacy was maintained, the skill performance declined. Some studies reported a false feeling of self-efficacy in first-aid

Cardiopulmonary Resuscitation (CPR) trainings (e.g., Glendon, McKenna et al., 1988; McKenna and Glendon, 1985; Ramirez, Weaver, et al., 1977). In these studies, a great number of participants indicated unjustified confidence to perform CPR correctly, with Ramirez et al., (1977) reporting 88% of confident subjects whereas only 1% adequately performed the CPR. Glendon, McKenna et al., (1988) suggested that the perceived ability to carry out CPR may be a function of previous training and not self-efficacy.

In addition, Schumann's (2012) examination of the retention of both Wilderness First-AID (WFA) skills and WFA knowledge along with self-efficacy in students, utilising retention intervals of 4, 8, and 12 months, did not show any enhancing relationship between self-efficacy and knowledge and skill retention. All skill and knowledge types examined decreased with time of non-use independently from self-efficacy (Schumann, Schimelpfenig, et al., 2012). Another study (Andreatta et al., 2016) examined the retention of paediatric and neonatal intubation skills using simulation-based training and included retention intervals of 6, 18, and 52 weeks. Their study showed that there was no relationship between the curves of affect and self-efficacy scores on the one hand and cognitive performance on the other hand. Affect and self-efficacy remained unaffected at 6 weeks but deteriorated after 18 weeks, whereas cognitive performance already declined after 6 weeks (Andreatta et al., 2016). A fast decline in cognitive performance was also reported by Soo and Hea Kung (2013) in their study relating to skill and knowledge retention (retention intervals of 2 and 6 weeks) of basic life support training (i.e., cardiopulmonary resuscitation) in nursing students. Besides knowledge and skill performance, self-efficacy was included in the design. The effectiveness of the training was retained at week 2 but not at week 6. Additionally, Bell et al., (2008) studied knowledge retention of physicians with retention intervals of 3 – 8 days and 55 days. Knowledge decay already occurred after one week. Besides self-efficacy, Bell et al., (2008) examined the influence of age, expertise (number of rotations in endocrinology), critical appraisal skill score, and computer attitude. None of these individual characteristics influenced the rate of decline.

Finally, we found one straightforward positive impact of self-efficacy in a study by Gist, Stevens, et al., (1991). Pre-test levels of self-efficacy contributed positively to both the initial and the delayed performance of interpersonal communication skills after 6 weeks.

Hence, against expectation, the majority of the studies that measured self-efficacy showed that self-efficacy may be a risk –factor rather than a positive factor since it may facilitate the development of false feelings of capability Although self-efficacy is often considered to positively impact learning (Anderson, 1995; Arthur, Day et al., 2013) it was not found to improve retention.

2.2.2.4 Motivation

Tasks are better retained when they are meaningful, well-organised and when they show some coherence (Annett, 1977). Obviously, meaningfulness can vary across individuals, and it may be related to motivation. Dweck and Legett (1988) linked motivation to the degree of subsequent learning, be it learning oriented (i.e., to master information) or performance oriented (i.e., to acquire a prescribed score to avoid negative feedback); hence comparable with intrinsic and extrinsic motivation respectively. Although overlearning (i.e., additional training beyond that of proficiency level, Arthur, Bennett et al., 1998) has been shown to be vital in certain training programs – such as stress and emergency contexts, for instance (see Cohen, Smith et al., 1979; Goldstein, 1975; Salthouse and Somberg, 1982) – it risks being inversely related to motivation. It enhances automaticity by strengthening stimulus-response connections (Schendel and Hagman, 1982) but may open the door for monotony (Arthur, Day et al., 2013). Similarly, effortful training, although efficacious, might be experienced in an aversive and demotivating manner (Hesketh, 1997). There are some indications that motivation and retention can be positively affected when the initial training has been voluntarily chosen by the trainee (e.g., Schmidt and Ford, 2003), which also links to self-efficacy or self-management. This was, for instance, shown by Granito and Chernobilsky (2012) who found that students had higher retention when they had the freedom to choose their project, and that the project itself had no significant impact. The authors linked the freedom to choose to motivation. A study about the optimal frequency of endoscopic skill training to achieve the maximum skill retention, found that – although motivation increased with the number of training sessions – it did not influence the retention curves (De Win, Van Bruwaene, et al., 2013). Hence, the influence of motivation is variable and appears to be dependent on the type of motivation as well as the type of task, training and feelings of self-management. In general, motivation positively affects learning and therefore also retention but can vary across contexts.

2.2.2.5 Prior Knowledge

The prior knowledge obtained before or during initial training is an important impact factor in retention processes (e.g., Anderson and Warren, 2011; Sanli and Carnahan, 2018). Annett (1977) even labelled it as the best predictor of competence retention. Several studies have shown fast and steep declines in the retention curves of first aid and CPR skills, and it is in these studies that the impact of the initial learning level is very salient. According to Annett (1981), this may be due to the fact that first aiders rarely practice their skills. Also, Braun, Reitman et al., (1965) obtained similar findings among organised volunteer rescue squads. It has been suggested that when retraining is provided, however, this may enhance motivation (Tweed, Wilson, et al., 1980). Further, the type of retraining may have an impact as well. For instance, first aid on mannequins appears to stimulate real-life feelings of reality and with that motivation (Glendon, McKenna et al., 1988). Although knowledge shows considerable deterioration in studies, the steepest declines concerned skills (Skelton and McSwain, 1977), pointing to the importance of skill retraining. However, a more recent study (Anderson, Gaetz et al., 2011) showed a decline in both skills and knowledge. Anderson, Gaetz, and Masse (2011) investigated the retention of first aid skills and knowledge of 257 participants with retention intervals ranging from less than one month to more than three years. They observed at Time 1 (less than one month) an already dramatic decline in both knowledge and skills towards unacceptable levels that did not restore afterwards (e.g., percentage of persons that correctly opened the airway declined from 71% to 21% in month 1). Those who had renewed their certification scored however better than those who did not. The number of renewals was in line with retention levels. In Glendon, McKenna et al., (1988) similar curves with an early stage decline were observed. Moreover, besides the initial learning level, age and gender played a role as well. Finally, Magura et al., (2012) found no positive impact of three new CPR refresher methods (i.e., on an online website, by e-mail and by text messaging) given at month 6 and 9. The retest was performed 12 months after initial training.

Hence, these studies indicate that opportunities of retraining –certainly in the skill domain- are crucial for later retention. However, again, the initial training shows great impact as well. For instance, Mills and Muir (1999) suggested that the lack of success in a standard performance assessment may overrule the eventual positive effects of refresher trainings in a rescue sequence of helicopter underwater egress. It might be beneficial to consider the individual differences in learner characteristics (measured prior to training) when developing refresher courses (Mills and Muir, 1999; Sanli and Carnahan, 2018). A similar helicopter underwater egress retention study showed beneficial effects of the number of trials in the initial training, in that those who experienced more trials (six versus two trials) were more likely to pass the retention test successfully (Kozey, McCabe et al., 2007).

2.2.2.6 Age

Although it might be assumed that age would improve expertise and experience, and therefore would have a positive impact on retention processes, age is not shown to be a beneficial predictor of retention. Indeed, many studies reported even a negative association between learning and age (e.g., Arthur, Day et al., 2013; Grace, Korinek et al., 2011; McCausland, King et al., 2015; Phipps, Prieto, et al., 2013; Riegel et al., 2005; Rodrigue, Kennedy et al., 2005). Specific to retention, Glendon, McKenna et al., (1988) observed more rapid declines in CPR skills in older participants despite being more likely to have increased retraining opportunities. Also, Papalexopoulou, Chalkias et al., (2014) found a negative relation between age and retention of CPR skills. Grace, Korinek et al., (2011), Riegel, Birnbaum et al., (2005) and Rodrigue, Kennedy et al., (2005) found age to be negatively related with skill retention. This may be due to processing speed, because when processing speed was intact, no age effect was found (Rodrigue, Kennedy et al., 2005). Besides age, also the time out of practice was a significant predictor of less success in a physician's re-entry programme after leave. Obviously, the impact of age may be dependent on the skill and the profession (Papalexopoulou, Chalkias et al., 2014). For instance, a study of pilots showed that even though older pilots initially performed worse than younger pilots in a simulation task, over a time-line of three years, the older pilots showed less decline in flight summary scores than younger pilots (Taylor, Kennedy et al., 2007).

2.2.2.7 Gender

It has been reported that males have higher retention than females (Bryant and Angel, 2000; Riegel, Birnbaum et al., 2005). However, this may be explained by differences in the level of mastery achieved by males and females following initial training, rather than gender. Once again this underlines the importance of the initial training process as a factor influencing skill retention. Indeed, Glendon, McKenna et al., (1988) observed that males were likely to score higher in the initial testing which resulted in smaller levels of decay.

2.2.2.8 Individual States and Traits: Stress-Induction, Errors and Deviations

There is a lot of literature on the relation between emotional states and performance or learning, but there is a salient hiatus in the literature regarding the impact of emotional states, anxiety and stress-regulation specifically in skill decay studies. Nevertheless, the few studies that we found showed a clear significance of the impact of individual-related or situational-related emotional aspects.

A study by Anton, Mizota et al., (2019) showed that regulatory mental skill training could counteract the skill decay of operative surgery technical skills (laparoscopic suturing) under stressful conditions. The performance of the mental-skill-trained group was superior to the control group when having to operate under pressure. However, no group differences in skill retention were found under normal stress conditions. A study by Chittaro and Buttussi (2015) that compared an immersive virtual reality serious game to train aviation safety instructions with the common safety card instruction procedure showed that both subjective and objective measures of negative arousal reported during the game versus safety card version were positively related with knowledge retention. Individuals trained in virtual reality reported higher levels of fear-arousal and showed higher skin conductance levels (i.e., an indicator of sympathetic stress) as well as a significant improvement in the retention of safety procedures in comparison with safety card informed persons. The fact that stress-induction in terms of arousal can enhance retention can be associated with the research of Boyd and Oswald (2013) and Keith and Frese (2005), who stated that committing errors can facilitate skill transfer and subsequently skill retention. An error can be defined as 'performing an action that deviates from an individual's intended performance' (Boyd and Oswald, 2013, p. 284). Such a deviation receives greater attention and experiences of failure leave a larger and more salient imprint in one's memory than those of gain (e.g., De Dreu and McCusker, 1997). Boyd and Oswald (2013) used both errors of commission and omission and linked those to skill decay. They found a negative correlation between both types of errors and skill decay and a positive correlation between state anxiety and the occurrence of errors.

Hence, tasks during which arousal caused a certain imprint, be it by making an error or by the experienced physiological arousal due to anxiety may show better retention than when this arousal had not occurred. It should be noted here, that during an error, sympathetic arousal can be expected to increase as well.

2.3 TASK-RELATED FACTORS

2.3.1 Introduction

The nature of the task (i.e., the type and complexity of activity required) to perform has a well-known influence on the retention of the competencies that are required to perform it. Review studies are rather consistent in identifying the major task-influencing factors (or for short task-related factors) on retention, for example the type of skill a task requires (Adams, Webb et al., 2003; Bryant and Angel, 2000; Farr, 1987; Sanli and Carnahan, 2018; Vlasblom, Pennings et al., 2020; Wang, Day et al., 2013). A relatively large volume of 'grey literature' (reports) has been published on the retention of military tasks, including review studies (e.g., Adams, Webb et al., 2003; Bryant and Angel, 2000), because of the practical value of this type of research. An understanding of the differences between types of tasks with regard to retention is relevant when deciding on refresher training requirements (i.e., frequency and content) and this is especially for high-risk job performers such as military personnel or pilots (Vlasblom et al., 2020).

A large body of empirical studies exists on task-related factors, since the dawn of experimental psychology in the 19th century (Hagman and Rose, 1983). As can be expected, the majority of these studies were performed under laboratory conditions using elementary tasks and focusing on specific knowledge items or simple skills, such as recalling nonsense words. Very few studies related to competencies which are integrated sets of such knowledge and skill elements. Moreover, there is a lack of longitudinal research (e.g., Arthur, Day et al., 2013). In addition, the applied test periods were short, a few days at most, which however seemed to be sufficient as the decay function on these tasks tended to show a rather steep power law curve.

One of the reported observations within these types of studies was that accuracy decayed much faster than speed of the task performance (Arthur, Bennett et al., 1998). However, the parameters of the decay functions for accuracy and speed depended considerably on the nature of the task, e.g., physical versus cognitive tasks (Arthur, Bennett et al., 1998). Accuracy and speed for cognitive tasks decline faster than for physical tasks. Such effects are amongst the most robust findings in psychology, even under more realistic conditions. These task differences are mentioned in many literature reviews, although they mainly rely on the retention of elementary tasks and simple skills (Arthur, Bennett et al., 1998; Hagman and Rose, 1983, Sanli and Carnahan, 2018). Moreover, many studies are about the retention of procedural tasks, because refresher training often focuses on retraining procedures as for instance emergency training for pilots or crisis managers (Vlasblom, Pennings et al., 2020).

The tasks and the associated competency elements have not been described under a single framework. This makes it rather challenging to draw generic conclusions for task-related influences on retention. Examples of extensive and influential reviews are Farr (1977) and Arthur et al., (1998), but the way task-related influences on retention are described depends on the taxonomy used.

Besides the nature of a task, task complexity may also correlate with retention (Sanli and Carnahan, 2018; Vlasblom, Pennings et al., 2020). Complex cognitive tasks are considered to require an integration of different types of knowledge and skills to be applied in cognitively demanding circumstances (e.g., Skinner, 2014; Van Merriënboer and Kirschner, 2007). These complex tasks are primarily open-looped, meaningful (in contrast to the random knowledge items or skills that have no purpose for participants), and require elaborate processing, and such open-looped types of tasks are known to be retained better (Wang, Day et al., 2013) than tasks that only require simple, univocal skills, such as applying a certain procedure. For experienced fighter pilots, Bennett, Alliger et al., (2012) and Svensson, Angelborg-Thanderz et al., (2013) clearly demonstrated a small and slow loss of proficiency of the skills necessary to perform complex missions. In recent work, Cahillane, MacLean, et al., (2020) disentangled the complex and simple skills involved in a number of defence tasks. One of the identified tasks involved the ability to wear and operate breathing apparatus amongst firefighters in the UK Royal Air Force. They found that this task could be broken down into three subtasks; wearing and operating the apparatus before, during and after entry into a burning structure (e.g., a building). Consultations with subject matter experts revealed that the pre-entry and after-entry subtasks involved relatively simple skills that were predominantly procedural (e.g., carrying out drills) but placed heavy demands on working memory capacity. In contrast, the during-entry sub-task was of a higher complexity, because the dynamic nature of the situation (e.g., a route being blocked) means that complex decision making (e.g., evaluating and choosing an alternative course of action) and multi-tasking may be required.

More complex or naturalistic tasks require a sequence, combination, or integration of a variety of skills and knowledge, making task performance less straightforward to interpret and classify (e.g., Farr, 1987). Since complex tasks often consist of multiple components, each of these components may have different decay rates. This complicates the study of competence retention of complex tasks even more. It is difficult to split up the components of the complex tasks and gain insights into the retention of these components, and thus determine which ones should get extra attention, for instance in refresher training. Personnel do not always want to practice the whole task each time. Arthur and Day (2013) noted that slowly decaying competences may facilitate recall or compensate for loss of proficiency on other competencies needed to execute a complex task. This also corresponds to the cue-dependent storage and retrieval principle described by Bjork and Bjork (1992): cueing or context-specific actions may trigger the retrieval of previously stored knowledge and skills. Furthermore, Arthur and Day (2013) and Bjork and Bjork (1992) argue that the time it takes to perform complex tasks also affects retention. Complex tasks may require half an hour or more. In such a long period, there is time to get re-acquainted with the task. Clearly, more research is needed to better understand the multifaceted factor of task complexity in greater detail.

In our review of task-related factors, a competency perspective has been applied to enable a wide application in military education and training. The body of evidence was reviewed accordingly, even though the majority of publications on skill decay and retention relate to predominantly the training of elementary tasks and test conditions that may have led to results that do not fully transfer to military training practice. However, during the last decades, more attempts were taken from an application perspective. In particular, the health sector generated a large body of publications on retention, often from the pragmatic point of view of a specific medical task. Such studies do not easily contribute to a generic framework of retention. Even the comprehensive overview on retention in the book edited by Arthur and Day (2013) reveals a variety of perspectives (with different reviews and meta-analyses based on them) on task-related factors by the various chapter authors.

2.3.2 Influencing Factors Description and Evidence

Twelve task-related factors have been found in our review. They can be categorised in terms of content demands and complexity. Regarding complexity, we propose to distinguish task sequence complexity and task integration complexity. These terms are not used in the literature, but we consider them helpful because the effects of the related influencing factors on retention are opposite. A summary of the task-related factors is provided in Annex-B, Table B-2.

The effects of task-related factors on retention need to be considered during training design in order to ensure that negative effects on retention can be tempered by appropriate initial and retention training. Therefore, the factors already need to be identified in the Training Needs Analysis phase of the training development cycle.

2.3.2.1 Task Content Demands

The first category is referred to as task content demands, a term derived from Wang, Day et al., (2013). Task content demands concern the nature of tasks, in terms of the type of activities that are required for successful performance. Task content demands can be divided into three (sub) categories, also in line with earlier, well-known taxonomies such as Fleishman, Quaintance et al., (1984): physical, cognitive, and interpersonal task demands. Physical demands refer to activities that mainly require perceptual motor skills. Cognitive demands concern perception, information processing, problem solving, sense making, idea generation, and decision making. Interpersonal demands involve interactions with others such as co-workers or peers (Wang et al., 2013). The review of Arthur et al., (1998) focussed on the differences between physical and cognitive tasks. They found that the amount of decay is larger for cognitive tasks than for physical tasks. The underlying reason is that physical tasks require repeated practice for automation and may include overlearning, which strengthen the bonds between stimulus and response (Schendel and Hagman, 1982). This automaticity reduces the amount of concentrated effort demanded (Arthur, Bennett et al., 1998).

This difference between physical and cognitive tasks was confirmed in the meta-review by Wang, Day et al., (2013), who followed a multidimensional approach with combinations of the three task content demands. The multidimensional character of tasks pointed at a non-linear function of decay, in which the amount of decay highly depends on the particular combination of task demands.

The number of studies on retention of interpersonal skills is very low. Wang, Day et al., (2013) found only two studies and considered this sample too small to include it in their meta-review. An individual performing interpersonal tasks works in a team of two or more people. A scarce amount of literature is available on retention at the team and collective levels, considering task influences as well (Adams, Webb et al., 2003; Cooke, Gorman et al., 2013; DiazGranados, Lazzara et al., 2013; Roth, 1992). Retention at team or collective levels is dependent on both individual competences, teamwork competences, and integrated team-level actions (DiazGranados, Lazzara et al., 2013). Both teamwork and taskwork play a role here, where teamwork is more generic and requires individual competences such as the ability to communicate, coordinate and collaborate with others (Adams, Webb et al., 2003). Collective tasks are often complex because of the interactions between different (sub) tasks to be performed, task execution by more team members, diversity and interdependencies between (sub) tasks, etcetera. (Adams, Webb et al., 2003; Roth, 1992). Similar factors are mentioned for determining the complexity of a task. Therefore, it can be assumed that interpersonal tasks are generally more complex than elementary cognitive and physical tasks. For that reason, despite the lack of empirical evidence, one could conjecture that retention is relatively high for interpersonal tasks, dependent on underlying factors such as diversity and interdependency of subtasks as well as retention at team or collective level.

In addition to the classification into three task content demands described by Wang, Day et al., (2013), procedural and declarative knowledge should be added to our framework. Retention of declarative knowledge refers to remembering facts and principles, while retention of procedural knowledge refers to remembering processes (Henik, Brain et al., 1999). Wang, Day et al., (2013) consider declarative and procedural knowledge as part of cognitive criteria for evaluation, derived from Kraiger, Ford et al., (1993). Nevertheless, they found that combinations of procedural and declarative knowledge showed more decay than only declarative knowledge. In their literature review, Sanli and Carnahan (2018) stated that declarative knowledge declined less quickly than practical skills which often include the application of procedures. A number of studies investigated the retention of procedural tasks as a separate category within cognitive tasks, because of its relevance for operational (e.g., military) tasks (Bryant and Angel, 2000). Procedural tasks typically involve series of discrete responses (responses with a distinct beginning and end) in contrast with tasks involving continuous responses (responses without a recognisable beginning or end; e.g., Schendel and Hagman, 1991). The literature generally agrees that procedures are more poorly retained than other cognitive tasks (e.g., problem solving) because of the large number of discrete steps to remember and the problem of remembering the precise sequence of steps. Tasks that have a meaningful organisation, coherence of steps, or steps that act as natural cues tend to be better retained (Arthur, Bennett et al., 1998; Bryant and Angel, 2000; Schendel and Hagman, 1991). The differences in complexity of procedures leads us to a new category of factors: task sequence complexity.

2.3.2.2 Task Sequence Complexity

Procedures may consist of a series of tasks or steps within a task. In general, more steps or subtasks within a task will have a negative effect on retention if the elements do not really integrate in terms of temporal interrelatedness of cues and responses. Also, high variety or diversity of team tasks impairs retention (Adams, Webb et al., 2003). The differences in the nature of the tasks and their sequence complexity are also used for prediction of retention in the definition of the amount and content of refresher training. The most frequently used and cited tool for this purpose is the User's Decision Aid (UDA; Rose et al., 1985), developed for the US Army and with a focus on procedural tasks (Adams, Webb et al., 2003). The UDA, empirically evaluated, helps to identify the likelihood of retention based on a series of questions about task dimensions such as the number of steps, organisation, difficulty of the task, etc.

The complexity of a procedure may be considered as a level of difficulty in performing it. Difficulty of a task in general is not often mentioned as a factor because, as Arthur, Bennett et al., (1998) indicate, it is not easy to operationalise in reviews. Procedural complexity or difficulty generally impairs retention. In contrast, if tasks and subtasks integrate into a new composite task, new competencies are formed on that integrative level, and difficulty and complexity may lead to positive retention, once the task is learned well. This forms the third task-related factor category: task integration complexity.

2.3.2.3 Task Integration Complexity

The way tasks are integrated may be indicated by four dimensions of task integration complexity (suggested by Wang, Day et al., 2013 and referring to earlier research): closed- vs open-looped, discrete vs continuous, dynamic complexity (from low to high), and component complexity (from few to many). Although specific complex tasks may have a different profile on the four dimensions, the dimensions tend to correlate. Open-looped tasks tend to be largely continuous, rather dynamic and contain several components. As such, open-looped tasks in retention research are often discussed in close relation to complexity and difficulty (Arthur, Bennett et al., 1998; Farr, 1978; Wang, Day et al., 2013).

Open-looped tasks relate to the way the results of the tasks feed back into the task flow, while the extent to which a task is discrete relates to the number of choices/actions to make during the task flow (Wood, 1986). Tasks with few choices/actions are discrete, tasks with many choices/actions are typically continuous. Fully closed-looped and discrete tasks relate to a fixed sequence with a clear and distinct end, whose results do not feed into a new execution of the same task sequence (e.g., follow a checklist for an emergency procedure of 8 steps). Open-looped and continuous tasks will feed back into the tasks that are continuously repeated (air traffic control is a good example) without a clear and distinct end. In general, open-looped tasks are more resistant to decay than closed-looped tasks (Arthur, Bennett et al., 1998; Farr, 1978). The typical continuous nature of open-looped tasks allows for repeated practice (and thus overlearning) which increases retention. An additional reason is that open-looped tasks may be more integrated or coherent than closed-looped tasks and thus may be retained better (Arthur et al., 1998).

Dynamic tasks relate to the level of inconsistent information or inconsistency between information and actions (Wood, 1986). In other words, there is a level of uncertainty in task information or context, requiring constant attention to the task environment and often decisions and actions to adapt to changing situations. Component complexity refers to the total number of distinct but interrelated processes and behaviours required to execute a task and the total number of distinct information cues that must be processed in performing actions (based on Wood 1986, but interrelatedness is added to make a clear distinction with the task sequence complexity factor). The meta-analysis by Wang, Day et al., (2013) showed strongest effect of component complexity (complex tasks decay less), but the results for other dimensions or combinations of dimensions were mixed or weak. Overall, Wang, Day et al., (2013) concluded that higher complexity tasks more often decay less than lower complexity tasks.

2.4 TRAINING AND EDUCATION RELATED FACTORS

2.4.1 Introduction

The literature relating to the influence of training and education on skill and knowledge acquisition and retention is vast and several meta-analyses or comprehensive literature reviews are reported (Driskell, Willis et al., 1992; Cepeda, Vul et al., 2006; Karpicke and Roediger, 2008; Cahillane, Launchbury et al., 2013, Arthur, Bennett et al., 2013, Pan and Rickard, 2018). Influencing factors which have attracted particular attention across the research community, relate to:

- Spacing of learning (spaced vs massed).
- Mastery training (overlearning or overtraining).

