Literature Review on Skill Fade

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1 Executive Summary

The following report has four main components. The first component is a summary of three papers written in 1998 on the area of skill fade. The first paper, written by Arthur et al., is a meta-analysis of all research pertaining to skill fade. The meta-analysis aimed to categorically state how training variables positively or negatively affect skill retention. The second paper, written by Healy et al., briefly reviews the skill fade literature, describes several experiments they conducted and then makes recommendations of how training programmes should be designed. The third paper, written by Summers et al., introduces the research on skill fade and divides it between five main psychological areas. Summers et al. then unsuccessfully attempt to validate a model aimed at predicting team skill fade and recommend a now widely accepted process for the whole training procurement and implementation process. The three papers are presented in sections three to five respectively.

The second component of this report is a summary of the research, post 1998, relating to the field of skill fade (see section six). Included in the summary is an explanation of whether the research is new or contradictory to previous research and a recommendation stating how the research should be used when training service personnel.

The third component uses the stable pre 1998 research and the updated research findings to update Healy et al.'s three class model to optimise training. The first class has had seven new points added aimed at optimising the conditions of training and now includes: encourage mental practice and rehearsal outside the class room; fear of erroneous mental practice is unnecessary during training providing feedback is provided on those errors at some point. The second class aimed at optimising the learning strategy has had two new points added and now includes: successfully tested material can be dropped from further study but should be continually tested for to increase long term retention. The third class aimed to automate the trained material, however, no additional literature was found that could be used to update this class. The nine additions to the first class and second class are explained in more detail in section seven.

The fourth and final component includes recommendations of further work aimed at progressing the research to a point where the area of skill fade is comprehensively understood. A comprehensive understanding will facilitate optimisation of all military training programmes, minimising costs for maximum results. Recommendations for further work include reviewing the types of tasks performed in the different areas of the military. Identifying the predominant tasks will facilitate the focus of our efforts towards training recommendations. Four booklets aimed at the key areas of procuring and designing efficient training programmes are recommended for the use of Project Managers, Human Factors Engineers and Trainers. Finally, further research into developing automaticity in tasks is recommended. With this knowledge we will be able to optimise the efficient use of training time and trainee ability to handle extreme situations in the field.

2 Introduction

Every day life is marred with the inability to recall useful and important information when desired. The enjoyment of games and sports are reduced when a player is annoyed because their performance is not as good as it was eight months ago, when they were playing four times a week. Was it just non-use that lead to the forgetting or was it poor training when the information was learnt? The following report reviews the findings from research looking at the causes and options for avoiding skill fade.

The first part of the report reviews and extends findings from three papers, published in 1998, on the subject of skill fade. Skill fade is the loss of knowledge or skills following training, to a success criterion, over a period of non-use. This work is provided in support of HFI DTC Work Package 10.3. The three documents are introduced briefly in this section and presented in more detail in sections three, four and five:

- Arthur, W., Jr., Bennett, W., Jr., Stanush, P. L., & McNelly, T. L. (1998): "Factors That Influence Skill Decay and Retention: A Quantitative Review and Analysis". Arthur et al. reviewed literature that focused on factors affecting the retention of skills and knowledge over extended periods of non-use.

- Healy, A. F., Clawson, D. M., McNamara, D. S., Marmie, W. R., Schneider, V. I., Rickard, T. C., Crutcher, R. J., King, C. L., Ericsson, E., Bourne, L. E. Jr. (1998): "The Long-Term Retention of Knowledge and Skills". In this paper, Healy et al. found three classes of guidelines to optimise long-term retention. They are, training conditions, optimising the strategies used and how to attain direct access or automate retrieval from memory.

- Summers, A., Gregory, D., Kelly, M., Harland, S. (1998): "Predicting Skill Fade and Procuring Performance" - introduces what was known about skill fade, the key psychological concepts and then goes on to describe a validation study on a predictive US model using BATES (Battle Artillery Target Engagement System). The paper then goes on to suggest future research to aid the development of a robust UK skill fade model. Summers et al. suggest the model assists trainers in making training decisions for new skills and systems in the digitized battle space era.

Section six presents the research that followed 1998. It introduces new work on "Overlearning" (showing it is not the most significant element in long term retention of skills or knowledge), "The Testing Effect", Inter-Study-Intervals, and further work on Individual Differences (ability, motivation and prior knowledge) and mental practice.

Section seven uses the updated literature review to make recommendation on the factors a trainer should aim to include in their training programmes. These recommendations are included into Healy et al.'s three class structure.

Finally, section eight recommends important and practical further work. In this section, it is made explicit how the three papers and subsequent work tie together. The cohesion between the three papers creates the opportunity to populate the Summers et al. model,

highlighting the areas that HF and Training personnel can rely on and the areas where further research efforts should be directed towards. Using this model a useful software program or web application could be built to assist in the design of optimum and efficient military training programmes, protecting their personnel from skill fade.

3 Paper 1: Arthur et al. (1998): Factors That Influence Skill Decay and Retention: A Quantitative Review and Analysis

Arthur et al. conducted a meta-analysis of 189 independent data points. The data points were generated by reading the abstracts to thousands of documents. From the documents read 270 were chosen for further analysis. They established a set of inclusion criteria. One example of a criterion used was that a study had to present both pre and post retention data. Using their criteria the team were left with 52 documents from the original list of 270. Arthur et al. report on 9 areas affecting skill fade, summarised in section 3.1 and described in more detail in sections 3.1.1 to 3.1.9.