- Mental practice (in the absence of overt physical movements).
- Retrieval practice and test-enhanced learning.
- Quality of feedback provided to the learner.

In addition to the above, and increasingly, the effects of learning technologies (including the qualities of media and interfaces) on the effective acquisition and retention of learning are being investigated.

Similar to task-related factors, historic studies have been conducted mostly within controlled environments and with a focus on simplistic and micro-cognitive skills and knowledge types (e.g., mirror tracing, spelling, math computation, verbal discrimination, free recall (Cepeda, (2006)). Furthermore, there has been a tendency towards considering retention intervals that are short in duration (i.e., weeks and months, rather than years) and this can be attributed to the typical costs associated with conducting longitudinal studies and the commitment required by participants to return at requested intervals. This history and emphasis can present a challenge to decision-makers and policy holders seeking evidence to inform effective ways to design, deliver and assess training and education. What is clear, however, is that practitioner guidance can be provided with caveats indicating how moderating factors such as the length of the retention interval, and the characteristics of the task and learner (in particular the learner’s experience) might influence the rate of skill fade for particular types of tasks.

More recently, Deighton, Richards et al., (2020) reported the growth in applied research studies where the influence of different types of learning and development interventions on competence retention have been examined. Examples include:

i) The use of structured self-debriefing techniques delivered via a smart phone, between training sessions, to support the retention of laparoscopic skills (Kun, Hubert et al., 2018);

ii) The investigation of the spacing of learning for paediatric resuscitation skills among emergency service providers (Patocka, Cheng et al., 2019); and

iii) Investigations of the acquisition and retention of knowledge of passenger safety information through the use of various media types including serious games (Chittaro and Buttussi, 2015; Buttussi and Chittaro, 2018; Buttussi and Chittaro, 2021).

Recent years have witnessed a growing interest in the use of digital games for learning, education and training. The term “serious game” has become mainstream in the literature and tends to be used interchangeably with “games for learning” (Boyle, Hainey, et al., 2016). Such an increase in interest is supported by the gradual build-up of empirical evidence about the general effectiveness of the serious game approach to learning in a diversity of domains, as highlighted by different meta-analyses (Boyle, Hainey et al., 2016; Clark et al., 2016; Connolly, Boyle et al., 2012).

Among the large number of domains for which serious games have been built, several projects are directly relevant to the NATO context because they focus on preparing trainees in preventing and/or handling risky situations, e.g., submarine safety (Stone, Caird-Daley et al., 2009), combat casualty care (Pasquier, Merat et al., 2016), terrorist threat preparedness (Chittaro and Sioni, 2015), work accidents (Guo et al., 2012), aviation safety (Chittaro, 2016).

Virtual Reality using Head-Mounted Displays (HMDs) that fully immerse trainees in a 3D computer graphics environment is another technology whose availability has greatly increased in the last few years, thanks to an impressive decrease in the cost of hardware. HMDs can be used to vividly simulate the scenarios the trainee should familiarise with, and the virtual reality approach can be also combined with the serious game approach. In their review of HMD-based education and training, Jensen and Konradsen (2018) identified a number of situations where HMDs appeared to be more useful than traditional methods for skills acquisition. They categorised them as:

i) Cognitive skills related to remembering and understanding spatial and visual information and knowledge;

ii) Psychomotor skills related to head-movement, such as visual scanning or observational skills; and

iii) Affective skills related to controlling one's own emotional response to stressful or difficult situations. This categorisation aligns with those of Wang, Day et al., (2013) and Fleishman and Quaintance (1984).

It is worth noting that the different media used in learning and training interventions, ranging from the more traditional (printed materials, videos, etc.) to the more innovative (serious games, virtual reality, etc.) are not mutually exclusive and can be combined (blended learning interventions).

In many respects, the existence of a breadth of literature relating to training and education factors is not surprising given that competence retention is influenced by the way in which knowledge and skills are initially acquired, developed, maintained, and assessed. Within this report our aim is to communicate this breadth of influencing factors and to signpost the reader to key studies (in particular meta-analyses and comprehensive literature reviews) to support further reading. In contrast to typical reviews on the topic, we also aim to highlight how future trends in learning technology and 'modern' approaches to learning and development might offer new perspectives and challenges relating to competence management.

2.4.2 Influencing Factors Description and Evidence

Within this section 14 key factors relating broadly to the design and delivery of training and education and the assessment of learning are described along with supporting evidence gathered primarily from meta-analyses and/or systematic reviews of the skill fade literature (see Annex A, RTG Methodology). This review is complementary to the information presented in Annex B, Table B-3.

2.4.2.1 Spacing of Learning

The spacing effect (also called the "distributed practice effect") refers to the '*interval separating different study episodes of the same materials*' (p. 354, Cepeda, Vul et al., 2008). Massed learning means that there are no interruptions, in terms of time or intervening items and spaced learning refers to the opposite. For example, a 40 hour 'learn to drive' course compressed into 5 days versus a standard 'spaced' learning course involving a one-hour session per day over 40 days.

The literature on spaced learning is vast and Cepeda, Vul et al., (2008) report several reviews (Moss, 1996; Lee and Genovese, 1988; Janiszewski, Noel et al., 2003) which provide evidence based mostly on studies involving simple motor tasks (Donavan and Radosvich, 1999) or simple cognitive tasks (Cepeda, Vul et al., 2008). Xue, Mei et al., (2011) report that spaced learning usually leads to better recognition memory when compared with massed learning. This may be due to an increased opportunity for mental rehearsal, information processing and retrieval practice, and a reduction in fatigue arising from intensive practice periods (Arthur, Day et al., 2013). Experimental research reported by Cepeda, Vul et al., (2008) investigated the retention of facts after an interval of 3.5 months with a final test after a delay of up to one year. Findings highlight two key educational implications. Firstly, that the optimum Interspace Interval (ISI) value is about 20% of the retest interval in cases where the interval was a few weeks; with the optimum ISI reducing to 5% where the delay was one year. Secondly, that whilst accuracy is affected by the inclusion of an ISI that is longer than the optimal value, these effects are less marked in comparison to those cases where the ISI is too small. The latter point is evidenced by findings which show that as the ISI increases, accuracy increases steeply and then declines much more gradually. Whilst the latter findings are persuasive, it is important to note that they are based on research investigating the recall of facts (i.e., knowledge) and that such guidelines may not be valid when applied to other simple or complex skill types. Cecilio-Fernandes, Cnossen et al., (2018) undertook a systematic review of the literature specifically addressing the spacing of training sessions for surgical motor skills. Evidence supported Cepeda's finding that spacing training sessions is beneficial to long-term retention when compared to massed practice. However, the optimal ISI is unclear.

New studies on the benefits of spaced vs massed learning have been conducted since Cecilio-Fernandes' review in 2018. In particular, Patocka (2019) (reported in Deighton, Richards et al., 2020), evaluated whether a Paediatric Advanced Life Support (PALS) course taught using spaced training conditions, compared with the PALS course taught using standard massed training conditions, had an impact on Emergency Medical services providers' retention of paediatric resuscitation skills over a 3-month period. In the spaced learning condition training was delivered in four, 3.5-hour weekly sessions per month, and the massed condition in two sequential 7-hour days. Three components of PALS were examined: Chest Compressions (CC), Bag Mask Ventilation (BMV), and Intraosseous insertion (IO). Overall, findings were generally consistent with previous research with spaced course delivery resulting in the retention of more skills than massed training – this was evident for the infant BMV and IO of the PALS course. However, in contrast, infant CC scores remained significantly improved, with respect to the baseline, for both groups over the 3-month interval. Patocka concludes that the 'differential retention of skills may be related to the nature of motor response required for the included skills with CC being a more continuous (cyclic movement pattern) response compared to BMC and IO which are discrete (having a definite beginning and end) responses' (p.6). This is in line with other studies which have demonstrated that continuous movements (i.e., continuous psychomotor skills) are likely to be retained better than discrete psychomotor skills (see Section 2.3 – Task-Related Factors).

2.4.2.2 Mastery Training

The level of proficiency achieved during initial learning is an important factor influencing skill retention. Mastery training may also be referred to as overlearning and overtraining and is a deliberate process whereby individuals receive training beyond the criterion set for a given task.

In research on overlearning, participants in the control condition typically perform the task until the set criterion is reached. Within the experimental condition the task would be practiced again until the criterion is reached, and then further practice trials are undertaken. Overlearning is defined as a percentage of the number of attempts that were made by the participant to achieve criterion (e.g., if the participant took 10 trials to reach the criterion then a further 5 trials would constitute 50% overlearning). In a meta-analysis of the effects of overlearning on retention, Driskell, Willis et al., (1992) report findings which indicate that overlearning results in a significant effect on retention that is 'moderate in magnitude' and that the influence of this factor is moderated by three variables: the degree of overlearning, the type of task, and the length of the retention period. Driskel, Willis et al., (1992) suggest that: firstly, a *'50% overlearning manipulation should be considered as a minimum practical operationalisation of overlearning and that small improvements in performance can be expected from this level of training*' (p. 619); secondly, that the effect of overlearning was greater for cognitive versus physical tasks; thirdly, that no overall relationship was observed between overlearning and the length of the retention interval (noting that the lengths of the retention intervals included within the meta-analysis ranged from < 1 to 56 days). Driskel acknowledges the drawbacks of overlearning in terms of additional costs, and Rohrer, Taylor et al., (2005), based on the findings of experimental research involving the recall of facts, concluded that overlearning is an 'inefficient strategy for learning materials for meaningfully long periods of time' (p.1). It is interesting to note however, that Schendel and Hagman (1982) found that, following a 2-month retention interval, participants who had been over trained required 22% fewer trials to retrain to the criterion level than did controls, thus partially offsetting the initial training investment in overlearning. Zakay and Wooler (1984), emphasise the importance of ensuring that where overlearning is implemented, the conditions under which overlearning takes place match those of the actual task. Most recently, the influence of overlearning has been re-examined from a neuroscience perspective with research reported by Shibata, Sasaki et al., (2017), indicating that overlearning may 'stabilise' and protect perceptual learning from subsequent new learning.

2.4.2.3 Deliberate Practice Opportunities

The issue of ‘exposure’ to opportunities to practise particular types of skills as part of the ‘flow of work’ is a key area within defence research (Deighton, Taylor et al., 2020). Sullivan, Elshenawy et al., (2019) notes that the main features of deliberate practice include motivated learners, well-defined learning objectives or tasks, focussed and repetitive practice, precise measures of performance and informative feedback concerning performance.

Vermeulen, Keijzers et al., (2019) report that deployed surgical teams in Iraq were rarely exposed to casualties and that these low workload deployments could result in a decline in surgical skills. As a result, they conclude that *‘military medical planning should be tailor-made and should include adjusting length of stay and (pre- / post-) deployment refresher training’* (p. 11). Mead, Tennent et al., (2017) point to medical readiness training exercises as a way to provide highly concentrated exposure of practitioners to injuries requiring a high level of surgical expertise that is not typically encountered in a garrison environment where most military surgeons practice. Similarly, Mikita (2017) reports the findings of survey research to investigate the requirements for post-deployment refresher training. Other longitudinal studies conducted within a clinical, non-defence context have identified benefits of readiness training in terms of increased procedural experience (Meerkov, Fischer et al., 2019), and competence and adherence to clinical procedures (Skare, Boldingh et al., 2018). Hossein, Perrone et al., (2020) point to the need for clinical research residents to engage in regular clinical activities, simulations or assessment to minimise skill decay during their research training years. In terms of future research, Petrosoniak, Lu et al., (2019) report a protocol that will be implemented to assess the benefits of simulation-based mastery learning and deliberate practice versus self-guided practice for a rarely performed surgical technical skill.

The latter studies take a strategic perspective with the deliberate planning by the organisation to ensure effective competence management. Practice opportunities that are ‘just-in-time’ are also relevant within this category (Sullivan, Elshenawy et al., 2019). For example, the “teaching time-out” approach is a novel framework for surgical education involving surgical teams pausing and reviewing critical information relating to the surgical case to ensure that nothing is missed. This approach helps to ensure that the individual and the team overall are competent to perform particular procedures given the specific conditions encountered (Guidolin, Yan et al., 2020).

2.4.2.4 Mental Practice

This is the cognitive practice of a physical procedural activity in the absence of overt physical movements being conducted and can be distinguished from the broader term, mental preparation which includes positive imagery, attention focusing, and cognitive and emotional preparation prior to performance (Driskell, Copper et al., 1994). Mental practice (i.e., recurrent training) promotes overlearning thereby reducing the detrimental effects of performance decay (Arthur, Day et al., 2013).

Evidence from a meta-analysis of the literature indicates that mental practice has a positive and significant effect on performance with effects moderated by variables including: the type of task, the retention interval between practice and performance, experience and the length or duration of the mental practice intervention (Driskell, Copper et al., 1994). In terms of the task type, findings indicated, in general, that mental practice is effective for both cognitive and physical tasks; and that this effect is significantly stronger the more a task involves cognitive elements. More specifically, findings indicated that for physical tasks, mental practice became less effective the more the task included strength and coordination requirements. In the case of cognitive tasks, mental practice was most effective where the task required mental operations. Comparatively weaker, but nonetheless significant, effects were evident for those cognitive tasks which required output and response activities as well as perceptual input activities. Considering the retention interval, findings indicated that the longer the delay between mental practice and performance the weaker the effects of this factor with initial effects reducing by 50% after a retention interval of 14 days and reducing to a small effect (Cohen, 1977) at approximately 21 days. When considering the relationship between the effectiveness of mental practice and experience, Driskell, Copper et al., (1994) report an interaction effect with the task type with novice participants benefiting more from mental practice on cognitive tasks than on physical tasks and experienced participants benefiting equally well. In terms of the length of time spent mentally practicing a particular task, findings indicated that the beneficial effect diminishes as the time spent practicing increases. As a practical guideline for implementing mental practice, Driskell, Copper et al., (1994) indicate an overall training period of approximately 20 minutes.

Kelc, Vogrin et al., (2020) note that during special circumstances, such as an epidemic (e.g., COVID-19), personnel may be deployed to work within environments that do not reflect their typical specialist areas. They argue that *'in the case of limited access to actual performance, mental practice seems to be reasonable if not mandatory for both novice and experienced surgeons. Not only would such training prevent surgical skill decay but it would probably also lower the anticipatory anxiety level on returning to the operating theatre'* (p.3). A caveat to the effectiveness of mental practice is that the individual must be familiar with the procedure prior to the imagery session, which may be developed through observation of recordings or access to other trusted sources.

2.4.2.5 Retrieval Practice and Test-Enhanced Learning

Research evidence has identified that retrieval practice and test-enhanced learning plays an important role in the long-term retention and transfer of competence (Roediger, et al., 2011; Roediger, Agarwal et al., 2010; Roediger and Butler, 2007; Cahillane, Launchbury et al., 2013; Fortino, and Lowrance, 2019; Foos and Fisher, 1988). This is opposite to the typical viewpoint that testing is a 'neutral' event, which does not contribute to learning (Karpicke and Roediger, 2008).

In a study involving the learning and recall of foreign language vocabulary, Karpicke and Roediger (2008) report that repeated retrieval practice enhanced long-term retention. Additionally, findings indicated that once information can be recalled, then repeated retrieval in test trials resulted in greater benefits for long-term retention in comparison to 'repeated encoding'. Testing benefits memory because it promotes the active retrieval of information – those tests which require more effortful retrieval (e.g., short answers) have greater benefits for learning and retrieval than those types of tests that require less effortful retrieval (e.g., multiple-choice) (Roediger and Butler, 2011). Practical implications for learning are indicated, e.g.,-*'instead of giving students summary notes to read, teachers should implement more frequent testing (of important facts and concepts) – using test formats that entail effortful retrieval – and provide feedback to correct errors'* (p. 21) (Roediger, Putnam et al., 2010). Effective feedback is important and required to correct errors on initial tests which are comparatively more challenging (Butler, Karpicke et al., 2007).

Retrieval practice and test-enhanced learning can be implemented in different ways and is not limited to classroom-based assessment. For example, retrieval practice could also be carried out via self-testing using sequence cards or simulation-based programmes (Roediger and Butler, 2011, cited in Cahillane, et al., 2013) (see the influencing factor 'Feedback' for further discussion). Whilst beyond the scope of this report, it is worth noting the broader benefits of retrieval practice and test-enhanced learning to the transfer of learning to different contexts (see Pan, 2018 for a meta-analytic review and synthesis).

2.4.2.6 Feedback

Constructive, timely, and meaningful feedback that is relevant and specific to the trainee and the learning process will reduce performance decay (Arthur, Day et al., 2013). Feedback may be created:

i) By the learner (e.g., as part of self-regulated learning and performance, Zimmerman and Schunk, 2011);

ii) Through peer-to-peer / social learning (Youngsuk et al., 2016);

iii) Traditionally via the trainer as part of training and education delivery. Feedback is distinguished from recognition cues, which are prompts which may help with acquiring task sequences (Cahillane, Launchbury et al., 2013).

In a study involving responses to knowledge-based questions, Dihoff, Brosvic et al., (2003) found that combining immediate feedback with the opportunity to answer questions until correct both teaches and promotes the retention of course materials after a two-week retention interval. Whilst feedback can enhance retention, too much feedback can result in an over-reliance on the trainer, disruption to information processing and failure to develop strategies to correct own performance (Arthur, Day et al., 2013).

Learning technology provides the means to support the generation and delivery of feedback. For example:

- Kun et al., (2018) investigated the use of self-coaching and feedback methods that included the provision of a practice video comprising a record of a 'perfect film' based on expert performance, the trainee's last three attempts at a surgical procedure; and participant selected elements of their own performance reflecting typical critical errors. Controlled access to these materials by participants in the experimental group enabled a regular progression in learning between training sessions, which were separated by a 72-hour delay, and a positive performance score at the end of the training. In their paper on the application of future technologies to detect skill decay and improve procedural performance,
- Linde and Miller (2019) consider the delivery of feedback in a variety of ways, for example, via augmented reality, haptics, and data analytics as well as through focussed, personalised feedback. The latter paper also highlights how a combination of learning approaches might be used to support the acquisition and retention of learning – in this case feedback, coupled with mastery training, repetitive practice and learning technologies.

2.4.2.7 Fidelity of the Learning Environment

This relates to the extent that the cues that are present within the learning environment are matched to the transfer environment (Arthur, Day et al., 2013). Such cues may be considered in terms of different types and levels of fidelity (Buttussi and Chittaro, 2018), and actual job equipment.

To classify different types and levels of fidelity of a learning environment, the framework proposed by Ragan, Bowman et al., (2015) categorises the different aspects of fidelity into three dimensions (scenario, display, interaction). Scenario fidelity is about the realism of the reproduced scenario, with its characteristic behaviours, rules, and properties. Display fidelity is about the realism supported by the devices that provide the trainees with stimuli, and how well real sensory stimuli are reproduced in the learning environment. Interaction fidelity is about the realism supported by the devices on which the trainee acts, and how well they reproduce physical actions that the trainee would perform in the real world. Although the framework was created in the context of virtual reality experiences, the definition of the three types of fidelity can be extended also to other contexts. In this report, we thus define the fidelity of a learning environment as a multidimensional construct (Figure 2-1) organised into three dimensions: scenario, sensory input and (inter)action. More specifically, the scenario dimension refers to the quantity and quality of the real world scenario elements that are included in the learning environment such as task duration (e.g., how much the length of the task matches the real duration) and task complexity (e.g., number of variables included and their range). The sensory input dimension captures how much the learning environment can recreate the real-world sensory experience in the trainee. Within this context, the five senses are all relevant, i.e., vision (e.g., use of text/pictures/video/computer graphics; amount of details in the visual field; reproduction of the range of light conditions), hearing (e.g., amount of auditory details, closeness in harmonic content and loudness to the real auditory stimuli), touch (e.g., reproduced force, velocity, texture, temperature), smell (e.g., odours that characterise specific environments, objects or processes), taste (e.g., intake of substances). The more the integration of the three dimensions approaches the real world, the higher the overall fidelity of the learning environment.

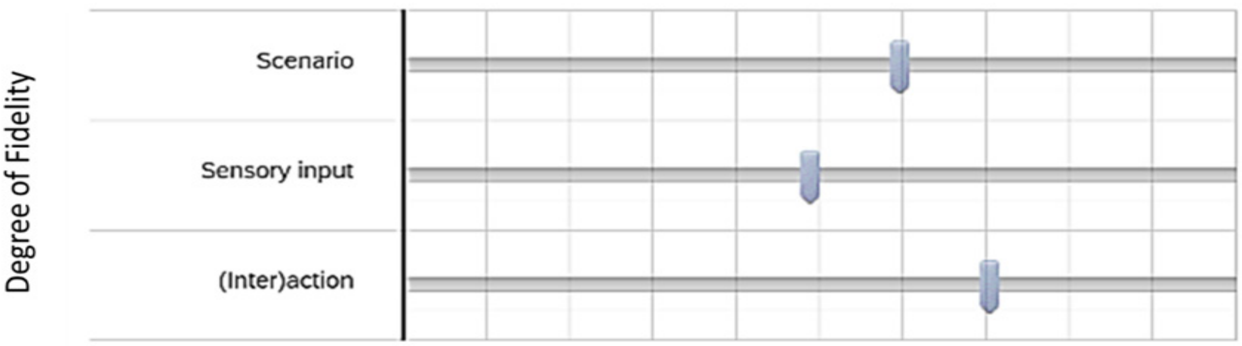

Figure 2-1: Degree of Fidelity as a Multidimensional Construct: The Overall Fidelity of a Learning Environment Depends on Three Different Dimensions.

In a meta-analysis, Arthur, Bennett, et al., (1998) investigated the relative effects of a range of moderators on skill decay and concluded that similarity of the training (acquisition) and work (retention) environments plays a major role in the retention of skills and knowledge over periods of non-use or nonpractice.[1]

Further discussion of the influence of training-related media on the acquisition and retention of skills and knowledge is provided in the following sections.

2.4.2.8 Printed Materials

Printed materials that contain text or pictures/pictograms or both are probably still the most used media in learning, education, and training interventions. In recent years, they are increasingly provided in electronic form (e.g., as PDF files) instead of printed paper, for readers' convenience, but they remain non-interactive, and their layout and content does not change: the learner simply receives a file that can be printed physically (on-paper) or displayed digitally (on-screen).

Different studies have contrasted printed materials with watching video in the context of remembering news, and with more sophisticated media such as virtual reality in the training context. While printed materials proved to be inferior to virtual reality in retention outcomes (Chittaro and Buttussi, 2015; Buttussi and Chittaro, 2021), not all video vs. text studies showed a superiority of video, highlighting the need for a careful design of audiovisual materials (DeFleur, Davenport et al., 1992; Furnham and Gunter, 1985; Furnham and Gunter, 1987; Gunter, Furnham et al., 1984; Gunter, Furnham, and Leese, 1986; van der Molen and Van Der Voort, 2000; Wicks and Drew,1991).

2.4.2.9 Videos

Unlike printed materials, which are static, videos contain dynamic elements (camera recordings and/or animated graphics) that can be accompanied by audio.

Different studies have contrasted watching video and reading text in the context of remembering news: some studies concluded in favour of video and some in favour of text (DeFleur, Davenport et al., 1992; Furnham and Gunter, 1985; Furnham and Gunter, 1987; Gunter, Furnham et al., 1984; Gunter, Furnham et al., 1986; Walma van der Molen and Van Der Voort, 2000; Wicks and Drew, 1991). An aspect that seems to influence the result is trainee's level of control on the media, for example the possibility of self-pacing the reading or the video watching experience.

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[1] However, it is noted that this finding is informed by a *'small number of data points'* (p. 81).

Different facets have been shown to improve video-based learning. Such facets include:

- Making interactive controls intuitive to use (Schwan and Riempp, 2004; Hasler, Kersten et al., 2007; Merkt, Weigand et al., 2011);
- Segmenting the flow of information into small, discrete segments of activity (Mayer and Chandler, 2001; Hasler, Kersten et al., 2007);
- Highlighting the boundary between activities in the video (Newtson and Engquist, 1976; Schwan, Garsoffky et al., 2000) and where the user should focus his/her attention in that boundary through cueing (de Koning, Tabbers et al., 2007); and
- Using contextually meaningful gestures, instead of simple taps on a touchscreen (Dube and McEwen, 2015).

2.4.2.10 Virtual Reality

As described in the Introduction, Virtual Reality (VR) is a relevant emerging media for learning and training. The first studies of its impact on retention are now available in the literature.

Chittaro and Buttussi (2015) contrasted learning cabin safety procedures with traditional printed pictograms or an immersive VR experience based on a Head-Mounted Display (HMD). A knowledge test administered before, immediately after, and one week after the experimental condition showed superior retention in the VR group rather than the printed pictograms group.

Buttussi and Chittaro (2021) contrasted learning cabin safety procedures with: traditional printed pictograms, a VR experience on an HMD, and the same VR experience on a smartphone touchscreen, extending the retention period to 2 weeks. Both VR setups produced better results than printed materials.

Silverstein, Dech et al., (2002) and Kruglikova, Grantcharov et al., (2010) conducted studies of VR training in surgery, showing that there was no significant competence decay after 4 – 6 weeks. Smith, Farra et al., (2016) studied retention at 5 – 6 months, considering decontamination procedures in a disaster scenario, with students from two different nursing programs. They compared learning with traditional methods and VR, concluding that VR is at least as good as traditional methods for developing decontamination skills, and is superior in some cases for retention of knowledge and performance of skills.

2.4.2.11 Engagement and Emotional Arousal

The importance of emotions is increasingly recognised in modern learning environments (Graesser, 2020). In particular, emotions are able to positively affect retention.

This initially emerged from neuroscience studies with audio-video narratives that showed better 1-week retention results with the more emotionally arousing versions (Sharot, Delgado et al., 2004; Labar and Cabeza, 2006; McCaugh, 2000; Nielson and Arentsen; 2012; Kensinger, 2009; Finn and Roediger, 2011; Kensinger and Schacter, 2008; Cahill et al., 1994).

More recent retention studies focussed on training and included additional media. Chittaro and Buttussi (2015) measured engagement and emotional arousal with subjective as well as physiological methods, comparing VR and printed pictograms as training media. Findings indicated that VR obtained more emotional arousal and retention than printed materials. Buttussi and Chittaro (2021) used subjective methods and distinguished between immersive VR (on an HMD), non-immersive VR (on a smartphone), and printed materials, finding three decreasing levels of trainee’s engagement and satisfaction.

A word of caution is needed about how high the level of arousal should be to be advantageous. The above cited studies support the fact that low emotional arousal results in less retention with respect to a greater level. However, the greater levels of arousal induced in the studies were relatively mild. Vogel and Schwabe (2016) warn that, while a mild level of stress facilitates learning and cognitive performance, excess stress impairs learning and is detrimental to memory performance.

2.4.2.12 Design of Training Media

The design space of any training media (printed materials, videos, serious games, VR) is large: the same content can be conveyed in many different ways, and the features (interactive or non-interactive) offered to the trainee can vary widely. Design choices should maximise both usability (for example, readability, clarity, simplicity, ease of use, logical organisation) and engagement (for example, narrative, emotion-inducing cues, aesthetics, interaction mechanics, incentives).

Usability has an impact on the effectiveness of any type of computer-based learning, for example Parlangeli et al., (1999) showed with three studies that difficult-to-use multimedia systems can negatively affect learning performance.

Recent designs of training systems emphasise the effectiveness of adapting design choices from video games into the training context to increase engagement. For example, Chittaro and Buttussi (2015) introduced in the VR experience a number of elements typical of action/survival games such as:

i) A narrative that includes emotionally intense events;

ii) Vivid audio-visual feedback about the consequences of players' actions, including harm to the player's avatar;

iii) Unexpected, surprising events.

More generally, Plass et al., (2015) described how adapting design choices from video games can lead to different types of trainee's engagement: cognitive (mental processing), affective (emotions and their regulation), behavioural (gestures, embodied actions, movement in using the training media), sociocultural (social interaction with other learners).

2.4.2.13 Hardware Display

Any kind of digital media needs hardware to be displayed and used by trainees. The choice of display affects also the way the trainee interacts with the media, e.g., touching the screen on smartphones/tablets, natural head and hands movements with HMDs, operating a mouse with PCs. This raises the question of whether the choice of hardware can affect retention of digital content.

Moreno and Mayer (2002) compared learning with HMD vs. a traditional PC display under different instructional modes. Results indicated that the choice of display did affect sense of presence in the training environment but did not affect how much they remembered of the content after using the media.

Buttussi and Chittaro (2018) measured 2-weeks knowledge retention (and also retention of self-efficacy) of procedures learned from a serious game concerning a runway overrun experience, with three groups using three different displays: one used a non-immersive display (PC monitor), the other two groups used immersive displays (one used an HMD with narrower field of view and head orientation tracking, the other used an HMD with wider field of view and tracking of head orientation and head position). No statistical differences were found in the retention measures between the 3 types of hardware setups, while engagement was instead significantly affected: the more immersive the display, the higher the engagement.

Buttussi and Chittaro (2021) measured usability and 2-weeks retention with immersive VR on a HMD, and non-immersive VR on a smartphone, two types of hardware that are receiving increasing attention for training purposes and offer very different levels of display and interaction fidelity. The study also included traditional printed pictograms as a third training condition. Both VR setups were better than traditional printed materials in terms of knowledge gain, 2-weeks retention, and reported trainee's confidence in the learned procedures. The differences in these measures between the two VR hardware setups were instead minor. However, only immersive VR on the HMD was significantly better than printed materials in terms of usability, and sense of presence was higher with the immersive VR setup than the non-immersive one. Finally, the type of VR hardware played an important role on engagement and satisfaction, with immersive VR on the HMD scoring better than both printed materials and non-immersive VR on a smartphone.

These two studies indicate that display type does not seem to be a factor that affects retention, at least when procedural knowledge is considered. The two studies combined may suggest that an HMD display should be preferable for reasons of greater engagement, which could affect motivation to train. Therefore, when the VR experience needs to be run instead on non-immersive hardware, the introduction of gamification elements could be especially important to promote engagement.

2.4.2.14 Haptic Hardware

Computer-based training that is based on audio-visual stimuli becomes insufficient when trainees need to learn fine motor skills or familiarise with physical forces of a work environment. In those cases, the addition of haptic hardware can extend computer-based training to encompass the missing aspects.

Depending on the type of haptic hardware adopted (e.g., special gloves, motion platforms, exoskeletons), it becomes possible to introduce computer-controlled tactile stimuli and/or physical forces in the training experience. Although technically more complex and costly, the viability of this approach with reference to its effectiveness on retention has been shown by Carlson, Peters et al., (2015). They considered the domain of assembly workers in a factory and compared virtual bimanual haptic training vs. traditional physical training. Results of the retention test, two weeks after the training, showed the same level of performance in participants trained in the virtual world or in the physical world

Chapter 3 – PSYCHO (PHYSIO) LOGICAL MECHANISMS

3.1 GENERAL OVERVIEW

The plethora of potential influencing factors and their impact on the rate at which skills decay over time have been highlighted by the review presented in Chapter 2. With the growth in modern approaches to learning (e.g., through formal, informal, and opportunistic events) and changes in the nature of work, the question arises whether the military or other industries can ever keep up with identifying the myriad of factors that may have a beneficial or detrimental effect on competence retention. One solution might be to take into consideration a comparatively smaller and more stable set of psycho (physio)logical mechanisms that provide a rationale for the effects demonstrated by those influencing factors.

To demonstrate this perspective Chapter 3 briefly describes examples of those psycho(physio)logical mechanisms which may inform our understanding of *why* particular types of person-, task-, and training and education-related factors might influence the rate at which skills decay.

Caveat: It should be noted that a comprehensive review of those psycho(physio)logical mechanisms explaining the effects of skill fade factors was beyond the scope of this RTG HFM-292 and this deeper review would benefit substantially from the expertise of other relevant specialisms (e.g., neuroscience).

3.2 DESCRIPTION OF PSYCHO (PHYSIO) LOGICAL MECHANISMS

Psychological Mechanisms outlined within this section include:

- Automaticity.
- Cortical plasticity and 'ecphory.'
- Boredom/mind-wandering.
- Distribution of processing among different channels.
- Information processing rate.
- Perception of fidelity of a virtual experience.
- Embodied cognition.
- Role of emotion in memory consolidation and psychophysiological stress regulation.
- Need for cognition.

A judgement on those skill fade factors relating to the person, the task, and training and education, which may be partly or fully explained by a given psychological mechanism, was made by members of the RTG HFM-292 and the output of this activity is reported within the following Sections 3.2.1 to 3.2.9. These judgements may be considered as hypotheses for future research.

3.2.1 Automaticity

This psychological mechanism is relevant to the following influencing factors:

- Mastery training.
- Deliberate practice.
- Mental practice.

- Spacing of learning (indirectly, via the increased opportunity for mental practice).
- Task-content demands.

Research on skill acquisition has frequently highlighted three phases of learning (Langan-Fox, Armstrong, et al., 2002 cite the following theories: Anderson, 1982; Fitts and Posner, 1967; Schneider and Shiffrin, 1977). In the first phase of learning, performance on a novel task relies on controlled (i.e., conscious) processing or declarative knowledge, is cognitively demanding and requires substantial attentional resources. In the second phase of learning, both controlled and automatic processing underpin performance with less reliance on cognitive processes. In the third phase of learning, automatic processing and procedural processes underpin skilled performance with no requirement for conscious control and fewer demands placed on attentional resources. Practice and repeated performance of the skill supports this gradual transition from controlled to automatic processing.

In general, the transition to automatic processing is regarded as a positive step in the learning process and is associated with mastery or expertise in a skill. However, Toner, Montero et al. (2015) highlighted that the environments in which a skill is executed can be highly variable and an over-reliance on automatic processes can lead to a number of different performance errors.

Specifically, they suggest that automaticity can lead to:

- **Mistakes in planning or decision making** – prior experience leads to a familiar solution being applied inappropriately to a new problem without consideration of alternative solutions.
- **Slips in performance during the execution of a skill** – an automated skill (e.g., motor action) might be executed inappropriately through habit, even though this is inconsistent with the initial plan or decision.
- **Lapses in performance during the execution of a skill** – automated processes may prevent an individual responding flexibly or reacting when a situation becomes challenging and unpredictable during task execution (i.e., where the precise details of the task are novel and differ from previous experience).

- **Lapses in performance during the execution of a skill** – automated processes may prevent an individual responding flexibly or reacting when a situation becomes challenging and unpredictable during task execution (i.e., where the precise details of the task are novel and differ from previous experience).

Toner, Montero et al. (2015) suggest that optimal performance on a range of skills may rely on a dynamic mixture of automatic and controlled processes. Under challenging or novel conditions, skilled performance may rely on recognising that automated processes are inappropriate and switching to more controlled processing in order to evaluate the demands and nuances of a situation.

These findings suggest that more may not always be better when considering mastery training, and mental practice. Instead, identifying the optimal level of practice and rehearsal may be beneficial, where the individual is able to flexibly transition between controlled and automatic processing according to the demands of the situation. That is, training and education may want to focus on helping the learner reach the second (rather than third) phase of learning during the acquisition of new skills.

Automaticity may partially explain the impact of task content on the rate of skill decay. The level of automaticity achievable depends on the type of task to be learned. Tasks with, for example, a highly repetitive motor aspect can be automatised well and do not rely on working memory capacity as much as higher order cognitive tasks such as decision making. While the level of automaticity allowed by the demands of the tasks explains the task-content demands factor to some extent, deeper explanation may be found in neurobiological principles.

3.2.2 Cortical Plasticity and 'Ecphory'

This psychological mechanism is relevant to the following influencing factors:

- Retrieval practice and test-enhanced learning.
- Similarities with the learning environment.
- Spacing of learning (indirectly, via the increased opportunity for information processing and time to make links with previous knowledge).

The neurobiological underpinnings of memory provide an explanation for the beneficial effects of retrieval practice, test-enhanced learning, and learning environments that are similar to subsequent performance environments. Hebscher, Wing et al. (2019) recently highlighted that the representation of memories in neocortical networks facilitates their long-term retrieval. They cite previous research, which typically suggests that newly formed memories rely on the hippocampus for a significant period of time (weeks to years) and only then, after consolidation, are migrated and represented in neocortical networks. However, the authors also cite more recent contradictory research suggesting that these neocortical representations can occur considerably more rapidly (within hours or days). This recent research suggests that cortical memories can be encoded in parallel with, and rapidly become independent of, hippocampal memories. Given the likely benefits to long-term retrieval, it is important to understand the learning conditions that enable the early representation of memories in neocortical networks. Hebscher, Wing et al. (2019) argue that the formation of new cortical memories is facilitated by learning conditions that simultaneously promote the activation of existing cortical representations. Specifically, the authors highlight the following learning conditions:

- **Relatedness to prior knowledge –** learning is improved if new information is encountered in the context of prior knowledge. The new information can be integrated into existing cortical representations and networks.
- **Repeated retrieval (testing effect) –** research suggests that active retrieval/testing (as opposed to restudying) consolidates new material because the process also reactivates related general knowledge and similar episodes such that new memories can be integrated into existing cortical representations. Research suggests that the effectiveness of repeated retrieval relies on prior knowledge also being activated.

The importance of the learning environment and its similarity to the performance environment can be explained by a process called 'ecphory.' Ecphory involves internal or external cues interacting with stored memory traces (engrams) to facilitate retrieval; it is the cue-induced 'reawakening' of an engram (Frankland, Josselyn et al., 2019). Tulving and Thomson (1973) highlighted that the successful retrieval of an engram relies on 'encoding specificity', where there is a high level of overlap in the environmental features and internal (cognitive or affective) states that were present at both encoding (i.e., the learning environment) and retrieval (i.e., the performance environment). From a neurobiological perspective, Frankland, Josselyn et al. (2019) highlight that the 'encoding specificity' principle is evident in patterns of neural activity that overlap (spatially and temporally) at encoding and retrieval. The degree of overlap in neural activity has an impact on retrieval success. The authors highlight that neural ensembles in hippocampal-cortical networks that were active at the time of encoding can be reactivated by retrieval cues.

3.2.3 Boredom/Mind-Wandering

This psychological mechanism is relevant to the following influencing factors:

- Retrieval practice and test-enhanced learning.
- Spacing of learning (indirectly, where shorter periods of learning that occur through spaced learning may reduce boredom/fatigue in comparison with massed learning).
- Learning technology (VR/AR) (indirectly, where these technologies may enhance interest/engagement and reduce boredom/mind-wandering).

Peterson and Wissman (2020) recently hypothesised that the positive effects of test-enhanced learning (vs. restudying information) may be due to a reduction in mind-wandering (i.e., where an individual processes internal information rather than task-relevant information). They argue and find some evidence that mind-wandering has a negative impact on memory retrieval.

The literature on learning and training increasingly recognises the role of emotions in reducing/eliminating boredom and creating engagement and a motivation to learn, leading Graesser (2020) to describe emotions as "the experiential glue of learning environments in the 21st century". Further discussion on the role of emotions as a psychological mechanism can be found in Section 3.2.8.

3.2.4 Distribution of Processing Among Different Channels

This psychological mechanism is relevant to the following influencing factors concerning training:

- Printed materials.
- Video.
- Virtual Reality.
- Design of training media.

The cognitive theory of multimedia learning (Mayer, 2014) states that the human information processing system includes dual channels for visual/pictorial and auditory/verbal processing (i.e., dual-channel assumption). Each channel has a limited capacity for processing (i.e., limited-capacity assumption), and active learning entails carrying out a coordinated set of cognitive processes during learning (i.e., active processing assumption).

Multimedia instructional messages should thus be designed to guide appropriate cognitive processing during learning without overloading the learner's cognitive system. In particular, printed training materials rely entirely on a single channel (visual/pictorial) and, therefore, could rapidly overload cognitive capacity. In contrast, training videos and virtual reality training offer the opportunity to distribute learning material across the visual/pictorial and auditory/verbal channels, potentially reducing cognitive load. Note that this psychological mechanism is likely to only have an indirect (rather than direct) impact on skill retention.

3.2.5 Information Processing Rate

This psychological mechanism is relevant to the following influencing factors concerning training:

- Video.
- Virtual Reality.
- Design of training media.

Cognitive abilities of trainees vary (see Section 2.2.2), and this includes the ability to process and organise information that is presented at a given rate (Schwan and Riempp, 2004). Lack of adaptability in processing different presentation rates may thus lead to shallow processing or even cognitive overload, as shown by different studies on learning from video media (Wetzel, Radtke et al., 1994). Giving trainees control over training videos allows them to adjust the pace of the presentation to their individual cognitive needs, supporting self-regulated information processing (Merkt et al., 2011).

3.2.6 Perception of Fidelity of a Virtual Experience

This psychological mechanism is relevant to the following influencing factors concerning training:

- Virtual Reality.
- Design of training media.
- Hardware display used in computer-based training.

VR can provide familiarity with the associated real-world environment, allowing learners to rehearse specific sequences of actions with a high level of physical and psychological fidelity, and enabling immediate feedback (Feng, Gonzalez, et al., 2018; Rose, Attree, et al., 2000; van Ginkel, Gulikers et al., 2019). This mechanism is likely to be closely related to the process of ecphory (see Section 3.2.2); that is, the high level of overlap between the features present at encoding (the virtual learning experience) and retrieval (the real-world test experience) facilitates the retrieval of memory traces in the test environment.

However, there is a need to understand what determines perception of fidelity of a virtual experience in trainees. The framework introduced in Section 2.4.2 categorises the different aspects of VR fidelity and can help in better understanding fidelity perception.

3.2.7 Embodied Cognition

This psychological mechanism is relevant to the following influencing factors:

- Virtual Reality Training.
- Design of training media.

Theories of embodied cognition (e.g., Mayer, 2014; Shapiro, 2011; Wilson, 2002) propose that bodily cues and physical interactions can positively affect higher level cognitive processing. This perspective posits that there is an intimate connection between our motor and visual processes, and the more explicit the connection, the better the learning. From this standpoint, VR training interventions would have positive effects on learning outcomes to the extent that trainees are able to physically interact with and in the VR environment. Note that this psychological mechanism is likely to only have an indirect (rather than direct) effect on skill retention.

3.2.8 Role of Emotions in Memory Consolidation

This psychological mechanism is relevant to the following influencing factors:

- Test-enhanced learning (indirectly, via the increased stress/anxiety that may occur in a test environment).
- Printed Training Materials.
- Training Videos.
- Virtual Reality Training.
- Engagement in the training experience.
- Design of training media.
- Hardware display used in computer-based training.

A large body of literature in psychology and neuroscience highlights how emotional arousal – especially negative emotions such as fear – can positively affect retention (Sharot et al., 2004; Labar and Cabeza, 2006; McGaugh, 2000; Nielson and Arentsen; 2012; Kensinger, 2009; Finn and Roediger, 2011; Kensinger and

Schacter, 2008; Cahill, Prins et al., 1994, Tyng, Amin, et al., 2017). It has been hypothesised that the arousal-related increase in norepinephrine (a stress hormone) secretion in the amygdala (a brain region important for emotional arousal detection and processing) is responsible for enhanced memory consolidation. There is empirical evidence to support this hypothesis (e.g., Cahill, Prins et al., 1994). However, an important distinction should be made between acute stress experience at the level of training and processes of chronic stress which can, in contrary, impair long-term memory (Tyng, Amin et al., 2017). Under normal circumstances, a stressor activates the Hypothalamic-Pituitary-Adrenal (HPA) axis stress-system to make energy quickly available in order to facilitate a well-adapted, flexible response to a short-term challenge. This stress-system can reset by means of feedback mechanisms (Sapolsky, 1994; McEwen, 2004). Based on recent models of stress and regulation during operational performance (e.g., Van Puyvelde, Neyt et al., 2018), it can be stated that excessive stress or chronic stress, however, puts this system at risk in two ways: firstly, by its duration and secondly because excessive stress evokes an emergency condition in the bodily system. Inefficient and/or insufficient stress coping results in negative stress related with a variety of mental and physical stress-signals due to HPA-dysregulation such as immunity problems (i.e., leukocyte depletion) (Palma-Gudiel et al., 2021; Troubat, Barone et al., 2021), flattened cortisol response curves (exteriorised as a lack of flexible reactivity) (Sapolsky, 1994; McEwen, 2004), decreased cognitive performance (due to hippocampal deterioration) (Sapolsky, 1994), increased depression and anxiety (Saxbe, 2008) and thus deteriorated performance levels (e.g., Angeloni and Demontis, 2020).

An additional role of emotions is highlighted by Bacon, Windall et al. (2012). They discuss the importance of training while evoking an emotional state similar to the emotional state trainees would be confronted with in a real scenario, because of the strong effect of emotions on decision making, problem solving, and learning. Immersive VR has the potential to evoke this state by providing very vivid, first-person experiences and a high level of psychological presence (Bertram, Moskaliuk et al., 2015; Makransky, Lilleholt et al., 2017; Makransky, Terkildsen et al., 2019), which enables the construction of context-dependent knowledge (Mikropoulos and Natsis, 2011).

3.2.9 Need for Cognition

This psychological mechanism is relevant to the following influencing factors:

- Individual differences and, more specifically, cognitive abilities and motivation.
- Task-Content Demands.
- Task-Complexity Integration.

Higher initial abilities have been shown to have an advantage that has been explained by higher accessibility to more effective strategies (Hall, Ford et al., 1983; Farr, 1987) and less time required to acquire an expected minimum level of performance (Arthur, Bennett et al., 1998). An underlying psychological mechanism, however, could be an intrinsic need for cognition (Cacioppo and Petty, 1982 in Day, Espejo et al., 2007). Need For Cognition (NFC) has been defined as “a stable individual difference in people’s tendency to engage in and enjoy effortful cognitive activity” (Cacioppo and Petty, 1982, p. 197). It is a specific motivational aspect that has been shown to provide an advantage in the acquisition of and processing of new and certainly complex tasks. Day, Espejo et al. (2007) showed for instance how need for cognition predicted complex skill acquisition mediated by learning orientation (i.e., the urge to learn or ‘learning for the sake of learning’). However, to the best of our knowledge, we have not encountered research that examined the relationship between the need for cognition and skill retention. This would be an interesting road to explore since the outcome could be two-folded. On the one hand, NFC could benefit skill retention because of the initial advantages in training level. However, on the other hand, in a skill retention retraining program, NFC could be a countermeasure due to the individual need for new information that would not be found during retraining. Hence, there is an argument for the individual tailoring of retraining programs based on, among others, one’s need for cognition (i.e., the addition of new challenges in the retraining program for persons with high NFC).

The NFC may also relate to findings that learning tasks that are meaningful lead to better results than tasks that are inherently meaningless. Tasks that require an understanding will require construction of mental models and the cues in task performance are meaningful within those mental models. As a result, once mastered, meaningful tasks will retain better (Craik and Lockhart, 1972). While NFC is a construct to explain individual differences, all people will apply their level of NFC better when the tasks to learn allow it (i.e., are meaningful).

Chapter 4 – MANAGING SKILL FADE AND COMPETENCE RETENTION: KEY APPROACHES

4.1 GENERAL OVERVIEW

The fourth industrial revolution with technologies such as digital automation, artificial intelligence, and autonomous systems is starting to become a feature of defence capability and provides the opportunity for new and enhanced ways to manage skill fade among military personnel. For example:

- Sophisticated competence management systems that support the capture, recording, and tracking of knowledge, skills, and experiences held by military personnel;
- The use of automation and intelligent systems that reduce demands on operator memory;
- The possibility to monitor physiological stress reactivity; and
- The increased availability of mobile personal devices to support learning and the refreshing of skills and knowledge outside of the traditional classroom environment.

Chapter 4 outlines three general approaches that may be incorporated within an organisation's strategy to enable the effective management of competence retention. In describing these approaches, we have reflected upon the following:

- The breadth of person-, task-, training and education-related factors that may influence skill fade and competence retention (see Annex A);
- Key steps comprising a systems approach to training (i.e., analysis, design, delivery and evaluation); and
- The range of conditions and environments in which learning may take place (e.g., peer-to-peer; within the classroom, or operational / workplace environments).

4.2 REFRESHER TRAINING

Specifying the frequency at which particular types of skills and knowledge need to be refreshed is a traditional approach to managing competence retention. Job-holders are then required to attend refresher training events at set intervals. For example, the British Army requires personnel to undertake Military Annual Training Tests (MATTs) in order that the knowledge, skills, and attitudes developed during initial training are maintained at the required standard.[1] Currently such intervals are standardised for particular types of roles and are not based on concrete evidence, but rather on practical experience, resources (people and financial), and operational-related issues.

A key question arising is how to 'set' an appropriate refresher training interval, i.e., the time that elapses between the acquisition, or re-acquisition of knowledge and skills and refreshment. This is important in ensuring that personnel retain the level of competence needed to perform their job to the required standard, even if they were not able to practice their profession for a certain period. An appropriate trade-off between the interval duration and motivational as well as economic considerations is important. For instance, setting the interval too low may result in individuals receiving refresher training more often than required – leading to the unnecessary expenditure of finite training resources. Whilst recognising that the development of a comprehensive and fully validated approach to defining the refresher training interval does not yet exist, guidance is nonetheless provided by quantitative models of skill decay.

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[1] Examples of MATTs include weapons handling, fitness, battlefield casualty drills, values and standards, and in some cases may be refreshed and tested once or twice a year.

Quantitative models predict the amount of skill decay that will occur in a given time period in the absence of practice. Such models are typically described by a power law function showing the steepest decline in skills at early time points, followed by a more gradual decline at later points (see Stothard and Nicholson, 2001). The power laws of learning and forgetting have provided the basis for a number of skill decay models (e.g., Kim, Ritter et al., 2013; Siu, Best, et al., 2016). However, it should be noted that such research models are typically based on decay curves after a single learning event rather than after re-learning. This means that the research informing such models is of particular relevance to novices but may not fully describe expert performance following re-learning event(s) (Richards and Deighton, 2019). Within the defence context the User Decision Aid (UDA), Trainer's Decision Aid (TDA), and Competence Retention Analysis Technique (CRA-T) are the most relevant measures and models of skill decay. A brief description of each is provided below.

User Decision Aid – developed by the United States Army Research Institute (Rose et al., 1985) as a tool to predict how rapidly skills and knowledge decay over a maximum of 1-year without practice. It consists of a 10-item survey which can be used by trainers to rate a given task with questions including:

1) Are job or memory aids used by the soldier in performing (and in the performance evaluation of) this task?
2) How would you rate the quality of the job or memory aid?
3) Into how many steps has the task been divided?
4) Are the steps required to be performed in a definite sequence?
5) Does each task provide built-in feedback so that you can tell if you are doing each step correctly?
6) Does the task or part of the task have a time limit for its completion?
7) How difficult are the mental processing requirements of this task?
8) How many facts, terms, names, rules or ideas must a soldier memorise in order to do the task?
9) How hard are the facts and terms that must be remembered?
10) What are the motor control demands of the task?

A pre-defined set of weightings, to reflect the relative importance of a given item, are applied to each rating, and aggregated to generate a total score. Total scores are used to generate predicted skill retention curves. It is important to note that these curves plot the percentage of personnel who will retain a skill as a function of time. The following limitations of the UDA have been identified (see Bryant and Angel, 2000):

- Comparisons between predicted and actual retention values indicate that the UDA tends to overestimate skill decay; it is pessimistic in its predictions (Rose, Czarnolewski, et al., 1985).
- The frequency of practice after training is not taken into consideration and there is an assumption that no practice has taken place.
- It does not incorporate an analysis of the level of skills and knowledge acquired at initial training.
- Development and validation were based on a relatively limited range of tasks, and it is more applicable to procedural skills than cognitive, motor, or collective skills.
- It can only be applied to predict skill decay for the 12-month period following training.

Trainer Decision Aid – developed by Cianciolo et al., (2010) is a revision of the UDA and includes questions that assess task practice, the impact of technology, and the fidelity between the training and operational environment. The following questions are included within the TDA:

1) How much do memory aids reduce the memory demands of this task?
2) How many performance steps is the task divided into?
3) Are the steps in the task required to be performed in a definite sequence?
4) How complex are the mental demands of this task?
5) How many facts, terms, names, rules and/or ideas much a Soldier or leader memorise in order to earn a "GO" on this task?
6) How difficult are the facts, terms, rules and/or ideas that must be remembered?
7) How severe is the time pressure under which this task must be performed?
8) How strongly has the Battalion Command emphasised the importance of learning this skill?
9) How closely did the initial training conditions of this skill match its performance conditions under combat conditions?
10) How often has this skill been used?
11) On average, how user-friendly are the information displays that are most important to performing this task?
12) How frequently has the technology involved in performing this task changed?
13) How reliable is the technology involved in performing this task?

The key limitation of the TDA is that the questions and responses are not weighted and, therefore, the relative importance of each factor is not reflected in the score.

Competence Retention Analysis Technique (CRA-T) – This technique presents a significant evolution of the UDA and is also included within the UK MOD Joint Services Publication 822 (Part 2) as an approach to the specification of job-related refresher training intervals. The CRA-T User Guide (Cahillane, et al. 2015) outlines five steps involved in the application of the technique to include:

Step 1 – Job Information – Access or develop a clear understanding of the task and identify the required skills and knowledge. Reference should be made, where possible, to key sources of information that are typically collected as part of a training needs analysis (e.g., job scalars, operational performance statements).

Step 2 – Psychological Domain mapping – Match the sub-tasks to the standard set of five psychological domains that have been constructed as part of the development of the CRA-T (see Table 4-1, column 1).

Step 3 – Assign a retention interval – Consider the frequency of applying the skill/knowledge and assign the corresponding retention level (high, moderate, low) (see Table 4-1, column 3). This indicates the percentage of personnel that will be competent at 12, 5 and 2 months for the high, moderate, and low retention levels, respectively (see Table 4-1, column 4).

Step 4 – Apply moderators – Consider how relevant factors might moderate (i.e., increase or decrease) the retention level selected at step 3. Such moderating factors might include:

i) The frequency of any changes in relevant technology;
ii) The reliability of any relevant technology; and
iii) Individual differences in aptitude and cognitive ability. A criticality analysis should also be performed to assess whether failure is likely to be 'very critical', 'moderately critical', or 'not critical' (defined respectively as a severe, moderate, or no impact on operational capability, personnel, or equipment).

Step 5 – Inform training design and delivery – guidance on how the outputs of the analysis conducted at step 2 might be used to inform, in broad terms, an identification of relevant strategies to enhance the acquisition and/or retention of skills and knowledge. Sixteen examples are described (e.g., assessment-enhanced learning, provision of recognition cues, part-task training, appropriate simulation fidelity, task-oriented training, variable practice training).

Table 4-1: Mapping Generic Psychological Knowledge and Skill Domains to Indicated Retention Levels After Considering the Frequency of Application.

1) Psychological Domain	2) Description	3) Frequency	4) Indicated Retention Level
Continuous Psychomotor skills Explicit Knowledge	The ability to perform (repeated) motor actions that do not have distinct beginnings or endings. For example, flying aircraft, driving, soldering, welding. Explicit knowledge required to conduct a task such as facts, concepts, theories, quality and engineering hygiene measures, safety regulations, knowledge of how to use hand tools and testing equipment.	*Very Frequent	High
		*Moderately Frequent	High
		*Infrequent	High
Discrete psychomotor skills Decision-making skills	The ability to conduct physical tasks with discrete beginnings and endings. These physical tasks have a procedural element (e.g. weapon handling). Application of cognitive processes such as judgement, problem solving, reasoning and analysis in order for an individual to arrive at a decision.	Very Frequent	High
		Moderately Frequent	Moderate
		Infrequent	Moderate
Procedural skills	Ability to remember a sequence of steps and their order so as to execute a task. Application of this type of skill relies on the working memory capacity of an individual, and hence the procedural aspect of the execution of the task is inherently cognitive in nature. Motor or physical elements are minimal.	Very Frequent	Moderate
		Moderately Frequent	Low
		Infrequent	Low

A number of studies have successfully applied the CRA-T to defence tasks involving, e.g., the operation and maintenance of military vehicles, battlefield casualty drills, weapons handling, military annual training tests, and use of communication systems. It is important to note that the UDA is the underpinning model to the CRA-T and that the validity and effectiveness of the CRA-T is critically dependent on the reliability and validity of the UDA. General limitations to the scope, validity, and application of the CRA-T to both current and future defence roles are acknowledged. In particular:

1) The technique does not support an assessment of the retention interval for those types of complex tasks which require the operator to multitask or switch attention, adapt to new situations; or which require complex decisions to be made. It is acknowledged that the need for such skills will only increase in the future military operating environment with the greater use of automation, decision-support systems, human-machine teaming, cyber operations and so forth. It is therefore important that quantitative models are developed to include such skills.

2) Predictions of skill retention using the CRA-T relate to the time point at which 50% of a ‘unit’ would remain competent, and in addition, this estimate is regarded as overly pessimistic. Furthermore, there is a lack of underpinning evidence gathered from experimental research conducted over time, through longitudinal research studies, to substantiate fully the proposed refresher training intervals.

3) Whilst the CRA-T does identify examples of factors moderating the rate of skill fade (see step 4), these are not comprehensively defined and guidance on those factors that present the greatest effect on skills retention is not provided.

4) Finally, whilst examples of strategies to enhance the acquisition and retention of skills and knowledge are provided, the set presented at step 5 does not incorporate some significant developments, e.g., personalisation of learning, adaptive learning and intelligent tutoring systems, augmented and virtual reality systems.

Some research efforts to address the above limitations of the CRA-T have been made.

Firstly, and with reference to limitation 1, as part of a UK Defence funded research activity, Cahillane et al. (2022) undertook a significant revision and expansion of the set of five psychological domains included within the CRA-T User Guide. This work resulted in the development of a *‘Revised Task and Job-Related Knowledge, Skills and Attitudes Taxonomy,’* with key additional elements including:

- Simple and complex decision making.
- Adaptive cognition (i.e., the ability to adapt behaviour to meet the demands of a new situation, set of circumstances or event).
- Attentional control (an essential psychological meta-skill in job roles where two or more coordinated components of a task must be performed concurrently).
- Implicit knowledge (i.e., tacit, unconscious knowledge about ‘doing’ that cannot be articulated).

The research activity confirmed the content of the revised taxonomy as relevant to a sample of military roles involving high-risk operations (e.g., fire fighter, unmanned air system operator, piloted operations); and used the taxonomy to design an experimental trial to collect longitudinal evidence for tasks requiring complex and cognitive skill types. The potential for this revised taxonomy to inform the development of common standards in the design of future skill fade research and data collection is considered at Chapter 6 (see Section 6.4.3). This research activity also involved the development of a consultation plan that could be used to elicit information from subject matter experts about the nature and complexity of military tasks. The consultation plan includes adapted versions of the UDA and TDA questions; crucially, it also includes two new questions that are designed to gather information about the complexity of the military task.

- To what extent is multi-tasking (i.e., task switching) involved in the integration of sub-tasks and any associated elements during task performance?
- In unfamiliar, unpredictable, and dynamically changing conditions, to what extent do informational inputs and behavioural outputs change?

Secondly, and of relevance to limitation 2, there is a developing body of research that seeks to model and predict an individual's refresher training interval. This approach is a departure from the traditional focus of quantitative models on the specification of a refresher training interval for particular jobs or roles.

Thirdly, and with particular reference to limitation 3, the NATO RTG 292, through the medium of this report, provides a contemporary review and qualitative analysis of the breadth of factors influencing competence retention. It is noteworthy that this review considers the influence of individual differences (e.g., motivation, experience) and novel trends in learning (e.g., virtual reality, engagement, and emotional arousal) on competence retention. These influences, in particular, are not incorporated within the models and techniques described above and could inform future approaches to the management of competence retention. The sheer breadth of factors influencing competence acquisition, retention, and management requires some prioritisation – this point is considered further at Chapter 6. So far, this chapter has provided an historical perspective identifying popular, quantitative models that have been used to support an identification of the refresher training interval for military roles. Whilst the focus on defining a standard refresher training interval for specific jobs or roles still exists, there is a growing recognition of the benefits afforded by additional approaches. In the remainder of this chapter consideration is given to two such approaches: personalisation of learning and experiential learning through virtual experiences.

4.3 PERSONALISATION OF LEARNING

Managing the retention of skills and knowledge by manipulating the refresher training interval is a strategy that is typically applied at the job level. The optimal situation is that retention at the individual level is continuously measured over time, and that personalised refresher training, job aids or specific tasks are offered to someone just in time. Advanced technology, including data management (c.f. learning analytics) and performance support tools are needed to achieve this goal ultimately.

In a review of the literature Deighton and Mundy (2019) define personalisation of learning as the "orchestration of a customised learning experience that is tailored for and/or adapted to the requirements of the individual learner, in order to optimise learning outcomes in line with the organisational goal(s)" (Deighton and Mundy, 2019, p.4). Placing the learner at the centre of learning is regarded as key, enabling the learner to set the pace and place of their own learning, once again emphasising the importance of individual characteristics in both the acquisition and retention of skills, knowledge and more broadly competence over time.

Personalisation of learning is a holistic strategy (rather than a specific training method or media type) which may be implemented to support initial, maintenance, booster or refresher training (Sullivan, 2019); and should be conducted throughout an individual's career. Advances in learning technology (e.g., Adaptive Learning Systems[2], Intelligent Tutoring Systems[3]), increased connectivity, and data analytics are important enablers to the adoption of PL as part of an organisation learning and development strategy (Boyce, DeFalco et al., 2018).

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[2] Learning technologies which monitor students' progress, using data to modify instruction at any time.

[3] Adaptive, personalised instructional systems designed to mimic one-on-one tutoring.

Taken together this capability has the potential to:

- Enable the design and delivery of refresher learning to meet the specific needs of the individual. For example, tailoring learning content taking into account the individual's prior experience, strengths and particular areas for refreshment and development.
- Allow the individual to learn at their own pace, thus controlling the 'spacing' of their own learning.
- Allow learning content to be adjusted according to the individual's progression.
- Enable learning to take place within 'non-traditional' teaching environments (e.g., within the workplace environment) and at intervals that are relevant to the individual learner's needs.

At the time of writing this NATO technical report, research is being conducted by the UK Ministry of Defence to investigate personalisation of learning using an Adaptive Learning Platform with the potential to inform an individual's refresher training requirements based on an individual's initial performance (Richins, Caldeira-Hankey et al., 2021).

4.4 VIRTUAL TRAINING EXPERIENCES

As we have seen in Section 2, the adoption of Virtual Reality (VR) technology in training can lead to better learning and retention than less realistic and less interactive media. Resort to VR experiences in training is also motivated by different pedagogical theories, as discussed in Chittaro and Ranon (2007). First, it is supported by constructivist theories of learning. Constructivist pedagogy highlights that individuals learn through a direct experience of the world, through a process of knowledge construction that takes place when they are intellectually engaged in personally meaningful tasks. Following this theory, interaction with the world is essential to the learning process. The possibility of providing highly interactive, realistic experiences is thus one of the best-valued features of VR. Second, since VR allows to recreate life-like experiences that link experience to theory, it supports the situated learning approach, which suggests that it is more effective for trainees to learn concepts in the same context where these will be applied. Third, research in human learning processes demonstrates that individuals acquire more information if more senses are involved in the acquisition (multimodal learning). In VR, one can support this human capability by providing multisensory stimuli (visual, auditory, and haptic).

In addition, VR allows trainees to learn in a safe environment while being at the same time immersed in reproductions of very dangerous situations. This is of particular importance to tasks that involve relevant safety risks in the real world, such as those of interest in domains ranging from disaster preparedness to military operations. Safety needs often force trainers to reduce the realism of real-world drills to limit risks to trainees, and some scenarios can be impossible to reproduce in a real-world drill for reasons of safety as well as cost. In such contexts, virtual experiences can both increase realism, reduce the cost of drills, and allow to increase their frequency. However, adopters of digital training solutions should be careful not to make the oversimplification of reasoning only at an abstract level in terms of type of technology, e.g., "Is it better to adopt VR or traditional e-learning?" as if one type of technology should be superior per se to another one. This oversimplification disregards the fact that for each technology there are several different hardware and software options, with different levels of accuracy, precision, convenience, usability, and engagement. In addition, the design of the training experience can significantly affect the outcomes of the training. Adopters of digital training are often unaware that, due to the virtual nature of the experience, software developers can flexibly create a wide spectrum of possible trainee experiences, and the design space one can choose from is thus very large. For example, considering the possible ways a user can interact with a VR environment, Jerald (2016) described how a designer can choose among 15 different interaction techniques to support virtual object selection, 7 to manipulate the selected objects, 17 to move one's viewpoint in the environment, and 9 to use menus. Since the classification is not exhaustive, this means that the design space for the interaction aspect and for VR technology is made of at least 16,065 possibilities.

Knowledge of this aspect helps to empower training organisations in adopting virtual experiences of appropriate quality. First, since not every possible design of a digital training experience has been evaluated in the literature due to the size of the design space, they can search available studies for evidence that the specific design they want to adopt is suitable for their specific context and task, in order to take informed choices. Second, if the specific design they are considering has never been evaluated, they can decide if they want to switch to a different design for which evidence is available or if they want instead to carry out a pilot study of the new design. Third, if there are available studies of the specific design they are considering that do not support adoption for the specific task and context, they can use the limitations identified by those studies to inform the choice of a better alternative in the design space. It is also worth noting that the research communities in digital media are distilling guidelines to help in the design of effective experiences, e.g., Jerald (2016) has collected a 50-pages set of guidelines that can help designers in creating an effective VR experience.

The different types of fidelity introduced in Section 2.4.2 can all affect the outcomes of training. Lack of sufficient fidelity also poses the risk of negative training, which is the acquisition of skills that are successful in the virtual experience but do not produce the desired result in the real-world context for which the training was meant. However, it should not be assumed that it is necessary to achieve the maximum possible level of fidelity to produce the best retention, and adopters can focus on the right level of fidelity that suits their needed outcomes. Given a task, the question is thus what are the minimum (to avoid negative training) and the optimal level of fidelity that produce satisfactory retention in trainees. Gaining such insights allows to design and deploy a training that produces the greatest outcome-to-cost ratio. For example, Buttussi and Chittaro (2018) showed that three different levels of display fidelity produced the same level of knowledge retention about an emergency procedure at 2 weeks.

Chapter 5 – DISCUSSION

5.1 GENERAL OVERVIEW

This chapter opens with an overview of the status of competence retention research along with the key insights based on the results of the current report and literature analysis activities. Next, we will describe the key challenges related to research on the topic of competence retention. Finally, future areas of research on competence retention are proposed.

5.2 COMPETENCE RETENTION RESEARCH

5.2.1 Status and Insights

Firstly, the literature showed that competence retention and its management is complex and influenced by a plethora of factors associated with the person, the tasks to be performed, and the training and education that had been provided during the learning phase. Consequently, the findings over studies often show a variated and inconsistent pattern probably due to large inter-individual variances that can occur in different stages of a retention course. Therefore, future competence retention research should take inter-individual differences and their underlying mechanisms into account in order to explain more specific pathways of retention processes.

Secondly, there is a lack of studies focusing on competence retention of complex tasks and how the variety of potential influencing factors may impact this process. Up to now, the current body of research evidence has centred on the retention of simple skills and knowledge items requiring a short period of training. The retention processes over time of each of these elementary competencies, when not practiced, and the extent that specific factors such as the type of task, quality and quantity of training, and individual differences may influence these processes are relatively well-known and described in the literature. However, an in-depth investigation of complex tasks, taking into account individual learning and/or retention pathways remains under investigated.

More specifically, research evidence on retention relating to the interaction between individual differences, task characteristics and the effective use of learning technology is required to fully understand the complexity of the underlying mechanisms of retention. Therefore, in the current discussion, we proposed some examples of potential mechanisms that may explain why certain factors may or may not moderate competence retention and that may thus be interesting to investigate in future research.

Thirdly, our review has highlighted the potential value of deepening the research debate to include a consideration of certain neurobiological and psychophysiological mechanisms that may explain the influence of particular factors on competence retention (see Chapter 3). Whilst the consideration of this topic was provisional, it nonetheless highlighted a different perspective or framework for the grouping of the breadth of factors influencing competence retention. This viewpoint may be useful to organisations concerned with the fundamental science of competence retention. They might use insights from this report to predict the potential benefits of emerging or as yet undiscovered technology or non-technology based solutions in the measurement and management of competence retention.

A fourth and final insight arising from the RTG activity has been the need to build and extend the international military community involved in research on competence retention. The greater attraction of organisations and individuals can offer novel perspectives which draw upon the latest thinking in learning analytics and neuroscience.

5.2.2 Perspective on Competence Retention

Perspectives on retention or decay and definitions have often been developed in relation to the context that is being investigated (e.g., laboratory vs field). When scientifically studied in a laboratory situation, this research may only relate to the decay of newly learned knowledge or skills specifically for the experiment without intermediate practice (in order to examine the effects and nature of decay) and without the influence of the particular field context. When studied or applied in a practical (military) training context, it is more relevant to consider the decay of full competence below a pre-defined minimum level of proficiency by the training organisation with or without relevant intermediate experiences (in order to determine the level of currency or combat readiness). Therefore, for military operational goals, a purely research-oriented conceptualisation of retention might work in a reductive manner. For the same reasons, we approached the literature from a wider perspective of competence, that is, competence retention instead of skill fade or skill decay. In the future, the development of more generic competences is considered as increasingly important to be able to deal with future situations and tasks that will change more often. Such a competence-based perspective on retention will be more future proof for learning in the next decades.

Visions on future learning take a more individual-centred perspective, in which training is provided in a more personalised, self-responsible, and highly informed way. This also fits in with the future expectation that employees will have to learn more new tasks from a lifelong learning perspective. It also matches with the transition of various military organisations (e.g., The Netherlands, UK) into more flexible career structures in which, for instance, individuals are increasingly moving between Regular, Reservist, and Civilian roles within Defence. In this individual-centred, flexible learning approach, retention should not be considered as the maintenance of competence in relation to a pre-defined standard or to the exit level of initial training. Instead, military career pathways may become much more flexible and individually tailored with jobs changing more frequently over time and personnel transferring between jobs more frequently. Therefore, competence and skill transfer will become more frequent and fixed standard tracks less relevant.

Consequently, a retention baseline in studies should relate to the person's individual baseline which may obviously differ between professionals. This baseline may refer to the original level of competence after initial training or to a modified level of competence as a result of, for instance, further development of employees and/or changes within the job over time. Moreover, specific individual traits such as motivation, need for cognition, self-efficacy, emotion, and stress regulation may be of influence as well, certainly on the initial training level. In all cases the pre-defined standard of proficiency as specified by a professional organisation or legislative authorities will need to be met.

Moreover, since a military track over the years may become more variable in the future, the necessity to focus on complex, operational tasks in retention research, requiring (generic) competences will only increase. It is here, however, that the current lack of knowledge about retention of complex skills enters the scene.

5.3 KEY CHALLENGES IN CONDUCTING COMPETENCE RETENTION RESEARCH

Retention research differs considerably in the approach used: lab vs field, realistic vs generic, short-termed vs longitudinal measures. Reported studies consequently are not easy to compare in the highly needed meta-analyses. This is made even worse by the way in which characteristics of the training, type of measures, and tests are reported. For example, tasks, competencies, measures, training criteria, training design, participant information are often described in a limited and inconsistent way. In this section, we will highlight some key challenges for researchers to consider in setting up future competence retention research studies.

5.3.1 Laboratory versus Field Research

Classical research on retention involves longitudinal data collection with certain intervals of no practice in order to collect evidence on the retained level of competence during these intervals. A key question that is often overlooked in this type of retention research is the effect of the test environment and how valid the retention measurements are in that test environment compared to the operational setting (ecological validity). Ideally, the measurement should be taken in practical, real-world contexts, but this type of research is far from popular for several reasons. Field research is hard to organise because one has to adapt to reality, it is time-consuming and therefore expensive in terms of personnel, and it adds an additional workload on the participants. Therefore, applied field research in a military or related context remains scarce whereas it is hardly needed. Moreover, there is unfortunately also a tendency for such studies to not be published since small research populations with drop-outs are not favoured.

The fact that the realism of the testing environment is typically poorer than the actual field context threatens the fidelity and with that the applicability of the results (see also Section 2.4.2). As an example, Patil, Cogoni et al. (2014) contrasted low fidelity, paper-based representations of life-threatening situations vs. higher fidelity, VR presentations of the same situations, showing effects of the test environment on participant's responses and decision making. In particular, participants in the paper-based testing were less emotionally aroused and acted in a less utilitarian way (less outcome-based in terms of lives saved), while participants in the VR testing were more emotionally aroused and acted in a more utilitarian manner. While in Section 2.4.2 we defined fidelity for learning environments, the same multidimensional definition can be used for testing environments for the investigation of competence retention. The decision about the level of fidelity of the research environment in each of the dimensions will depend on the desired output without losing track of measurement load (e.g., physiological measures, eye-tracking, video-recording), possibilities to use certain lab or field set-ups (e.g., available space, location, time), number of participants, goal of the study (e.g., studying micro-mechanisms vs macro-processes).

Both field and laboratory measurements have certain advantages and disadvantages. Field studies (e.g., field exercises of military units, operational pilots), as mentioned above, often offer less standardised conditions than a laboratory environment and may interfere with standard training procedures. In case of dangerous skill trainings, a field study approach may even not be feasible. On the contrary, lab studies are popular for their highly standardised conditions, but they may be jeopardised by ecological validity issues. That is, the environment used in the lab often does not or cannot represent the task completely (e.g., security reasons, knowledge of the operation, time constraints, team size constraints) or its full context (e.g., simulator constraints, limitations of opponent behaviour).

A related issue is that retention research is domain- and task-dependent. Longitudinal data collection in the real-life context should be used to collect concrete and practically applicable evidence for domain-specific mitigation strategies in retention management. For instance, determining the exact frequency and content of refresher training or the particular benefits afforded by virtual reality systems to support situation awareness training among aircrew. Laboratory studies are necessary to increase knowledge in fundamental research (e.g., underlying psychological mechanisms, ways to manage skill fade) in highly standardised and controlled conditions and to determine the influence of particular factors. Evidence from the latter studies supports the development of general principles relating to which types of tasks require a more or less frequent refresher training interval. Where exact evidence of the refresher training interval is required then job-specific research is inevitable. The right balance should be found between domain-specific (field) and generic (lab) research concerning retention. In finding this balance it is acknowledged that resources and operational pressures may preclude the gathering of data within the real-life context to confirm the validity and specificity of more generic research evidence. Accordingly, a process to support risk-based decision making, which is informed by the evidence presented within this report, is required.

It is recognised that test environments in retention studies seldom match the real-life physical and psychological context in which participants are expected to demonstrate their competence. Ways to recreate the types of realisms that are encountered within the real world environment need to be identified and investigated to determine their effectiveness. As an example, Rovira, Swapp et al. (2009) reviewed experimental methods used in lab studies of responses to violence and aggression situations, a research domain that has been criticised for a lack of ecological validity. They concluded that the recent introduction of immersive VR into these studies is promising, because there is evidence that people tend to respond realistically to virtual simulations of real-life events.

5.3.2 Measuring Military Proficiency

Military proficiency studies require valid performance measures with multiple measurements over time that can occur in a laboratory or field context. To obtain these measures, on the one hand, data should contain enough construct validity and test-retest reliability. On the other hand, as discussed above, the study context should approach operational reality as much as possible. Moreover, the difficulty level of the operation should be taken into account when evaluating the performance. The latter may be related to the context as well. For instance, some military jobs may be performed operationally during peace time (e.g., border patrol, transport, Quick Reaction Alert). However, other military tasks require an actual conflict or war situation before operational skills can be performed for real. Field measurement therefore includes the training as provided, either using live training systems (aircraft, tanks, guns, etc.) in a live training range, or virtual systems in a virtual world, and, in the future, combinations of virtual and live elements in training can be expected more often. Each of these performance contexts has its advantages and disadvantages. The simulated world is obviously lacking in providing all physical cues in a realistic way, for example, environmental conditions (50 degrees Celsius in a helicopter cockpit?) or forces (9g turns in a fighter aircraft?). Although simulation has the potential to generate a tactically rich and realistic scenario that is perfectly developed to challenge or test specific competences, most simulation does not yet provide this level of fidelity. Field exercises often cannot provide for the conditions that would be desired for the training objectives at hand, for example, weather, level of threat, the environment of the anticipated enemy. Laboratory studies lack the challenges of the operational reality. Proficiency monitoring in either simulated or real environments will have certain fidelity issues and it may be recommendable to not rely on either simulation or live training only, but on a well-designed balance between both.

5.3.3 The Treatment of Individual Differences

The literature showed that while individual differences have been researched a lot with regards to learning in general, they remain often understudied in the retention literature. As mentioned above, this is a common phenomenon in several research domains. Individual differences are often reported as unexplained variability whereas they may be the window into more complex underlying mechanisms (Van Puyvelde, Neyt et al., 2018). Hence, in retention studies, by treating the individual differences as a signal instead of noise, they may increase the insight as to why certain skills may be more difficult to retain than others. For instance, there are some indications that the general underlying cognitive ability of an individual may comprise an important predictive value in retention processes independent of the task or knowledge that has to be retained (Arthur, Bennett et al., 1998; Hall, Ford et al., 1983; Vineberg, 1975; Wilson, Wolf et al., 2010). This has been shown in a study on the relationship between individuals' level of literacy and their capability to retain health information in a folder (Wilson, Wolf et al., 2010). Wilson, Wolf et al. (2010) showed that it was the basic cognitive ability that was predictive for retention rather than literacy. This means that – in the specific occasion of Wilson, Wolf et al. (2010) – it was better to train persons with low literacy in their general cognitive ability than in specific reading tasks. Hence, to better understand retention processes, it is of extreme importance to better understand the underlying explanatory mechanism irrespective of the task or knowledge to retain.

Another aspect in which information on individual differences may be important is in the decision of which learning strategies or technologies one would want to apply. For instance, although there is a mounting access to new learning technologies and an increased notion of learning ecosystems that have shown to provide the individual learner with the opportunity to both acquire and refresh their knowledge and skills, the motivation to use these systems is at least as important as its efficacy. The literature, however, showed that this motivation can be dependent on a variety of factors. Intrinsic motivation may be more stable than extrinsic motivation. That is, from the moment the extrinsic pressure to learn something is not present anymore, the motivation to maintain certain skills may disappear as well. On the other hand, intrinsic motivation may change due to over-training (Schendel and Hagman, 1982), the demanded effort that was too high (Hesketh, 1997), or also the freedom of choice one has to use a certain training technology (Granito and Chernobilsky, 2012). This means that a training program has to be well-balanced in terms of training load, challenge and number of re-trainings.

When studying the potential impact of individual differences during training and retention processes, it may be important to study their impact in each component, i.e., the initial learning part, the training part, and the retention part. For instance, individual differences in the learning stage may still be more controllable and observable whereas after a period of non-use they may become part of a black-box process in which they start to interact with multiple other ongoing processes. Moreover, whereas some authors claimed that the initial learning capacities may be predictive of further retention capacities (e.g., Hall et al., 1983), other authors (e.g., Vineberg, 1975) suggested that the advantage of better initial learning does not take place at the moment of retention as such (i.e., the retention curves are identical in every individual), but that better initial learning creates better starting conditions. Hence, it is important to include each initial performance level in order to be able to calculate individual difference scores.

Finally, we propose that individual differences may be important in the design of training and retention programs. For instance, a few studies reported a false sense of self-efficacy in certain individuals, leading to a dramatic skill fade over time (e.g., Glendon, McKenna et al., 1988; McKenna and Glendon, 1985; Ramirez, Weaver, et al., 1977). Obviously, this is of extreme importance within a military setting where fatigue and high performance are often demanded at the very same moment, a combination that is known to lead to over confidence, being the cause of human errors (Wang, Day et al., 2013).

5.3.4 Common Standard and Knowledge, Skills, and Attitudes (KSA) Taxonomy

There are various issues that tended to hinder the consolidation of findings across studies and the exploitation of evidence to provide practitioners with guidance on competence retention. Our review of literature in particular highlighted that studies differed considerably in the following areas:

- The reporting of the tasks under investigation;
- How initial training was designed and implemented;
- How the study was controlled for potential influencing factors;
- The data and measurement approach; and
- The way terminology was used, particularly with regard to the expression of knowledge, skills and attitudes or behavioural types.

From a scientific point of view, this has impacted considerably the ability of Defence researchers to reuse evidence to validate or strengthen existing predictive models of competence retention (Richards and Deighton, 2019). Given this situation there is a need to define a minimum ‘common’ standard with regard to the reporting of field and laboratory studies concerning skill fade or competence retention. Important features of the suggested ‘standard’ might include:

- To use a common language, or taxonomy as a basis for describing the tasks and Knowledge, Skills and Attitude types under investigation by the research;

- To report a minimum set of influencing factors;
- To report features that are inherent within high fidelity or live environments that may have a particular influence on competence retention (e.g., presence or absence of feedback and memory aids);
- To report the initial training provided (e.g., learning effects, end-criteria, spacing, amount of overlearning); and
- To strive for a generalisability framework; the extent to which skill fade evidence that has been gathered from one safety critical group (e.g., medicine) may translate to other occupational groups (e.g., military pilots).

It is recognised that the development of such a standard requires collaboration across national and international communities along with clear guidance.

Chapter 6 – FUTURE CONSIDERATIONS

6.1 GENERAL OVERVIEW

Although a large number of studies have already been conducted to understand skill and competence retention, a science-based, but yet pragmatic approach is yet needed in retention management. A better understanding should be achieved in how developments in learning technologies and approaches to learning might impact retention. Due to the methodological challenges, some topics are over-investigated, such as retention of procedural tasks which is relatively easy to investigate, whereas others are under-investigated, such as real-life tasks requiring the application of complex cognitive skills. The latter type of research is necessary to progress our understanding of skill fade and competence retention in military and other domains. This section summarises some important topics for further research.

6.1.1 Balancing Laboratory and Field Studies

Section 5.2.1 pinpointed the difficulty of measuring retention in a (operationally) valid way in the lab as well as in the field. Although fundamental laboratory research remains equally important, in our vision for the future, improved and standardised field research has high priority. These field studies on competence retention, which are scarce, are important to enable the collection of task- and domain-specific evidence relating to how often particular types of skills should be refreshed. Moreover, they will give insights into the benefits of new and novel ways to manage competence retention.

A traditional barrier in conducting field studies has been obtaining the agreement from the operational training establishments to collect what might be regarded as ‘additional data and information’. Advances in data technology (i.e., learning analytics) provides a significant opportunity for militaries to gather basic performance measures as an integral part of daily training (practice) and over time. The availability of large data sets affords a significant opportunity for both the operational organisations and science and technology establishments to expedite understanding in the area of competence retention and management. If successfully harnessed and made available to the research community, then the requirement to set up and gain approvals for longitudinal field trials involving military personnel over time is reduced. It is acknowledged that the need to define the most critical and relevant types of human performance measures and metrics to be collected remains and that this is a priority activity.

A growth in opportunities to gather field data does not negate the need for ‘laboratory’ based research. Rather, the conduct of research within low-mid fidelity research environments should be regarded as an integral part of an applied programme of competence retention and management research. In some circumstances the operational retention findings may still reveal unclear findings which would trigger the requirement for specific and well-controlled experiments within low or mid fidelity context. More generally within the laboratory environment: a) additional and more in-depth measures may be collected by specialist researchers; b) levels and combinations of variables can be examined to reveal interaction effects (e.g., between learning and motivational factors); and c) smaller groups of military or non-military personnel can be included within participant samples to study unclear retention mechanisms or effects.

In addition to the above, the laboratory environment also provides a critical opportunity to rapidly test and evaluate the potential benefits to retention that may be afforded by novel and emerging learning approaches such as adaptive learning, intelligent tutoring systems, and serious games.

With the above approach, a planned and iterative approach to the conduct of competence retention and management research emerges involving a blend of field and laboratory studies. To put this in place requires a strong and collaborative ‘single team’ approach between the military training schools and science and technology research communities. In order to allow for scientific progress, it is critical that discoveries and learning from both field and laboratory studies are released to scientific journals in some form (after taking into account security and privacy measures). This includes analysis of the massive performance databases that will become integral to future training systems. In particular (more detailed) insight in retention influencing factors and underlying mechanisms should be shared with the international science community.

6.1.2 Common Standard and KSA Taxonomy

In Section 5.2.4, inconsistencies in the way in which Knowledge, Skills, Attitudes and Behaviours are reported within competence retention research was highlighted. Several different taxonomies of KSA exist, which are described at varying levels of granularity depending on their use – to inform job descriptions, training needs analysis, psychometric testing to support selection processes etc. From our perspective, the question arises relating to which taxonomy is most appropriate:

a) To the description and reporting of an operational task (executed in the field); and

b) In the design of experimental research studies to investigate differences in the rate of decay between particular types and combinations of KSA. Can one taxonomy serve both purposes? Further considerations relate to the content validity of the taxonomy in relation to 'future types of skills' – suggesting the need to include skills such as adaptability and complex decision making.

The above questions are currently being considered as part of UK MOD defence research (Cahillane, Anderson et al., 2022), which has revised an existing KSA taxonomy (Cahillane et al., 2013) to:

1) Better represent the cognitive domain; and
2) Demonstrated the application of the taxonomy to a sample of Defence roles; and
3) Successfully applied the taxonomy in the experimental design of a 12-month longitudinal experimental trial involving a mission planning task.

The further test and evaluation of the KSA taxonomy to confirm its scope and usefulness as a common approach is strongly recommended.

6.1.3 Operational Tasks, Interactions and Individual Differences

The complexity of all influencing factors and interactions involved in the process of retention, as well as the complex underlying psychological mechanisms, makes it challenging to come to concrete recommendations for practical use. To understand task influences on retention of complex, operational tasks, a multifaceted approach is needed to derive evidence-based guidelines for training design. This requires:

- Data collection over time based on performance measures obtained at various retention intervals after initial training with individual baseline measures;
- Analysis of the task such that its required competencies are decomposed in its constituent components (of more elementary knowledge and skills); and
- More elaborate experimental designs (2 x 2 and more) to find interaction effects.

The primary solution for this knowledge gap would be to collect basic retention data in all training events for all forces at all times. Field studies in larger training organisations with many measurements can be most useful to find interaction effects. In general, studies should aim at measuring more (personal) data from many participants for a longer period of time. When field data reveals interesting but inconclusive findings or when there is a need to identify underlying mechanisms, a more rigorous experiment using the elaborate design mentioned above may be required.

Performance scores (not necessarily assessments) should be more differentiating than the more familiar, but small ordinal scale ranging from insufficient to excellent. This may also include differences in initial training over cohorts of trainees as well as differences in practice and experience after training. Aspects often considered as confounding factors by researchers and consequently avoided may need to be addressed explicitly in the research set up.

Defining and developing reliable and valid measures for performing retention research over time is challenging, especially in live training and at the workplace. Usually, performance measures are collected but these may not always be representative of competence if external factors that affect performance play a role. Learning analytics (collection, analysis, and presentation of data on learning) is an increasing field of research that pays attention to these type of measurement issues. More research in the use of learning analytics in the context of retention is needed to get more grip on these kinds of measurement issues.

6.1.4 Retention Models

Early models of retention (i.e., generating retention intervals in weeks or months for certain skills) were based on expert opinion and apply to large groups of professionals (e.g., User Decision Aid checklists). These models may serve as rough advice but are not based on predicted retention for smaller groups or individuals. Initial modelling of performance-based retention models (e.g., measured in simulator tests of former pilots under well-controlled conditions) have demonstrated predictive power.

Retention in practice, however, is less well-controlled and subject to much more variation, ‘confounding factors’ (such as experience in similar types of tasks) and ‘noise’, such as fatigue, distractions, and test conditions. The question here is whether it would be worthwhile to focus our efforts on developing predictive models of skills management and retention, or whether we can state upfront that this will become too big a task. This question has a number of aspects:

- Reflect on the breadth of influencing factors/moderators that have been identified by our work.
- The need to set a ‘boundary’ in terms of the scope of a model and use of the model. This boundary may depend on the options for an organisation to overhaul its refresher training and scheduling approach. The more data that can be gathered (without consuming time from trainees or supervisors) the more specific a model can be developed and applied.
- Automatically gathered and processed data may increasingly rely on non-transparent methods and (neural network) techniques. However, this could have implications in a safety critical environment.
- There might be alternatives to a ‘model’ that we might suggest.

Chapter 7 – CONCLUSIONS

Skill fade and competence retention are crucial issues for the safe and effective execution of tasks in the military and other work domains. They are complex topics that have been researched considerably in the last two decades, with a progressive shift from a narrower focus on skill fade to a broader perspective on competence retention. However, despite these efforts, the number of factors involved, and their combinations are considerable, and each study can focus only on a few aspects. Against this background, this technical report took a step forward by collecting, categorising, and describing the known influencing factors in a consistent framework that comprises three categories and 38 factors. Moreover, to provide a firmer ground to the factors, the report identified and described nine psychological mechanisms that are important for competence retention. Finally, practical aspects of managing skill fade and competence retention were considered, identifying and describing three broad approaches.

Given the current body of knowledge on these topics, four general considerations can be made. First, the complexity and the many facets of skill fade and competence retention have been only partially tackled by research and in the literature and continued international collaboration would be important to drive the field forward. We have realised this as part of our RTG, both when we drew together international thinking and when we extended the current perspective by including expertise from our different countries on aspects such as individual differences and novel, technology-enhanced learning approaches.

Second, future research needs to focus on understanding the impact of evolving operational environments as well as emerging learning technologies on skill fade and competence retention. Since the breadth of the research area can pose a significant challenge that may detract research investment, the importance of collaboration across organisations is further underlined: although the level of individual funding may be limited, a coordinated effort among several groups is going to make a difference. More specifically, although we have covered quite a large area of influencing factors from different viewpoints, we also noticed that research evidence is often partial or scarce, especially when it comes to complex skills. A major reason for this lies in the fact that such research is complex, costly, and time-consuming to carry out, because of methodological difficulties such as longitudinal data collection and the fidelity of the experimental setting. For this reason, in addition to focusing on collecting evidence in practical contexts, it would be appropriate to undertake deeper investigations of the psychological mechanisms underlying competence retention.

Third, the design of more effective training experiences that promote competence retention is another crucial area for both researchers and practitioners. With the continuous increase in the number of available technologies, some of which have been discussed in this report, the design space of training experiences becomes wider and wider. This calls for research on the effects of incorporating new hardware devices into the training experience, but also on the different opportunities at the software level, e.g., exploiting learning analytics, creating engagement and motivation through emotion-inducing techniques and gamification, personalising the experience based on monitoring and measuring individual’s performance and competence over time, possibly including physiological measurements.

Fourth, a central theme that kept coming up in our RTG discussions is the need to translate existing research evidence into practical guidance for a range of communities, including individual practitioners, training managers, and regulators, with caveats where needed. We believe this report makes a step forward in that direction, and hope that members of the different communities will find in it valuable information that could help them to better focus and develop their retention activities and encourage them to become more involved in the advancement of the field.

Chapter 8 – REFERENCES

Ackerman, P.L., Beier, M.E., and Boyle, M.O. (2005). Working memory and intelligence: The same or different constructs? Psychological Bulletin, 131(1): 30-60. doi: 10.1037/0033-2909.131.1.30.

Adams, B.D., Webb, R.D.G., Angel, H.A., and Bryant, D.J. (2003). Development of theories of collective and cognitive skill retention, DRDC-TORONTO-CR-2003-078.

Ali, J., Howard, M., and Williams J.L. (2003). Do factors other than trauma volume affect attrition of ATLS-acquired skills? The Journal of Trauma, 54(5), 835-841.

Anderson, G.S., Gaetz, M., and Masse, J. (2011). First aid skill retention of first responders within the workplace. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine, 19(1), 1-6.

Anderson, J.M., and Warren, J.B. (2011). Using simulation to enhance the acquisition and retention of clinical skills in neonatology. Seminars in Perinatology, 35(2), 59-67. doi: 10.1053/j.semperi.2011.01.004.

Anderson, J.R. (1982). Acquisition of cognitive skill. Psychological Review, 89(4), 369-406. doi: 10.1037/0033-295X.89.4.369.

Anderson, J.R. (1995). Cognitive Psychology and Its Implications (4th Ed.). New York: W.H. Freeman and Company, New York.

Andreatta, P.B., Dooley-Hash, S.L., Klotz, J.J., Hauptman, J.G., Biddinger, B., and House, J.B. (2016). Retention curves for pediatric and neonatal intubation skills after simulation-based training. Pediatric Emergency Care, 32(2), 71-76.s.

Angeloni, D., and Demontis, G.C. (2020). Endocrine adaptations across physical and psychological stressors in long-term space flights. Current Opinion in Endocrine and Metabolic Research, 11, 21-26. doi: 10.1016/j.coemr.2019.12.005.

Annett, J. (1977). Skill loss: A review of the literature and recommendations for research. University of Warwick.

Annett, M. (1981). The genetics of handedness. Trends in Neurosciences, 4, 256-258. doi: 10.1016/0166-2236(81)90080-1.

Anton, N.E., Mizota, T., Whiteside, J.A., Myers, E.M., Bean, E.A., and Stefanidis, D. (2019). Mental skills training limits the decay in operative technical skill under stressful conditions: Results of a multisite, randomized controlled study. Surgery, 165(6), 1059-1064. doi: 10.1016/j.surg.2019.01.011.

Arthur, W., Bennett, W., Day, E.A., and McNelly, T.L. (2002). Skill decay: A comparative assessment of training protocols and Individual differences in the loss and reacquisition of complex skills. Air Force Research Lab Mesa AZ Human Effectiveness Directorate.

Arthur, W., Bennett, W., Stanush, P.L., and McNelly, T.L. (1998). Factors that influence skill decay and retention: A quantitative review and analysis. Human Performance, 11(1), 57-101. doi: 10.1207/s15327043hup1101_3.

Arthur, W., and Day, E.A. (2013). A look from "aFarr" (1987): The past, present, and future of applied skill decay research. In W. Arthur, E.A. Day, W. Bennett, and A.M. Portrey (Eds.), Individual and Team Skill Decay: The Science and Implications for Practice (pp. 405-427). Routledge/Taylor & Francis Group. doi: 10.4324/9780203576076.

Arthur, W., Day, E.A., Bennett, W., and Portrey, A.M (2013). Individual and team skill decay: The science and implications for practice. Routledge/Taylor & Francis Group. doi: 10.4324/97802 03576076.

Bacon, L., Windall, G., and MacKinnon, L. (2012). The development of a rich multimedia training environment for crisis management: Using emotional affect to enhance learning. Research in Learning Technology, 19(1), 67-78. doi: 10.3402/rlt.v19i3.7780.

Baker, M.A., Robinson, J.S., and Kolb, D.A. (2012). Aligning Kolb's experiential learning theory with a comprehensive agricultural education model. Journal of Agricultural Education, 53(4), 1-16.

Baldwin, T.T., and Ford, J.K. (1988). Transfer of training: A review and directions for future research. Personnel Psychology, 41(1), 63-105. doi: 10.1111/j.1744-6570.1988.tb00632.x.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioural change. Psychological Review, 84(2).

Barrick, M.R., and Mount, M.K. (1991). The big five personality dimensions and job performance: A meta-analysis. Personnel Psychology, 44(1), 1-26. doi: 10.1111/j.1744-6570.1991.tb00688.x.

Barrick, M.R., Mount, M.K., and Judge, T.A. (2001). Personality and performance at the beginning of the new millennium: What do we know and where do we go next? International Journal of Selection and Assessment, 9(1-2), 9-30. doi: 10.1111/1468-2389.00160.

Bell, B.S., Kanar, A.M., and Kozlowski, S.W. (2008). Current issues and future directions in simulation-based training in North America. The International Journal of Human Resource Management, 19(8), 1416-1434.

Bennett, W., Alliger, G.M., Rowe, L., and Colegrove, C. (2012). Skill decay and value of training. RTO-MP-SAS-095. NATO Science & Technology Organization, Neuilly-sur-Seine, France.

Bennett, N., and Lemoine, G.J. (2014). What a difference a word makes: Understanding threats to performance in a VUCA world. Business Horizons, 57(3), 311-317. doi: 10.1016/j.bushor.2014.01.001.

Bertram, J., Moskaliuk, J., and Cress, U. (2015). Virtual training: Making reality work? Computers in Human Behavior, 43, 284-292. doi: 10.1016/j.chb.2014.10.032.

Bjork, R.A., and Bjork, E.L. (1992). A new theory of disuse and an old theory of stimulus fluctuation. In A. Healy, S. Kosslyn, and R. Shiffrin (Eds.), From Learning Processes to Cognitive Processes: Essays in Honor of William K. Estes (Vol. 2, pp. 35-67). Erlbaum.

Blume, B.D., Ford, J.K., Baldwin, T.T., and Huang, J.L. (2010). Transfer of training: A meta-analytic review. Journal of Management, 36(4), 1065-1105. doi: 10.1177/0149206309352880.

Boyce, M., DeFalco, J., Davis, R.C., Kober, E.K., and Goldberg, B.S. (2018). Mitigating skill decay in military instruction and enemy analysis via GIFT. In D. Schmorrow and C. Fidopiastis, C. (Eds.), Augmented Cognition: Users and Contexts (Vol. 10916, pp. 171-182). doi: 10.1007/978-3-319-91467-1_14

Boyd, E.M., and Oswald, F.L. (2013). Individual difference variables as predictors of error during multitasking training. In W. Arthur, E.A. Day, W. Bennett, and A.M. Portrey (Eds.), Individual and team skill decay: The science and implications for practice (pp. 302-318). Routledge/Taylor & Francis Group. doi: 10.4324/9780203576076.

Boyle, E.A., Hainey, T., Connolly, T.M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., and Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. Computers & Education, 94, 178-192. doi: 10.1016/j.compedu.2015.11.003.

Bowles, S.V., Feely, M.S.A., Weis, E.J., DiBella, A., Bartone, P.T., and Kimmel, K. (2017). Adaptive leadership in military and government settings. In S. Bowles, and P. Bartone (Eds.), Handbook of Military Psychology (pp. 301-329). Springer. doi: 10.1007/978-3-319-66192-6_19.

Braun, P., Reitman, N., and Florin, A.A. (1965). Closed-chest cardiac resuscitation: Problems in the training of laymen in volunteer rescue squads. New England Journal of Medicine, 272(1), 1-6. doi: 10.1056/NEJM196501072720101.

Bryant, D.J., and Angel, H. (2000). Retention and fading of military skills: Literature review. Humansystems Incorporated.

Butler, A.C., Karpicke, J.D., and Roediger, H.L. (2007). The effect of type and timing of feedback on learning from multiple-choice tests. Journal of Experimental Psychology, 13(4), 273-281. doi: 10.1037/1076-898X.13.4.273.

Buttussi, F., and Chittaro, L. (2018). Effects of different types of virtual reality display on presence and learning in a safety training scenario. IEEE Transactions on Visualization and Computer Graphics 24(2), 1063-1076. doi: 10.1109/TVCG.2017.2653117.

Buttussi F., and Chittaro, L. (2021). A comparison of procedural safety training in three conditions: Virtual reality headset, smartphone, and printed materials. IEEE Transactions on Learning Technologies, 14(1), 1 15. doi: 10.1109/TLT.2020.3033766.

Cacioppo, J.T., and Petty, R.E. (1982). The need for cognition. Personality and Social Psychology, 42(1), 116-131. doi: 10.1037/0022-3514.42.1.116.

Cahill, L., Prins B., Weber M., and McGaugh L.J. (1994). β-adrenergic activation and memory for emotional events. Nature, 371, 702-704. doi: 10.1038/371702a0.

Cahillane, M., Launchbury, C., MacLean, P., and Webb, S. (2013). Competence Retention. Defence Human Capability Science & Technology Centre.

Cahillane, M., MacLearn, P., and Webb, S. (2015). Competence retention analysis user guide. Final Report, v4, O-DHCSTC_I2_T_T2_057/002a.

Cahillane, M., MacLean, P., Smy, V., Anderson, T., and Caird-Daley, A. (2020). Skill Fade. Human Social Science Research Capability.

Cahillane, M., Anderson, T., and MacLean, P. (2022). Competence Retention Analysis Handbook. O-HSSRC-1.004-029, v3.

Campbell, J.P., and Pritchard, R.D (1976). Motivation theory in industrial and organizational psychology. In M.D. Dunnette (Ed.), Handbook of industrial and organizational psychology, 63-130. Rand McNally.

Carlson, P., Peters, A., Gilbert, S.B., Vance J.M., and Luse, A. (2015). Virtual training: Learning transfer of assembly tasks. IEEE Transactions on Visualization and Computer Graphics, 21(6), 770-782. doi: 10.1109/TVCG.2015.2393871.

Carron, A.V. (1971). Reactions to “anxiety and motor behavior.” Journal of Motor Behavior, 3(2), 181-188.

Carron, A.V., and Marteniuk, R.G. (1970). Retention of a balance skill as a function of initial ability level. Research Quarterly. American Association for Health, Physical Education and Recreation, 41(4), 478-483.

Cecilio-Fernandes, D., Cnossen, F., Jaarsma, D.A.D.C., and Tio, R.A. (2018). Avoiding surgical skill decay: A systematic review on the spacing of training sessions. Journal of Surgical Education, 75(2), 471-480. doi: 10.1016/j.jsurg.2017.08.002.

Cepeda, N.J., Pashler, H., Vul, E., Wixted, J.T., Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. Psychol Bull May;132(3):354-80. doi: 10.1037/0033-2909.132.3.354. PMID: 16719566.

Cepeda, N.J., Vul, E., Rohrer, D., Wixted, J.T., and Pashler, H. (2008). Spacing effects in learning: A temporal ridgeline of optimal retention. Psychological Science, 19(11), 1095?1102. doi: 10.1111/j.1467-9280.2008.02209.x.

Chittaro, L. (2016). Designing serious games for safety education: “Learn to brace” vs. traditional pictorials for aircraft passengers. IEEE Transactions on Visualization and Computer Graphics, 22(5), 1527-1539. doi: 10.1109/TVCG.2015.2443787.

Chittaro, L., and Buttussi F. (2015). Assessing knowledge retention of an immersive serious game vs. a traditional education method in aviation safety. IEEE Transactions on Visualization and Computer Graphics, 21(4), 529-538. doi: 10.1109/TVCG.2015.2391853.

Chittaro, L., and Sioni, R. (2015). Serious games for emergency preparedness: Evaluation of an interactive vs. a non-interactive simulation of a terror attack. Computers in Human Behavior, 50, 508-519. doi: 10.1016/j.chb.2015.03.074.

Chittaro, L., and Ranon, R. (2007). Web3D technologies in learning, education and training: Motivations, issues, opportunities. Computers & Education, 49(1), 3-18. doi: 10.1016/j.compedu.2005.06.002.

Cianciolo, A.T., Brabb, B.T., Schaefer, P., Jackson, S. And Grover, J. (2010). Sustainment of individual and collective future combat skills: Modeling and research methods. US Army Research Institute for the Behavioral and Social Sciences. Research report 1918.

Clark, D.B., Tanner-Smith, E.E., and Killingsworth S.S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. Review of Educational Research, 86(1), 79-122. doi: 10.3102/0034654315582065.

Cohen, A., Smith, M.J., and Anger, W.K. (1979). Self-protective measures against workplace hazards. Journal of Safety Research, 11(3), 121-131.

Cohen, J. (1977). Statistical Power Analysis for the Behavioural Sciences (2nd ed.). Academic Press.

Colquitt, J.A., LePine, J.A., and Noe, R.A. (2000). Toward an integrative theory of training motivation: A meta-analytic path analysis of 20 years of research. Journal of Applied Psychology, 85(5), 678.

Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., and Boyle, J.M. (2012). A systematic literature review of empirical evidence on computer games and serious games. Computers in Education, 59(2), 661-686.

Converse, P.D., and Oswald, F.L. (2014). Thinking ahead: Assuming linear versus nonlinear personality-criterion relationships in personnel selection. Human Performance, 27(1), 61-79.

Cooke, N.J., Gorman, J.C., Duran, J., Myers, C.W., and Andrews, D. (2013). Retention of team coordination skill. In W. Arthur, E.A. Day, W. Bennett, and A.M. Portrey (Eds.). Individual and Team Skill Decay: The Science and implications for Practice, 344-363. Routledge.

Costa, P.T, and McCrae, R.R. (1992). The five-factor model of personality and its relevance to personality disorders. Journal of Personality Disorders, 6(4), 343-359.

Craik, F.I., and Lockhart, R.S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11(6), 671-684.

Crowley, R., Bendor, D., and Javadi, A.H. (2019). A review of neurobiological factors underlying the selective enhancement of memory at encoding, consolidation, and retrieval. Progress in Neurobiology, 179, 101615.

Day, E.A., Arthur Jr, W., Villado, A.J., Boatman, P.R., Kowollik, V., Bhupatkar, A., and Bennett Jr, W. (2013). Relating individual differences in ability personality and motivation to the retention and transfer of skill on a complex command-and-control simulation task. In W. Arthur, Jr., E.A. Day, W. Bennett, Jr., and A.M. Portrey (Eds.). Individual and Team Skill Decay: The Science and Implications for Practice. Routledge/Taylor & Francis Group.

De Dreu, C.K.W, and McCusker, C. (1997). Gain-loss frames and cooperation in two-person social dilemmas: A transformation analysis. Journal of Personality and Social Psychology, 72, 1093-1106.

DeFleur, M.L, Davenport, L., Cronin, M., and DeFleur, M. (1992). Audience recall of news stories presented by newspaper, computer, television and radio. Journalism and Mass Communication Quarterly, 69(4), 1010-1022.

De Koning, B.B., Tabbers, H.K., Rikers, R.P., and Paas, F. (2007). Attention cueing as a means to enhance learning from an animation. Applied Cognitive Psychology, 21, 731-746.

De Win, G., Van Bruwaene, S., De Ridder, D., and Miserez, M. (2013). The optimal frequency of endoscopic skill labs for training and skill retention on suturing: a randomized controlled trial. Journal of Surgical Education, 70(3), 384-393.

Deighton, C.D., and Mundy, D. (2019). Personalisation of learning, a scoping study: Final technical report. QinetiQ/EMEA/CIT/CR1901476, QinetiQ.

Deighton, C.D., Richards, H.J., and Green, L. (2020). Skills management and retention – 2020 refresh. DSTL/WP121609, Dstl Defence and Security Analysis.

DiazGranados, D., Lazzara, E.H., Lyons, R., Wooten, S.R., and Salas, E. (2013). Team performance decay: why does it happen and how to avoid it? In W. Arthur, E.A. Day, W. Bennett & A.M. Portrey (Eds.), Individual and Team Skill Decay: The Science and Implications for Practice, 364-395. Routledge.

Diefendorff, J.M., and Chandler, M.M. (2011). Motivating employees. In S. Zedeck (Ed.), APA Handbook of Industrial and Organizational Psychology, Vol. 3. Maintaining, expanding, and contracting the organization, 65-135. American Psychological Association. doi: 10.1037/12171-003.

Dihoff, R.E., Brosvic, G.M., and Epstein, M.L. (2003). The role of feedback during academic testing: The delay retention effect revisited. The Psychological Record, 53(4), 533-548.

Day, E.A., Espejo, J., Kowollik, V., Boatman, P.R., and McEntire, L.E. (2007). Modeling the links between need for cognition and the acquisition of a complex skill. Personality and Individual Differences, 42(2), 201-212.

Donavan, J.J., and Radosevich D.J. (1999). A meta-analytic review of the distribution of practice effect: Now you see it, now you don’t. Journal of Applied Psychology, 84(5), 795-805.

Driskell, J.E., Copper, C., and Moran, A. (1994). Does mental practice enhance performance? Journal of Applied Psychology, 79, 481-492.

Driskell, J.E., Willis, R.P., and Copper, C. (1992). Effect of overlearning on retention. Journal of Applied Psychology, 77(5), 615-622.

Dube, A.K., and McEwen, R.N. (2015). Do gestures matter? The implications of using touchscreen devices in mathematics instruction. Learning and Instruction, 40, 89-98.

Dweck, C.S., and Leggett, E.L. (1988). A social-cognitive approach to motivation and personality. Psychological Review, 95(2), 256.

Eskreis-Winkler, L., Shulman, E.P., Beal, S.A., and Duckworth, A.L. (2014). The grit effect: Predicting retention in the military, the workplace, school and marriage. Front Psychol. 2014 Feb 3, 5(36). doi: 10.3389/fpsyg.2014.00036. PMID: 24550863; PMCID: PMC3910317.

Farr, M.J. (1987). Relationship between Acquisition and Retention. In M.J. Farr (Ed.), The Long-Term Retention of Knowledge and Skills, 25-43. Springer.

Feng, Z., González, V.A., Amor, R., Lovreglio, R., and Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. Computers & Education, 127, 252-266.

Finn, B., and Roediger, H.L. (2011), Enhancing retention through reconsolidation: Negative emotional arousal following retrieval enhances later recall. Psychological Science, 22(6), 781-786.

Fitts, P.M., and Posner, M.L. (1967). Human Performance. Brooks/Cole.

Fleishman, E.A., Quaintance, M.K., and Broedling, L.A. (1984). Taxonomies of human performance: The description of human tasks. Academic Press.

Fletcher, J.D., Belanich, J., Moses, F., and Fehr, A. (2017). Effectiveness of augmented reality and augmented virtuality. MODSIM Modelling and simulation of systems and applications world conference (paper no. 48).

Ford, J.K., Sego, D., Quinones, M., and Speer, J. (1991). The construct of experience: A review of the literature and needed research directions. In Sixth Annual Conference of the Society for Industrial and Organizational Psychology, St. Louis, MO.

Fortino, A., and Lowrance, R. (2019). Practice makes perfect: Memory retrieval strategies to improve student academic performance. Academy of Management Annual Meeting Proceedings.

Fox, W.L., Taylor, J.E., and Caylor, J.S. (1969). Aptitude level and the acquisition of skills and knowledges in a variety of military training tasks. George Washington University, Alexandria VA, Human Resources Research Office.

Foos, I., and Fisher, R. (1988). Using tests as learning opportunities. Journal of Educational Psychology, 80(2), 179-183.

Frank, B., and Kluge, A. (2014). The predictive quality of retentivity for skill acquisition and retention in a simulated process control task. Conference Proceedings of the Human Factors and Ergonoimcs Society. Europe Chapter 2014 Annual Conference: Lisbon.

Frankland, P.W., Josselyn, S.A., and Kohler, S. (2019). The neurobiological foundation of memory retrieval. Nature Neuroscience, 22(10), 1576-1585.

Furnham, A.F., and Gunter, B. (1985). Sex, presentation mode and memory for violent and non-violent news. Journal of Educational Television, 11(2), 99-105.

Furnham, A.F., and Gunter, B. (1987). Effects of time of day and medium of presentation on immediate recall of violent and non-violent news. Applied Cognitive Psychology, 1(4), 255-262.

Gerhardt, R.T., Mabry, R.L., DeLorenzo, R.A., and Butler, F.K. (2012). Chapter 3: Fundamentals of Combat Casualty Care. Combat Casualty Care: Lessons Learned from OEF and OIF. Falls Church, VA: Office of the Surgeon General, Borden Institute, United States Army, 88-120.

Ginzburg, S., and Dar-El, E.M. (2000). Skill retention and relearning-a proposed cyclical model. Journal of Workplace Learning, 327-332.

Gist, M.E., Stevens, C.K., and Bavetta, A.G. (1991). Effects of self-efficacy and post-training intervention on the acquisition and maintenance of complex interpersonal skills. Personnel Psychology, 44(4), 837-861.

Glendon, A.I., McKenna, S.P., Hunt, K., and Blaylock, S.S. (1988). Variables affecting cardiopulmonary resuscitation skill decay. Journal of Occupational Psychology, 61(3), 243-255.

Goldstein, I.L. (1975). Training. In B.L. Margolis and W.H. Kroes (Eds.), The Human Side of Accident Prevention, C.C. Thomas.

Grace, E.S., Korinek, E.J., Weitzel, L.B., and Wentz, D.K. (2010). Physicians reentering clinical practice: Characteristics and clinical abilities. Journal of Continuing Education in the Health Professions, 30(3), 180-186.

Granito, M., and Chernobilsky, E. (2012). The effect of technology on a student’s motivation and knowledge retention. NERA Conference Proceedings 2012 Paper 17.

Graesser, A.C. (2020). Emotions are the experiential glue of learning environments in the 21st century. Learning and Instruction, 70, 101212.

Gronlund, S.D., and Kimball, D.R. (2013). Remembering and forgetting: From the laboratory looking out. In W. Arthur, Jr., E.A. Day, W. Bennett, Jr., and A.M. Portrey (Eds.), Individual and Team Skill Decay: The Science and Implications for Practice, 14-52. Routledge/Taylor & Francis Group.

Gross, J.J. (Ed.). (2013). Handbook of Emotion Regulation. Guilford Publications.

Guidolin, K., Yan, H., and Quereshy, F. (2020). The “teaching time-out”: A novel framework for surgical education. Canadian Journal of Surgery, 63(3), E208.

Gunter, B., Furnham, A.F., and Gietson, G. (1984). Memory for the news as a function of the channel of communication. Human Learning: Journal of Practical Research & Applications, 3(4), 265-271.

Gunter, B., Furnham, A., and Leese, J. (1986). Memory for information from a party political broadcast as a function of the channel of communication. Social Behaviour, 1(2), 135-142.

Guo Li, H., Chan, G., and Skitmore, M. (2012). Using game technologies to improve the safety of construction plant operations. Accident Analysis and Prevention, vol. 48, 204-213.

Hadziomerovic, A., Vollick, S., and Budgell, G. (2014). Learning modalities and delivery systems for officer professional development period 3: Literature review.

Hagman, J.D., and Rose, A.M. (1983). Retention of military tasks: A review. Human Factors, 25, 199-213.

Hall, E.R., Ford, L.H., Whitten, T.C, and Plyant, L.R. (1983). Knowledge retention among graduates of basic electricity and electronics schools (HumRRO Tech. Rep 149). Orlando, FL: Training Analysis and Evaluation Group, Department of the Navy.

Hancock, P.A., and Krueger, G.P. (2010). Hours of boredom, moments of terror: Temporal desynchrony in military and security force operations. National Defense Univ Washington DC Center for Technology and National Security Policy.

Hasler, B., Kersten, B., and Sweller, J. (2007). Learner control, cognitive load and instructional animation. Applied Cognitive Psychology 21, 713-729.

Hebscher, M., Wing, E., Ryan, J., and Gilboa, A. (2019). Rapid cortical plasticity supports long-term memory formation. Trends in Cognitive Sciences, 23(12), 989-1002. Doi: 10.1016/j.tics. 2019.09.009.

Henik, A., Brain, E., Ze’evi, V., and Schwartz, D. (1999). The preservation and the decay of military skills. Report (R&D 7699-RB-01).

Herold, D.M., Davis, W., Fedor, D.B., and Parsons, C.K. (2002). Dispositional influences on transfer of learning in multistage training programs. Personnel Psychology, 55(4), 851-869.

Hesketh, B. (1997). Dilemmas in training for transfer and retention. Applied Psychology, 46(4), 317-339.

Hossein, M., Perrone, K., Peterson, K., Garren, M., Chembian, P., Adhira, S., Zinn, M., and Pugh, C. (2020). Can virtual reality be used to track skills decay during the research years? Journal of Surgical Research, 247, 150-155.

Jaeggi, S.M., Buschkuehl, M., Shah, P., and Jonides, J. (2014). The role of individual differences in cognitive training and transfer. Memory & Cognition, 42(3), 464-480.

Janiszewski, C., Noel, H., and Sawyer, A.G. (2003). A meta-analysis of the spacing effect in verbal learning: Implications for research on advertising repetition and consumer memory. Journal of Consumer Research, 30, 138-149.

Jensen, L., and Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. British Journal of Educational Technology, 23(4), 1515-1529.

Jerald, J. (2016). The VR Book: Human-Centered Design for Virtual Reality, ACM Press.

Karpicke, J.D., and Roediger, H.L. (2008). The critical importance of retrieval for learning. Science, 319, 966-968.

Karwowski, W. (2005). Ergonomics and human factors: The paradigms for science, engineering, design, technology and management of human-compatible systems. Ergonomics, 48(5), 436-463.

Keith, N., and Frese, M. (2005). Self-regulation in error management training: emotion control and metacognition as mediators of performance effects. Journal of Applied Psychology, 90(4), 677.

Kelc, R., Vogrin, M., and Kelc, J. (2020). Cognitive training for the prevention of skill decay in temporarily non-performing orthopedic surgeons. Acta Orthopaedica, 91(x).

Kensinger, E.A. (2009). Remembering the Details: Effects of Emotion, Emotion Review, 1(2), 99-113.

Kensinger, E.A., and Schacter, D.L. (2008). Memory and Emotion, in Handbook of Emotions, 3rd ed., M. Lewis, J.M. Haviland-Jones, and L. Feldman Barrett, Eds. New York, NY, USA: Guilford Press, 601-617.

Kim, J., Ritter, F., and Koubek, R. (2013). An integrated theory for improved skill acquisition and retention in the three stages of learning. Theoretical Issues in Ergonomics Science, 14(1), 22-37, Kirkpatrick, D.L (1967).

Kintsch, W. (1994). Text comprehension, Memory, and learning. American Psychologist, 49(4), 294-303.

Kozey, J., McCabe, J., and Jenkins, J. (2007). The effects of different training methods on egress performance from the modular egress training simulator. In proceedings of the 44th Annual SAFE Symposium, Reno Nevada.

Kraiger, K., Ford, J.K., and Salas, E. (1993). Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation. Journal of Applied Psychology, 78(2), 311.

Kruglikova, I., Grantcharov, T.P., Drewes, A.M., and Funch-Jensen, P. (2010). The impact of constructive feedback on training in gastrointestinal endoscopy using high-fidelity virtual-reality simulation: A randomized controlled trial. Gut, 59(2), 181-185.

Kun, Y., Hubert, J., Bin L., and Huahn, W.X. (2018). Self-briefing model based on an integrated video-capture system: an efficient solution to skill degradation. Surgical Education, 76(2), 362-368.

LaBar, K.S., and Cabeza, R. (2006). Cognitive neuroscience of emotional memory. Nature Reviews Neuroscience, 7(1), 54-64.

Langan-Fox, J., Armstrong, K., Salvin, N., and Anglim, J. (2002). Process in Skill Acquisition: Motivation, Interruptions, Memory, Affective States, and Metacognition. Australian Psychologist, 37(2), 104-117.

Larouzee, J., and Le Coze, J.C. (2020). Good and bad reasons: The Swiss cheese model and its critics. Safety Science, 126, 104660.

Lee, T.D., and Genovese, E.D. (1988). Distribution of practice in motor skill acquisition: Learning and performance effects reconsidered. Research Quarterly for Exercise and Sport, 59, 277-287.

Linde, A., and Miller, G.T. (2019). Applications of future technologies to detect skill decay and improve procedural performance. Military Medicine, 184(1), 72-77.

Locke, E.A., and Latham, G.P. (2004). What should we do about motivation theory? Six recommendations for the twenty-first century. Academy of Management Review, 29(3), 388-403.

Machin, M.A., and Fogarty, G.J. (2004). Assessing the antecedents of transfer intentions in a training context. International Journal of Training and Development, 8(3), 222-236.

Magura, S., Miller, M.G., Michael, T., Bensley, R., Burkhardt, J.T., Puente, A.C., and Sullins, C. (2012). Novel electronic refreshers for cardiopulmonary resuscitation: A randomized controlled trial. BMC Emergency Medicine, 12(1), 1-10.

Makransky, G., Lilleholt, L., and Aaby, A. (2017). Development and validation of the multimodal presence scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. Computers in Human Behavior, 72, 276-285.

Makransky, G., Terkildsen, T.S., and Mayer, R.E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learning and Instruction, 60, 225-236.

Makransky, G., Andreasen, N.K., Baceviciute, S., and Mayer, R.E. (2020). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. Journal of Educational Psychology, 4 (113), 719-735.

Mayer, R.E. (Ed.) (2014). The Cambridge Handbook of Multimedia Learning, Cambridge University Press.

Mayer, R., and Chandler, P. (2001). When learning is just a click away: does simple user interaction foster deeper understanding of multimedia messages? Journal of Educational Psychology 93, 390-397.

Mautone, P.D., and Mayer, R.E. (2001). Signaling as a cognitive guide in multimedia learning. Journal of Educational Psychology, 93, 377-389. doi:10.1037/0022-0663.93.2.377.

McCausland, T.C., King, E.B., Bartholomew, L., Feyre, R., Ahmad, A., and Finkelstein, L.M. (2015). The technological age: The effects of perceived age in technology training. Journal of Business and Psychology, 30(4), 693-708.

McComas, J., MacKay, M., and Pivik, J. (2002). Effectiveness of virtual reality for teaching pedestrian safety. CyberPsychology & Behavior, 5(3), 185-190.

McGaugh, J.L. (2000). Memory – a Century of Consolidation, Science, vol. 287, no. 5451, 248-251.

McEwen, B.S. (2004). Protection and damage from acute and chronic stress: Allostasis and allostatic overload and relevance to the pathophysiology of psychiatric disorders. Annals of the New York Academy of Sciences, 1032, 1-7.

McKenna, S.P., and Glendon, A.I. (1985). Occupational first aid training: Decay in cardiopulmonary resuscitation (CPR) skills. Journal of Occupational Psychology, 58(2), 109-117.

Mead, K.G., Tennent, D.J., and Stinner, D.J. (2017). The importance of medical readiness training exercises: Maintaining medical readiness in a low-volume combat casualty flow era. Military Medicine, 182, 1734-1737.

Meerkov, M.S., Fischer, J.B., and Saba, T.G. (2019). A simulation procedure curriculum to increase paediatric resident exposure to procedures rarely performed in clinical practice. Medical Education Online, 24(1), 1611305, DOI: 10.1080/10872981.2019.1611305.

Merkt, M., Weigand S., Heier A., and Schwan S. (2011). Learning with videos vs. learning with print: The role of interactive features. Learning and Instruction 21, 687-704.

Mikita, J.A., Niven, A.S., Drizin, D.L., Gada, S.M., and Deering, S. (2017). The impact of deployment on the practice of the military internist: A needs assessment for post-deployment refresher training. Military Medicine, 182, 1987-1991.

Mikropoulos, T., and Natsis, A. (2011). Educational Virtual Environments: A Ten-Year Review of Empirical Research (1999 – 2009). Computers & Education, 56, 769-780.

Mills, A.M., and Muir, H., 1999. Executive summary final report: Development of a training standard for underwater survival. Human Factors Group, Cranfield, Bedford.

Moreno, R., and Mayer, R.E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. Journal of Educational Psychology, 94(3), 598-610.

Moreno, R. (2007). Optimizing learning from animations by minimizing cognitive load: Cognitive and affective consequences of signaling and segmentation methods. Applied Cognitive Psychology, 21, 765-781.

Moss, V.D. (1996). The efficacy of massed versus distributed practice as a function of desired learning outcomes and grade level of the student. Doctoral dissertation, Utah State University, 1995. Dissertation Abstracts International, 56, 5204.

Newtson, D., and Engquist, G. (1976). The perceptual organization of ongoing behavior. Journal of Experimental Social Psychology, 12, 436-450.

Nielson, K.A., and Arentsen, T.J. (2012). Memory modulation in the classroom: Selective enhancement of college examination performance by arousal induced after lecture. Neurobiol. Learn. Mem., 1981, 12-16.

Noe, R.A., and Colquitt, J.A. (2002). Planning for training impact: Principles of training effectiveness. Creating, Implementing, and Managing Effective Training and Development, 53-79.

Palma-Gudiel, H., Prather, A.A., Lin, J., Oxendine, J.D., Guintivano, J., Xia, K., ... and Zannas, A.S. (2021). HPA axis regulation and epigenetic programming of immune-related genes in chronically stressed and non-stressed mid-life women. Brain, Behavior, and Immunity, 92, 49-56.

Pan, S.C., and Rickard, T.C. (2018). Transfer of test-enhanced learning: Meta-analytic review and synthesis. Psychological Bulletin 144(7), 710-756.

Papalexopoulou, K., Chalkias, A., Dontas, I., Pliatsika, P., Giannakakos, C., Papapanagiotou, P., ... and Xanthos, T. (2014). Education and age affect skill acquisition and retention in lay rescuers after a European Resuscitation Council CPR/AED course. Heart & Lung, 43(1), 66-71.

Parlangeli, O., Marchigiani, E., and Bagnara, S. (1999). Multimedia systems in distance education: effects of usability on learning. Interacting with Computers, 12(1), 37-49.

Patocka, C., Cheng, A., Sibbald, M, Duff, J.P., Lai, A., Lee-Nobbee, P., Levin, H., Varshney, T., Weber, B., and Farhan, B. (2019). A randomized education trial of spaced versus massed instruction to improve acquisition and retention of paediatric resuscitation skills in emergency medical service (EMS) providers. Resuscitation, 141, 73-80.

Pasquier P., Mérat S., Malgras B., Petit L., Queran X., Bay C., Boutonnet M., Jault P., Ausset S., Auroy Y., Perez J.P., Tesnière A., Pons F., and Mignon A. (2016). A Serious Game for Massive Training and Assessment of French Soldiers Involved in Forward Combat Casualty Care (3D-SC1): Development and Deployment, JMIR Serious Games; 4(1):e5, DOI: 10.2196/games.5340

Patil I., Cogoni C., Zangrando N., Chittaro L., and Silani G. Affective basis of Judgment-Behavior Discrepancy in Virtual Experiences of Moral Dilemmas. I(1), 2014, 989-993

Peterson, D.J., and Wissman, K. (2020). Using tests to reduce mind-wandering during learning review. Memory, 28(4), 582-587.

Petrosoniak, A., Lu, M., Gray, S., Hicks, C., Sherbino, J., McGowan, M., and Monteiro, S. (2019). Perfecting practice: A protocol for assessing simulation-based mastery learning and deliberate practice versus self-guided practice for bougie-assisted cricothyroidotomy performance. BMC Med Educ, 19, 100.

Phipps, S.T., Prieto, L.C., and Ndinguri, E.N. (2013). Understanding the impact of employee involvement on organizational productivity: The moderating role of organizational commitment. Journal of Organizational Culture, Communications and Conflict, 17(2), 107.

Plass, J.L., Homer, B.D., and Kinzer, C.K. (2015). Foundations of Game-Based Learning, Educational Psychologist, 50(4), 258-283.

Purdy, B.J., and Lockhart, A. (1962). Retention and relearning of gross motor skills after long periods of no practice. Research Quarterly. American Association for Health, Physical Education and Recreation, 33(2), 265-272.

Ragan, E.D., Bowman, D.A., Kopper, R., Stinson, C., Scerbo, S., and McMahan, R.P. (2015). Effects of Field of View and Visual Complexity on Virtual Reality Training Effectiveness for a Visual Scanning Task, IEEE Trans. Vis. Comput. Graph.,21(7)., 794-807.

Ramirez, A.G., Weaver, F.J., Raizner, A.E., Dorfman, S.B., Herrick, K.L., and Gotto Jr, A.M. (1977). The efficacy of lay CPR instruction: an evaluation. American Journal of Public Health, 67(11), 1093-1095.

Richins, M., Caldeira-Hankey, A., and Deighton, C.D (2021). Personalisation of Learning: Developing the case for implementation within Defence Learning Establishments. Interservice/Industry Training, Simulation and Education Conference, 2021. Orlando, FL.

Richards, H.J., and Deighton, C. (2019). Skills Management and Retention. DSTL/TR114370, 1.0, 31 March 2019.

Riegel, B., Birnbaum, A., Aufderheide, T.P., Thode Jr, H.C., Henry, M.C., Van Ottingham, L., et al. and PAD Investigators (2005). Predictors of cardiopulmonary resuscitation and automated external defibrillator skill retention. American Heart Journal, 150(5), 927-932.

Rodrigue, K.M., Kennedy, K.M., and Raz, N. (2005). Aging and longitudinal change in perceptual-motor skill acquisition in healthy adults. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 60(4), P174-P181.

Roediger, H.L., Agarwal, P.K., Kang, S.H.K., and Marsh, E.J. (2010). Benefits of testing memory: Best practices and boundary conditions. In: G.M. Davies and D.B. Wright (Eds.), Current Issues in Applied Memory Research. DOI: 10.4324/9780203869611. Accessed 25 June 2020.

Roediger, H.L., Putnam, A.L., and Sumeracki, M.A. (2011). Ten benefits of testing and their applications to educational practice. Psychology of Learning and Motivation, 55, 1-36.

Roediger, H.L., and Butler, A.C. (2007). The critical role of retrieval practice in long-term retention. Trends in Cognitive Sciences, 15(1), 20-27. DOI:10.1016/j.tics.2010.09.003.

Rohrer, D., Taylor, K., Pashler, H., Wixted, J.T., and Cepeda, N.J. (2005). The effect of overlearning on long-term retention. Applied Cognitive Psychology, 19, 361-374.

Rose, A.M. (1989), Acquisition and retention of skills. In G.R. McMillan, D. Beevis, and E. Salas (Eds.), Applications of human performance models to system design (pp. 419-426). New York, NY: Springer Science and Business Media.

Rose, F.D., Attree, E.A., Brooks, B.M., Parslow, D.M., Penn, P.R., and Ambihaipahan N. (2000). Training in virtual environments: Transfer to real world tasks and equivalence to real task training. Ergonomics. 43(4), 494-511.

Rose, A.M., Czarnolewski, M.Y., Gragg, F.E., Austin, S.H., Ford, P., Doyle, J, and Hagman, J.D. (1985). Acquisition and retention of soldiering skills. US Army Research Institute for the Behavioral and Social Sciences. AD-A160 336.

Roth, J.T. (1992). Development of a methodology for collective training decision making in army units (Research note 92-95). Alexandria, VA: US Army Research Institute for the Behavioral and Social Sciences.

Rovira, A., Swapp, D., Spanlang, B., and Slater, M. (2000). The use of virtual reality in the study of people’s responses to violent incidents. Frontiers in Behavioral Neuroscience, 3(59).

Sabol, M.A., and Wisher, R.A. (2001). Retention and reacquisition of military skills. Military Operations Research, 59-80.

Salthouse, T.A., and Somberg, B.L. (1982). Skilled performance: Effects of adult age and experience on elementary processes. Journal of Experimental Psychology: General, 111(2), 176.

Sanli, E.A., and Carnahan, H. (2018). Long-term retention of skills in multi-day training contexts: A review of the literature. International Journal of Industrial Ergonomics, 66, 10-17. doi: 10.1016/j.ergon.2018.02.001.

Sapolsky, R.M. (1994). The physiological relevance of glucocorticoid endangerment of the hippocampus. Annals of the New York Academy of Sciences, 746, 294-304.

Saxbe, D.E. (2008). A field (researcher’s) guide to cortisol: Tracking HPA axis functioning in everyday life. Health Psychology Review, 2(2), 163-190.

Schendel, J.D., and Hagman, J.D. (1982). On sustaining procedural skills over a prolonged retention interval. Journal of Applied Psychology, 67(5), 605.

Schendel, J.D., and Hagman, J.D. (1991). Long-term retention of motor skills. Training for performance: Principles of Applied Human Learning, 53-92.

Schmidt, A.M., and Ford, J.K. (2003). Learning within a learner control training environment: The interactive effects of goal orientation and metacognitive instruction on learning outcomes. Personnel Psychology, 56(2), 405-429.

Schmidt, F.L., and Hunter, J.E. (1998). The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings. Psychological Bulletin, 124(2), 262.

Schneider, W., and Shiffrin, R.M. (1977). Controlled and automatic human information processing: In Detection, Search and Attention. Psychological Review, 84, 127-190.

Schumann, S.A., Schimelpfenig, T., Sibthorp, J., and Collins, R.H. (2012). An examination of wilderness first aid knowledge, self-efficacy, and skill retention. Wilderness & Environmental Medicine, 23(3), 281-287.

Schwan, S., and Riempp, R. (2004). The cognitive benefits of interactive videos: Learning to tie nautical knots. Learning and Instruction, 14, 293-305.

Schwan, S., Garsoffky, B., and Hesse, F.W. (2000). Do film cuts facilitate the perceptual and cognitive organization of activity sequences? Memory & Cognition, 28(2), 214-223.

Shapiro, L. (2011). Embodied cognition. Routledge Press.

Shibata, K., Sasaki, Y., Bang, J.W., Walsh, E.G., Machizawa, M.G., Tamaki, M., Chang, L., and Watanabe, T. (2017). Overlearning hyper-stabilizes a skill by rapidly making neurochemical processing inhibitory-dominant. Natural Neuroscience, 20(3), 470-475.

Sharot, T., Delgado, M.R., and Phelps, E.A. (2004). How emotion enhances the feeling of remembering. Nat. Neurosci.,7(12), 1376-1380.

Silverstein, J.C., Dech, F., Edison, M., Jurek, P., Helton, W.S., and Espat, N.J. (2002). Virtual reality: Immersive hepatic surgery educational environment. Surgery, 132(2), 274-277.

Siu, K.C., Best, B.J., Kim, J.W., Oleynikov, D., and Ritter, F.E. (2016). Adaptive virtual reality training to optimize military medical skills acquisition and retention. Military Medicine, 181(suppl_5), 214-220.

Skare, C., Boldingh, A.M., Kramer-Johansen, J., Calisch, T.E., Nakstad, B., Nadkarni, V., Olasveengen, T.M., and Niles, D.E. (2018). Video performance-debriefings and ventilation-refreshers improve quality of neonatal resuscitation. Resuscitation, 132, 140-146.

Skelton, M.B., and McSwain, N.E. (1977). A study of cognitive and technical skill deterioration among trained paramedics. Journal of the American College of Emergency Physicians, 6(10), 436-438.

Skinner, B.F. (2014). Contingencies of reinforcement: A theoretical analysis. BF Skinner Foundation.

Smith, S.J., Farra, S., Ulrich, D.L., Hodgson, E., Nicely, S., and Matcham, W. (2016). Learning and Retention Using Virtual Reality in a Decontamination Simulation. Nursing Education Perspectives, 37(4), 210-214.

Soo, J.J., and Hea Kung, H. (2013). Effectiveness and Retention of Repeated Simulation-based Basic Life Support Training for Nursing Students. Journal of Korean Critical Care Nursing, 6(2).

Stone, R.J., Caird-Daley, A., and Bessell, K. (2009). SubSafe: A Games-Based Training System for Submarine Safety and Spatial Awareness. Virtual Reality, 13(1), 3-12.

Stothard, C., and Nicholson, R. (2001). Skill acquisition and retention in training: DSTO support to the army ammunition study (No. DSTO-CR-0218). Salisbury, Australia: Electronics and Surveillance Research Laboratory, Defence Science & Technology Organisation.

Sullivan, A., Elshenawy, S., Ades, A., and Sawyer, T. (2019). Acquiring and maintaining technical skills using simulation: initial, maintenance, booster, and refresher training. Cureus, 11(9), e5729.

Svensson, E., Angelborg-Thanderz, M., Borgvall, J, and Castor, M. (2013). Skill decay, reacquisition training, and transfer studies in the Swedish Air Force. In W. Arthur, E.A. Day, W. Bennett, A.M. Portrey (Eds.), Individual and team Skill Decay: The Science and Implications for Practice, 258-281, Routledge.

Taylor, J.L., Kennedy, Q., Noda, A., and Yesavage, J.A. (2007). Pilot age and expertise predict flight simulator performance: a 3-year longitudinal study. Neurology, 68(9), 648-654.

Thayer, J.F., and Lane, R.D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. Journal of Affective Disorders, 61(3), 201-216.

Toner, J., Montero, B.G., and Moran, A. (2015). The perils of automaticity. Review of General Psychology, 19(4), 431-442.

Troubat, R., Barone, P., Leman, S., Desmidt, T., Cressant, A., Atanasova, B., ... and Camus, V. (2021). Neuroinflammation and depression: A review. European Journal of Neuroscience, 53(1), 151-171.

Tulving, E., and Thomson, D.M. (1973). Encoding specificity and retrieval processes in episodic memory. Psychological Review, 80(5), 352-373.

Tweed, W.A., Wilson, E., and Isfeld, B. (1980). Retention of cardiopulmonary resuscitation skills after initial overtraining. Critical Care Medicine, 8(11), 651-653.

Tziner, A., Fisher, M., Senior, T., and Weisberg, J. (2007). Effects of trainee characteristics on training effectiveness. International Journal of Selection and Assessment, 15(2), 167-174.

Tyng, C.M., Amin, H.U., Saad, M.N.M., and Malik, A.S. (2017). The influences of emotion on learning and memory. Frontiers in Psychology, 8, Article 1454.

Van Ginkel, S.M., Gulikers, J., Biemans, H., Noroozi, O., Roozen, M., Bos, T., van Tilborg, R., van Halteren, M., and Mulder, M., (2019). Fostering oral presentation competence through a virtual reality-based task for delivering feedback. Computers & Education, 134, 78-97.

Van Merriënboer, J.J.G., Kester, L., and Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. Applied Cognitive Psychology, 20, 343-352.

Van Puyvelde, M., Neyt, X., McGlone, F., and Pattyn, N. (2018). Voice stress analysis: A new framework for voice and effort in human performance. Frontiers in Psychology, 9, 1994.

Van Merriënboer, J.J.G., and Kirschner, P.A. (2007). Ten steps to complex learning: A new approach to instruction and instructional design. Routledge.

Vealy, R.S., and Walter, S.M. (1993). Imagery training for performance enhancement and personal development. In J.M. Williams (Ed.). Applied sport psychology: personal growth to peak performance, 2nd Edition, 200-224. Mayfield.

Velada, R., Caetano, A., Michel, J.W., Lyons, B.D., and Kavanagh, M.J. (2007). The effects of training design, individual characteristics and work environment on transfer of training. International Journal of Training and Development, 11(4), 282-294.

Vermeulen, C., Keijzers, P., Fredriks, E, Van der Hee, P., Van Waes, O., and Hoencamp, R. (2019). Dutch combat operations experiences in Iraq and Afghanistan: the conundrum of low surgical workload deployments. Injury, 50(1), 215-219.

Villado, A.J., and Arthur Jr, W. (2013). The comparative effect of subjective and objective after-action reviews on team performance on a complex task. Journal of Applied Psychology, 98(3), 514.

Vineberg, R. (1975). A study of the retention skills and knowledge acquired in basic training (HumRRO TR 75-10). Alexandria, VA: Human Resources Research Organization.

Vlasblom, J., Pennings, H.J.M., Oprins, E, and van der Pal, J. (2020). Longitudinal studies on skill retention in high-performance professions: a systematic literature review. Educational Research Review, 30, 100330.

Vogel S., and Schwabe R.L. (2016), Learning and memory under stress: implications for the classroom, Science of Learning, 1, Article 16011.

Walma van der Molen, J.H., and Van Der Voort, T.H.A. (2000). Children's and adults' recall of television and print news in children's and adult news formats. Communication Research, 27(2):132-160.

Wang, X., Day, E.A., Kowollik, V., Schuelke, M.J., and Hughes, M.G. (2013). Factors influencing knowledge and skill decay. In W. Arthur, E.A. Day, W. Bennett, A.M. Portrey (Eds.), Individual and Team Skill Decay: The Science and Implications for Practice, 258-281, Routledge.

Wetzel, C.D., Radtke, P.H., and Stern, H., (1994). Instructional effectiveness of video media. Erlbaum.

Wicks, R.H., and Drew, D.G. (1991). Learning from news: Effects of message consistency and medium on recall and inference making. Journalism and Mass Communication Quarterly, 68(1-2), 155-164.

Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9, 625-636.

Wilson, E.A., Wolf, M.S., Curtis, L.M., Clayman, M.L., Cameron, K.A., Eigen, K.V., and Makoul, G. (2010). Literacy, cognitive ability, and the retention of health-related information about colorectal cancer screening. Journal of Health Communication, 15(S2), 116-125.

Wisher, R.A., Sabol, M.A., Sukenik, H.K., and Kern, R.P. (1991). Individual ready reserve (IRR) call-up: Skill decay (ARI Research Rep. No. 1595), US Army Research Institute for the Behavioral and Social Sciences.

Wood, R.E. (1986). Task complexity: Definition of the construct. Organizational Behavior and Human Decision Processes, 37, 60-82.

Wood, R., and Bandura, A. (1989). Social cognitive theory of organizational management. Academy of Management Review, 14(3), 361-384.

Xue, G., Mei, L., Chuansheng, C., Lu, Z-L., Poldrack, R., and Dong, Q. (2011). Spaced learning enhances subsequent recognition memory by reducing neural repetition suppression. Journal of Cognitive Neuroscience, 23(7), 1624-1633.

Youngquist, S.T., Henderson, D.P., Goodrich, S.M., Lewis, R.J. (2008). Paramedic self-efficacy and skill retention in pediatric airway management. Academic Emergency Medicine, 15, 1295-1303.

Youngsuk, C., Sangmao, J, Yoon, Y.S., Roh, H.R., Chang, C., Kang, H., and Lim T. (2016). The effect of peer-group size on the delivery of feedback in basic life support refresher training: A cluster randomized controlled trial. BMC Medical Education, 16, 167.

Yost, P.R., and Plunkett, M.M. (2010). Ten catalysts to spark on-the-job development in your organization. Industrial and Organizational Psychology, 3(1), 20-23.

Zakay, D., and Wooler, S. (1984). Time pressure, training and decision effectiveness. Ergonomics, 27, 273-284.

Zimmerman, B.J., and Schunk, D.H. (Eds.) (2011). Handbook of self-regulation of learning and performance. Routledge.

Annex A – TECHNICAL APPROACH

The identification of factors influencing competence retention was an iterative, team-based approach in which teams of two Subject Matter Experts (SMEs) worked together. Teams of two conducted a literature search to identify those factors influencing competence retention and shared their experiences in the field with each other. The teams had periodic plenary meetings to exchange feedback on their respective work, and to discuss and integrate results in a uniform framework.

SMEs

The contributing researchers are eight SMEs in competence retention but with different backgrounds and expertise, ranging from military operational experience, psychophysiology, educational science, and human-computer interaction. All SMEs have several years of experience in studying retention in a military, medical, aviation, and/or safety context.

Procedure

Three categories of influencing factors were identified: individual differences, task-related influences, and training and education. The RTG was divided into three SME teams, one covering each category of influencing factors. We focused on competence retention instead of skills or knowledge, and we excluded team skill fade, organisational influencing factors and those management strategies relating to selection. A three-step process was applied:

1) Identify the influencing factors and their potential underlying psychological mechanisms,
2) Review and refine the results and evidence, and
3) Provide an overview of practical implications (such as retention management) and future research.

In **Step 1**, each team identified influencing factors within their respective categories. The cornerstone of Step 1 was a literature review, which focused primarily on extracting retention influencers from previously published original research articles, comprehensive reviews, systematic reviews, and meta-analyses.

The following information was captured for each influence factor identified:

- **Definition.** A brief definition/description for each individual factor or group of factors.
- **Direction of effect.** A description of how the factor influences competence retention – positive, negative, or non-directional.
- **Psychological Mechanism.** The (bio)psychological mechanism hypothesized to explain the impact of the factor on competence retention.
- **Scientific Evidence.** A summary of the selected references from the literature that support the factor illustrating the influence of the factor on competence retention.

Step 2 entailed the cross review of each category results by the other two teams. This review was designed to assess agreement on the influencing factor (e.g., did the factor warrant inclusion in this category, as an influencer of retention?) and the supporting information (e.g., defined adequate, sufficient rationale for psychological mechanisms, and convincing scientific evidence). Following this review the feedback was discussed and any area(s) of divergence resolved in order to achieve consensus.

Step 3 consisted of a discussion on the implications for future research and practice. This included identification of key challenges in competence retention research and exploring existing and new interventions and mechanisms to enhance retention, including retention management, predictive modelling of retention, more and appropriate use of virtual training means, and personalisation of learning. This step required a series of iterations and discussions in the full RTG using on-line collaboration tools.

Annex B – INFLUENCING FACTORS, EXPLANATIONS, AND EVIDENCE

This annex includes three tables summarising examples of those Person-, Task- and Training and Education-related factors influencing skill fade. Each table presents the title of the influencing factors and a brief descriptor and direction of influence (i.e., the ‘WHAT’), followed by a rationale explaining ‘WHY’ there is an effect, with reference in some cases to underlying psychological mechanisms. The final column of each table identifies example references which provide supporting evidence. These tables should be read alongside information contained within Chapter 2 of this document.

Table B-1: Person Related: Summary Table of Influencing Factors.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Age	Chronological age of individual.	Higher age results in less retention.	Memory and processing speeds may underlie the inverse association between age and retention (Rodrigue et al., 2005).	Age is inversely associated with retention (Day et al., 2014; Colquitt et al., 2000). In physicians who returned to practice and were tested with a clinical skill assessment before reintegration, age was a predictor of poorer retention (Grace et al., 2011). In a medical CPR training of lay volunteers, older age was associated with less retention (Riegel et al., 2005). In Glendon et al. (1988), age was related with the steepness of a decreasing retention curve in CRP. Long-term retention of perceptual motor skills declined with age, but older adults still retained the ability to learn. When processing speeds are comparable, the age effect disappears (Rodrigue et al., 2005). Ali et al. (2003) found no age effect in the attrition of Advanced Trauma Life Support (ATLS)-acquired skills and knowledge. Knowledge however had a larger attrition rate than skills. Bell et al. (2008) found no impact of age on the knowledge retention of physicians with retention intervals of 3 – 8 days and 55 days. Glendon and McKenna (1985) found no impact of age on CPR skill decay.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Gender	Male or female	Gender was reported to be an indirect impact factor with being male being associated with higher retention.	The impact of gender would be related to the interaction between the initial score and gender, rather than to gender itself (Glendon et al., 1988).	Males have higher retention than females (Bryant and Angel et al. 2000; Riegel et al., 2005). Glendon et al. (1988) observed males to score higher in the initial testing which resulted in smaller levels of decay. Ali et al. (2003) found no gender effect. McKenna and Glendon (1985) found no impact of gender on CPR skill decay.
Grit	A disposition to pursue long-term goals with sustained interest and effort over time.	Higher levels of grit result in more retention.	The propensity to strive for success, and sustained interest would positively affect retention.	Grit has been found to be positively related to retention in military Special Forces (SF), (Eskreis-Winkler, 2014).
Time Out of Practice	The time period a person did not perform their job.	Increased time out of practice predicts poorer retention.	Both declarative and procedural memory processes may underpin.	Grace et al. (2011) found the years one is out of practice to be a predictor of poorer retention in a group of 62 physicians that had a break ranging from 1.5 to 23 years.
Motor Ability	The initial motor ability a person shows at training level for tasks involving the musculoskeletal system, psychomotor movements, and fine motor skills.	Higher motor ability is a better predictor for retention than medium and low motor ability.	Muscle memory would facilitate retention.	Carron and Marteniuk (1970) reported an interaction effect on retention between motor ability and balance skills on a stabilometer from 2 weeks onwards (not after 1 day and 1 week) and Carron (1971) after 2 years (marginally significant). Purdy and Lockhart (1962) observed that high ability of gross motor skills was related with a better retention after one year of no practice.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Cognitive Ability	The initial ability a person shows at training level. Any cognitive process affecting learning and retention (e.g., working memory, long-term memory, spatial ability, processing speed, divided attention, prioritisation).	Higher cognitive ability is a better predictor for retention than medium and low cognitive ability.	High ability persons would use more effective strategies at the learning level to acquire their knowledge and skills (Farr, 1987; Hall et al., 1983). High ability persons would reach a higher initial training efficiency because they acquire more quickly the required minimal level (Arthur et al., 1998). Interaction with degree of training-structure. Higher ability persons would benefit from unstructured training whereas lower ability persons from structured training (Kintsch, 1994). Processing speed, working memory, and long-term memory are suggested to be mediating processes (Wilson et al., 2010). The hypotheses of functional and cognitive reserve (Ackerman et al., 2005) may give an explanatory framework such that a certain cognitive reserve may buffer for decay on the short and the long-term.	Higher mental aptitude based on the Armed Forces Qualification Test (AFQT) was related with higher skill and knowledge retention levels on various psychometric and operational army-related criteria (Fox, Taylor, and Caylor, 1969). Cognitive ability has been positively associated to transfer of skill retention and transfer scores, but no reacquisition scores, in university students in an experimental design of cognitively complex command-and-control task (Day et al., 2013). Training in basic electricity and electronics to a mastery level resulted in higher knowledge retention (interval ranging from 18 to 34 days) in Navy sailors with higher cognitive ability than those with lower ability (Hall et al.,1983). Vineberg (1975) observed an impact of cognitive ability primarily in the first stage of initial learning whereas the retention curves afterwards declined at a same rate in the three groups regardless of ability. The degree of literacy, as a proxy indicator of cognitive ability, was related with retention of knowledge in cancer patients on health-related information about colorectal cancer screening (Wilson et al., 2010).

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Self-Efficacy	One's belief in their ability to successfully perform specific behaviours (Wood and Bandura, 1989), and more specifically one's ability to perform a specific task in a certain way to assure certain outcomes, (emphasising the task specificity).	Higher self-efficacy positively impacts skill and knowledge retention.	Self-efficacy may stimulate associations with other knowledge during an initial training process (Anderson, 1995), hence it may work through skill transfer mechanisms (Arthur et al., 2013). The perceived ability to carry out CPR may be a function of previous training (Glendon et al., 1988), ergo increasing perceptions of self-efficacy. False feelings of self-efficacy may be understood from the perspective of vicarious learning of Bandura.	Gist, Stevens et al. (1991) reported that the retention of interpersonal communication skills after 6 weeks was positively impacted by the pre-test levels of self-efficacy Self-efficacy has been found to be positively related to skill retention and reacquisition scores in university students in an experimental design of cognitively complex command-and-control task (Day et al., 2013). Self-efficacy was negatively correlated with training efficacy and not predictive for retention periods varying from 1-18 months. Even when self-efficacy was maintained, the skill performance declined (Youngquist et al., 2008). Schumann (2012) investigated the retention of Wilderness First-Aid (WFA) skills and knowledge along with self-efficacy in students utilising retention intervals of 4, 8 and 12 months and found no enhancing relationship between self-efficacy and knowledge or skill retention (Schumann, 2012). Andreatta et al. (2016) found independent curves of self-efficacy and both pediatric and neonatal intubation skills using retention intervals of 6, 18 and 52 weeks. No relationship was found between self-efficacy and both CPR skills and knowledge utilising retention intervals of 2 and 6 weeks (Soo and Hea Kung, 2012).

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Self-Efficacy (cont'd)				False feelings of self-efficacy may exist. In first-aid CPR trainings, unjustified confidence to correctly perform a CPR was often reported (e.g., Glendon et al., 1988; McKenna and Glendon, 1985; Ramirez, Weaver et al., 1977). E.g., Ramirez et al. (1977) reported 88 % confident subjects whereas only 1% adequately performed the CPR.
Motivation	The willingness to perform a certain task. A difference may be made between intrinsic and extrinsic motivation.	Increased motivation to perform is related with better retention.	Motivation may be related with the perceived meaningfulness and organisation of the task (Annett et al., 1977). May be related with the context (e.g., laboratory versus real-life situation; Annett et al., 1977). May be linked to the degree or orientation of subsequent learning, be it learning oriented (i.e., to master information or intrinsic motivation) or performance oriented (i.e., to acquire a prescribed score to avoid negative feedback or extrinsic motivation); (Dweck and Legett, 1988). Motivation is possibly inversely related with: 1) Overlearning, which enhances automaticity by strengthening stimulus-response connections (Schendel and Hagman, 1982), but increases the risk for monotony (Arthur et al., 2013). 2) Effortful trainings (Hesketh, 1997).	Granito and Chernobilsky (2012) showed that students showed higher retention when they had the freedom to choose their project. The project itself had no significant impact. The authors linked this finding to motivation. First-aid on mannequins appear to stimulate real-life feelings of reality and thus motivation (Glendon et al., 1988). Tweed, Wilson et al., (1980) found high skill retention 12 months after training in a group of police subjects. They attributed their finding to motivation and overlearning of skills. De Win et al. (2013) examined the ideal frequency of endoscopic skill labs training to optimise skill retention. Although motivation increased with the number of trainings, it was not an influencing factor of the retention curves.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Motivation (cont'd)			Motivation has been linked to voluntary participation Granito and Chernobilsky, 2012; Schmidt and Ford, 2003).	
Initial Learning	The degree of initial or original learning.	Higher initial learning levels positively impact retention. It is also a confounding variable for individual differences.		Anderson, Gaetz, and Masse (2011) observed a protective impact of higher initial training levels on the renewal of the certification in first-aid skills on improving the typical first-aid dramatic decline. Glendon, McKenna, Hunt, and Blaylock (1988) showed a positive impact of initial learning on improved retention curves in CPR. Overlearning showed positive benefits in stressful emergency scenarios. (Cohen, Smith, and Anger, 1979; Goldstein, 1975; Norman, 1976; Salthouse and Somberg, 1982).
Emotional States, Traits, and Errors	Emotional state is a temporal presence of certain emotions. Emotional trait is an individual's temperament-related characteristic.	Emotion regulation improves retention skill test results under pressure. Individual and situational negative or stress-related emotional aspects may impact retention in a positive manner.	A trade-off between bottom-up arousal and top-down regulation is needed to perform in a balanced manner in situations under pressure (Thayer and Lane, 2000). Negative emotions and failure experiences (errors and deviations) receive greater attention and leave a more salient imprint in one's memory than those of gain (e.g., De Dreu and McCusker, 1997). Committing errors can reduce skill transfer and subsequently skill retention (Boyd and Oswald, 2013; Keith and Frese, 2005).	Anton et al. (2019) showed that regulatory mental skills training could counteract the skill decay of operative surgery technical skills (laparoscopic suturing) under stressful conditions. The mental skill trained group performed superior to the control group when having to operate under pressure. There was no difference in skill retention between both groups under normal stress conditions. Chittaro and Buttussi (2015) showed that low levels of both subjective and objective measures of negative arousal taken during an immersive Virtual Reality (VR) serious game on aviation safety instructions were positively related with knowledge retention. The VR-group reported higher levels of fear-arousal and showed higher skin conductance levels along with better retention scores than the control group.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Emotional States, Traits, and Errors (cont'd)	Emotional Stability is an enduring personality trait associated with remaining calm, even-tempered, and relaxed, and can function in demanding, stressful situations (Costa and McCrae, 1992). An error can be defined as "performing an action that deviates from an individual's intended performance" (Boyd and Oswald, 2013, p. 284).			Boyd and Oswald (2013) found a negative correlation between both omission and commission errors, and skill decay, and a positive correlation between state anxiety and the occurrence of errors.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Experience	Previous experience (e.g., work, training, education) leading to expertise in the area. **Expertise** is related to distinct and rich knowledge structures. They provide a deep understanding of complex relationships, and the ability to anticipate and solve potential problems more effectively (Hoffman et al., 2009 from Bryant and Angel, 2000).	Higher levels of experience result in more retention.	Increased experience either before training solidifies knowledge/skills resulting in gaining expertise and facilitating retention.	From Bryant and Angel, 2000: The more background about a topic/skill helps trainees "develop a more organised and coherent structure" that allows information to be better retained over time (Goodwin, 2006). Frank and Kluge (2014) demonstrated that the experience influenced both performance level and skill retention in an experimental design with engineering students.

Table B-2: Task Characteristics: Summary of Influencing Factors.

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Task content demands Tasks often require a combination of human behaviour and competences. Below, the major categories of task content demands, adopted from Wang et al. (2013), are listed. Retention research often used tasks that focused on one demand type. The studies that relate to such elementary competencies (skills or knowledge) resulted in the findings below. More composite tasks and related complex competencies are less studied (see topic Task complexity dimensions later in this table).				
Physical	Tasks requiring perceptual and/or psychomotor actions and skills.	Physical tasks are retained better than cognitive tasks.	After repeated practise, physical tasks are fully automated and occur unconsciously.	Most of the review studies discuss these main differences in type of tasks (Adams, Webb, Angel, and Bryant, 2003; Arthur et al., 1998; Bryant and Angel, 2000; Farr, 1987; Sanli and Carnahan, 2018; Vlasblom, Pennings, van der Pal, Oprins, 2020; Wang et al., 2013). Empirical studies are mainly based on simple, procedural tasks because research is easier to perform and procedural tasks are dominant in refresher training of operational jobs (e.g., Vlasblom et al., 2020). A prediction tool (UDA) is also based on procedural tasks (Rose et al.,1985). Research on retention of interpersonal tasks in relation to other tasks is almost non-existing (Wang et al., 2013). It relates to research on retention at team or collective level in which some information on retention of interpersonal tasks could be found (Adams et al., 2003; Cooke et al., 2013; DiazGranados et al., 2013; Roth, 1992).
Cognitive	Tasks requiring information processing, problem solving, sense making, idea generation, and/or decision-making actions and skills.		In cognitive tasks, one can rely on earlier acquired mental models and cueing; tasks are meaningful; not everything needs to be remembered literally.	
Interpersonal	Tasks requiring interaction with coworkers, clients, and/or peers and the communication and coordination skills in teamwork.	The expectation is that rate of decay is comparable with cognitive complex tasks (no empirical evidence).	Hypothesis: in interpersonal tasks, which are usually complex and meaningful, one can rely on experience, consisting of a variety of mental models.	
Declarative Knowledge	Tasks requiring retrieval and/ or application of facts and/or concepts.	Procedural knowledge declines faster than declarative knowledge.	Procedural knowledge should be remembered step-by-step; accuracy is important; they are not fully automated. Declarative knowledge can be retrieved based on cueing and mental models.	

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Procedural Knowledge	Tasks requiring retrieval and/or application of step-by-step actions (‘checklists’).	Applying procedures is retained worse than higher-order (problem solving) cognitive tasks.	Similar, also for performing tasks.	
Task sequence complexity This factor relates to task characteristics that make the task more complex, which may require more skills and knowledge, but not integration of these skills and knowledge. This primarily is the case for tasks that are sequenced in several subtasks or steps.				
Number of (Sub) Tasks	The number of tasks or subtasks in a procedure.	More (sub) tasks result in less retention.	More task aspects need to be remembered which negatively affects retention.	Complex tasks are investigated less frequently but receive increasing attention (e.g., Arthur and Day, 2013). Complexity (divided into various aspects) are mentioned in some (review) studies, including retention at team or collective level in which task complexity is usually high (e.g., Farr, 1987; Adams et al.,2003; Roth, 1992; DiazGranados et al.,2013), also in the context of retention at team level.
Number of Steps in a (Sub) Task	The number of total actions in a procedure (including the steps per subtask).	More steps in a (sub) tasks result in less retention.	A sequence of more different steps needs to be remembered which negatively affects retention.	
Diversity of Team Tasks	Procedures requiring tasks to be performed by various team members.	More diversity in tasks results in less retention.	Hypothesis: required actions of other team members may be understood or remembered less, which negatively effects the retention of the own action in the team task.	

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Task integration complexity This factor relates to task complexity on four dimensions (adopted from Wang et al., 2013), where higher complexity on one or more dimensions will require more integration of skills and knowledge. Although it can be expected that complexity on one dimension will correlate with complexity on the other dimensions, each complex task may have a specific configuration on the four dimensions.				
Closed-Open-Looped Task Dimension	Open-looped tasks relate to continuous responses that are repeated and tend to be more dynamic. Closed-looped tasks relate to a fixed sequence of discrete actions in a not very dynamic context.	Open-looped tasks are retained better than closed-looped tasks.	Open-looped, continuous tasks are more meaningful, rely more on existing, higher-order knowledge (mental models), and are more integrated; closed-looped tasks require many aspects to be remembered and are less integrated.	Not many empirical studies for complex tasks are available. An exception, for example, is Villado et al. (2013) using a complex decision-making game. A review study which explicitly pays attention to complex tasks is Wang et al. (2013). Most of the review studies discuss closed-open-looped tasks as a factor (Adams, Webb, Angel, and Bryant, 2003; Arthur et al., 1998; Bryant and Angel, 2000; Farr, 1987; Sanli and Carnahan, 2018; Vlasblom, Pennings, van der Pal, Oprins, 2020; Wang et al., 2013. The Wang 2013 meta-analysis tended to support the hypothesis that high complexity support retention, but results were inconclusive due to lack of empirical studies that cover sufficiently complex tasks (and details on each dimension).
Discrete – Continuous Dimension	Number of choices or approaches that can be adopted to perform task and reach an end goal.	Continuous tasks are retained better than discrete tasks.	idem	
Fixed – Dynamic Dimension	Level of uncertainty in task information or context, requiring attention to the different components in the task environment.	Dynamic tasks are retained better than fixed tasks.	idem	

Topic	Description	Direction of Effect	Psychological Mechanism	Scientific Evidence
Component Complexity Dimension	Number of distinct but interrelated processes and behaviours as required to execute a task and the total number of distinct information cues that must be processed in performing actions.	More complex tasks lead to more retention. Hypothesis: when processes or cues are concurrent and interrelated, higher retention is expected. However, when the processes/ cues are sequential and not interrelated, 'component complexity' is basically the same task sequence complexity, then a higher complexity will result in lower retention.	More interrelated tasks, in particular requiring high-level cognitive skills, may have positive effects, possibly due to internalised mental models, which are less prone to decay. Also, a higher level of integration of skills requires a longer training process and deeper learning, which may lead to higher automation of (sub)processes.	

Table B-3: Training and Education: Summary Table of Influencing Factors.

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Spacing of Learning	The length of the inter-study period which may be designed to be long (i.e., spaced) or by comparison, short (i.e., massed).	Spaced learning generally results in the retention of more skills than massed learning.	Greater spacing of learning increases the opportunity for mental rehearsal, information processing and retrieval practice, and it decreases fatigue arising from intensive practice periods (Arthur et al., 2013).	Supporting evidence drawn from the following: • Meta-analysis (Cepeda et al., 2006) and systematic literature review – surgical tasks (Cecilio-Fernandes et al., 2018); • Spaced learning and simple motor tasks (Donavan and Radosvich, 1999); • Improved recognition memory (Xue et al., 2011); experimental research (Cepeda et al., 2008); moderating effect of task type (Patocka, 2019; Arthur et al., 2019); • No absolute criteria defining spaced versus massed learning (Cecilio-Fernandes et al. 2018).
Mastery Training	Deliberately overtraining beyond the set criterion or competence level required to do a task (also known as overlearning and overtraining).	Mastery training improves retention. This effect is moderated by the degree of overlearning, the type of task, and length of retention period (Cahillane et al., 2013).	Extended training increases automaticity, which in turn reduces the likelihood of skill decay (Arthur et al., 2013). Overlearning decreases performance decay by increasing trainees' confidence via greater levels of self-efficacy and lesser levels of anxiety to perform (Arthur et al., 2013).	Supporting evidence drawn from the following: • Meta-analysis (Driskel et al., 1992); • Experimental research (Rohrer et al., 2005); reacquisition of skill and knowledge (Hagman, 1982); • Training transfer (Zakay and Wooler, 1984); • Neuroscience and hyperstabilisation (Shibata et al. 2017).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Mental Practise/Rehearsal	The cognitive rehearsal of a physical procedural activity in the absence of overt physical movements being conducted (Driskell et al., 1994). Distinguished from the broader term mental preparation which includes positive imagery, attention focusing, and cognitive and emotional preparation prior to performance (Driskell et al., 1994).	Mental rehearsal (i.e., recurrent training) improves skill retention.	Mental rehearsal promotes overlearning thereby reducing skill decay (Arthur et al., 2013). Mental rehearsal strengthens discrete psychomotor skills that involve cognitive control of physical movements and manipulations (Vealy and Walter, 1993, cited in Cahillane et al., 2013).	Supporting evidence drawn from the following: • Meta-analysis (Driskel et al., 1994); • Use mental practise when unable to practice specialist skills (Kelc et al., 2020).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Deliberate Practice	The provision of defined opportunities to practice specific types of skills within a workplace environment.	Exposure to deliberate practice opportunities within a workplace environment (if well designed, implemented and assessed) improves skill retention.	Performance is maintained through reinforcement and conditioning (Arthur et al., 2013).	Supporting evidence drawn from the following: • Longitudinal studies, (Meerkov et al., 2019, Skare et al., 2018); • Main features of deliberate practice (Sullivan, 2019); pre-/post-deployment refresher training (Vermeulen et al., 2019); • Medical readiness training (Mead et al., 2017, Mikita, 2017, Hossein et al., 2020); • "Just-in-time practice" (Guidolin et al., 2020); • Planned research – comparison of deliberate practice and self-guided learning (Petrosoniak et al., 2019).
Retrieval Practice and Test-Enhanced Learning	The extent that training and education is designed to include opportunities to test the learner's retrieval of knowledge and ability to demonstrate newly acquired skills.	Retrieval practice improves long-term retention and transfer of competence to related but non-tested material.	Test-enhanced learning reactivates related prior knowledge alongside the new material; new memories are integrated into existing cortical representations (Hebscher et al., 2019). Test-enhanced learning may also reduce mind-wandering / boredom (Peterson and Wissman, 2020).	Supporting evidence drawn from the following: • Meta-analytic review and synthesis (Pan, 2018); • Experimental studies to investigate benefits (Roediger et al., 2011; Roediger et al., 2010; Karpicke and Roediger, 2008); • Specific consideration of the moderating effect of feedback on test-enhanced learning (Butler et al., 2007).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Feedback	Detailed immediate feedback stemming from a learner's performance, combined with a chance to improve performance.	Constructive, timely and meaningful (i.e., relevant and specific to the trainee) feedback improves skill retention. It allows the learner to identify strengths and weaknesses in their performance and to continuously adjust their performance accordingly.	Performance is maintained through reinforcement and conditioning (Arthur et al., 2013).	Supporting evidence drawn from the following: • Experimental studies investigating feedback delivered via peer-to-peer / social learning (Youngsuk, 2016); and • The use of learning technology to enable practice and self-reflection outside of the learning environment (Kun et al., 2018; Linde and Miller). • Investigation of the provision and timing of feedback (Dihoff et al., 2012).
Fidelity of the Learning Environment	The extent that cues present within the workplace environment are replicated during training and education as indicated by different types and levels of fidelity: scenario fidelity, sensory fidelity, and (inter)action fidelity.	The rate of decay is slower when environmental cues during training are similar to those in the transfer environment (Arthur et al., 2013).	'Performance is more resilient to decay because the similarities in the environment trigger cues making information readily available and easier to retrieve from memory' (Arthur et al., 2013, p. 370).	The selection of appropriate methods and media to support the initial and recurrent training and education of personnel operating within a defence environment is embodied within Defence Standards and specifically within the Media and Methods options analysis process (e.g., Joint Services Publication 822 – Direction and Guidance for Training and Education). This process takes into consideration relevant types and levels of fidelity required to support training and education and importantly identifies key differences between the learning and real-world environments that need to be addressed within the workplace. (Buttussi and Chittaro 2018, McMahan et al., 2012, and Ragan et al., 2015).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Learning Technology	The use of learning technologies such as Augmented Reality (AR) to support training and education.	Appropriately designed learning that is delivered through the use of AR/AV provides a way to increase learner interest, engagement, and motivation to learn. This improves skill retention.	Performance is maintained given the quality of initial learning and the opportunity to tailor (i.e., personalise) training and education to the capabilities, prior experiences, and preferences of the learner.	Evidence from a review of published literature to determine the effectiveness of augmented reality and augmented virtuality on training and performance (e.g., Fletcher et al., 2017, Buttussi and Chittaro, 2018).
Printed Materials	Training based on printed materials (text, pictograms).	Retention is poorer when using printed materials for training compared with audiovisual materials, especially the most interactive ones such as VR.	Printed materials make it more difficult to guide appropriate cognitive processing and distribute stimuli among different processing channels; see cognitive theory of multimedia learning (Mayer, 2014).	Printed materials proved to be inferior to VR in retention outcomes (Chittaro and Buttussi, 2015; Buttussi and Chittaro, 2021).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Video	Training based on watching videos.	Videos are more effective than reading text, provided that trainees are given controls to self-pace video watching (for example, pausing, playing speed, rewinding). Positively affecting retention requires additional improvements to the video experience such as cueing to help learners in selecting relevant information and organising and integrating the information into a coherent representation.	Videos make it easier to guide appropriate cognitive processing and distribute stimuli among different processing channels; see cognitive theory of multimedia learning (Mayer, 2014). Individual ability to process information presented at a given rate influences learning outcome, making self-pacing important.	Watching videos vs. reading text (DeFleur et al., 1992; Furnham and Gunter, 1985; Furnham and Gunter, 1987; Gunter, Furnham, and Gietson, 1984; Gunter, Furnham, and Leese, 1986; van der Molen and Van Der Voort, 2000; Wicks and Drew, 1991; Wilson, 1974). Interactive aspects that improve video watching (Schwan and Riempp, 2004; Hasler et al., 2007; Merkt et al., 2011; Mayer and Chandler, 2001; Hasler et al., 2007; Newtson and Engquist, 1976; Schwan, Garsoffky and Hesse, 2000; de Koning, Tabbers, Rikers, and Paas, 2007; Dube and McEwen, 2015). Effects of cueing of animated content on retention (Mautone and Mayer, 2001; Moreno, 2007; de Koning et al., 2009).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Virtual Reality	Training based on Virtual Reality experiences.	Virtual Reality (VR) is more effective at improving retention than traditional training media.	Psychological fidelity of a VR experience can be very close to a real-world experience (Feng, Gonzalez, Amor, Lovreglio, and Cabrera, 2018; McComas, MacKay and Pivik, 2002; Rose, Attree, Brooks, Parslow, and Penn, 2000; Smith and Ericson, 2009; van Ginkel et al., 2019). Different learning theories (constructivism, situated learning, multimodal learning) emphasise characteristics of experiences that are important for human learning and can be provided by VR (see Section 5.3) The Deep Learning hypothesis (Makransky et al. 2020) states that learning in VR primes students to exert extra effort needed to process the material more deeply. VR can support embodied cognition.	VR vs. printed materials in aviation safety training (Chittaro and Buttussi, 2015; Buttussi and Chittaro, 2021). VR in surgery training (Silverstein et al., 2002; Kruglikova et al., 2010). VR in decontamination training (Smith et al., 2016).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Engagement and Emotional Arousal	Engagement and emotional arousal induced by the training experience.	Engagement and emotional arousal can positively affect retention.	Arousal and emotions contribute to memory consolidation.	Neuroscience studies of audio-video narratives (Sharot et al., 2004; Labar and Cabeza, 2004; McCaugh, 2000; Nielson and Arentsen; 2012; Kensinger, 2009; Finn and Roediger, 2011; Kensinger and Schacter, 2008; Cahill et al., 1994). Studies of VR (Chittaro and Buttussi, 2015; Buttussi and Chittaro. 2020).
Design of Training Media	Design choices that shape trainee's experience of the training media.	A training media that is designed to be easy to use and engaging improves learning and retention.	For engagement, see Engagement entry in this table. Regarding ease-of-use, since it focuses on features that reduce cognitive load (readability, clarity, simplicity, intuitiveness, help support), it facilitates trainee's information processing.	Engagement (Chittaro and Buttussi, 2015) ; Usability (Parlangeli et al., 1999).
Hardware Display Used in Computer-Based Training	The type of display used in the computer-based training experience (smartphone display, tablet display, PC monitor, head-mounted display, etc.).	Display fidelity positively affects engagement.	Displays that fill a larger portion of the trainee's field of view provide more sensory stimulation and thus more arousal/engagement.	HMDs vs. traditional displays (Moreno and Mayer, 2002; Buttussi and Chittaro, 2018). Different displays (VR headset, smartphone) vs. printed materials (Buttussi and Chittaro, 2021).

Influencing Factor	Description	Direction of Effects	Psychological Mechanism	Scientific Evidence
Haptic Hardware Used in Computer-Based Training	Presence of haptics, which is special hardware able to reproduce tactile stimuli and/or physical forces, in the training system.	Addition of haptic hardware can improve learning and retention of motor skills.	Haptics can extend the fidelity of the experience as well as the support to embodied cognition.	Carlson et al. (2015).

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14. Abstract

Competences acquired through training inevitably fade if they are not regularly practised. This can jeopardise personnel safety, operational effectiveness, and cost-effectiveness of training. The importance of approaches to minimise skill fade and maximise competence retention is likely to increase in NATO countries, because military personnel will need to learn and retain a greater number of competences across a career to face the instability and uncertainty of future threats. Familiarity with the different factors that influence skill fade, and the strategies to mitigate it, is essential to take proper choices aimed at the retention of competence. To address this need, this report offers a contemporary framework for identifying and understanding such factors. The framework was defined over a period of three years, after a thorough literature search and through a series of expert meetings of the HFM-292 "Understanding and Reducing Skill Decay" Research Task Group. The resulting framework highlights 38 factors that influence skill fade, organised into three categories: person-related, task-related, and training and education-related factors. This report provides a detailed description of each factor, the direction of its effect on competence acquisition and retention, and the supporting evidence from existing scientific literature. Moreover, it summarises the nine main psychological mechanisms that underlie the factors. Finally, key approaches for competence retention and recommendations for future developments are outlined, considering the context of both researchers and practitioners in the field.

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