3.1 Factors Affecting Skill Fade

Arthur et al. (1998) identify nine areas affecting skill fade:

- Retention Interval;
- Degree of Overlearning;
- Task Type (comprised of 3 sub-classes – Physical and Cognitive, Open-loop and Closed-loop and Natural and Artificial);
- Speed versus Accuracy;
- Methods of Testing for Original Learning and Retention;
- Condition of Retrieval: Similarity of Original Learning and Retention Testing Contexts;
- Evaluation Criteria;
- Instructional Strategies and Training Methods;
- Individual Differences - Ability.

The above nine areas are summarised in more detail below.

3.1.1 Retention Interval

It is widely accepted that the longer the period of non-use the greater the probability of decay (Annett, (1979); Farr, (1987); Gaurlin & Sitterly, (1972); Hurlock & Montague, (1982); Naylor & Briggs, (1961); Prophet (1976) cited in Arthur et al. (1998)). Other factors affect the amount of skill decay during periods of non-use and these factors are discussed in the following sections.

3.1.2 Overlearning

Overlearning is the amount of extra training beyond the point required to reach initial proficiency. Overlearning was reported as being the single most important factor in knowledge retention. There were several reasons given for overlearning being so responsible for decreasing the likelihood that the response will be forgotten.

- Overlearning could increase the cognitive association between stimulus and response (Schendel & Hagman (1982) cited in Arthur et al. (1998)).

- Increasing the practice increases the repetitions. This, in turn, increases the feedback to the trainee of the errors that can occur, how to avoid them and therefore build a better procedural model of how to successfully complete the task. Additionally, the trainee could increase in confidence reducing stress or anxiety which has been shown to reduce performance (Mathers (1974), cited in Arthur et al. (1998)).

- Overlearning possibly increases automaticity reducing the amount of concentration required and effort.

3.1.3 Task Type

Broad classifications of task type include: physical/cognitive, open-loop/closed-loop, natural/artificial, integrated/non-integrated and instrument/contact tasks. Arthur et al. only chose to define the first three pairs of task types, their definitions are summarised below. The reason for the distinction is that the type of task may moderate the effect of overlearning on skill retention.

3.1.3.1 Physical and Cognitive tasks

Physical tasks require physical strength, exertion of forces, endurance and coordination. Cognitive tasks require perceptual input, mental operations, problem solving and decision making.

In Arthur et al.'s introduction they report that cognitive tasks are retained better than physical tasks when mental practice is permitted. Driskell et al. (1994), (cited in Arthur et al. (1998)) showed that although both task types were open to mental rehearsal cognitive tasks lent themselves better to rehearsal than physical tasks. When the meta-analysis had been completed, excluding studies that included mental rehearsal, Arthur et al. showed that subjects retained knowledge better in physical tasks. Arthur et al's meta-analysis appears contradictory to their initial literature review where they state that cognitive tasks are retained better, however, their initial statement only holds when there is "mental practice" is present. When mental practice is excluded physical tasks are retained better than cognitive tasks.

3.1.3.2 Open-loop and Closed-loop Tasks

Open-loop tasks involve continuous responses with no beginning or end e.g., tracking or problem solving. Closed-loop tasks have a definitive beginning and end e.g., pre-flight checks.

Open-loop tasks were concluded as being better retained than closed-loop tasks. Several explanations are given as to why this maybe the case:

- Open-loop tasks are more likely to be part of everyday life, leading to practice thus leading to overlearning[1] (Adams (1967); Naylor & Briggs (1961), cited in Arthur et al. (1998)).

- The two task types may differ in the way they are measured for skill decay. Schendel et al. (1978, cited in Arthur et al., 1998) suggested, in the context of physical tasks, that measurements for closed-loop tasks may be more sensitive than open-loop tasks leading to better identification of skill decay.

3.1.3.3 Natural and Artificial Tasks

Natural tasks are those that are context specific and include: lunar landings, military tasks and piano playing. Artificial tasks are not context specific other than in the experiment and include: various forms of tracking, balancing, ball tossing, etc. Natural and artificial tasks differ in two main areas important to retention, complexity and motivation. As natural tasks are more complex, they are more elaborately processed, positively influencing how well they are learned and retained. Trainees generally have a genuine interest acquiring and retaining knowledge of natural tasks. Arthur et al. showed natural tasks are less susceptible to skill fade than artificial tasks.

3.1.4 Speed vs. Accuracy

Speed (time to complete task) and accuracy (number of errors) are dependant variables used in the measurement of skill fade. Arthur et al. found that, in experiments investigating skill fade, task accuracy was 3 times more susceptible to skill fade than task completion time. This finding while intuitive is caveated due to their lack of data when performing their statistical analysis.

3.1.5 Method of Testing For Original Learning and Retention

The usual structure for testing for original learning and retention sees the subject trained to a specific criterion and tested for retention at a later date. The retention test usually takes two forms, recall and recognition tests. An individual's ability to recognise an event

[1] More recent findings allow us to more accurately define this rehearsal as Inter-Study-Intervals which is discussed in more detail later in section 6.1.3.

is separate from their ability to recall it. The meta-analysis findings were that recall tests show greater skill fade than recognition tests.

3.1.6 Conditions of Retrieval: Similarity of Original Learning and Retention Testing Contexts

Arthur et al. found that the similarity between the functional task and environment in the training condition had a positive correlation with skill retention in the test environment.

Both the amount and quality of skill retention appear to depend on how the information was encoded and the types of cues present at retrieval. “Encoding Specificity Principle” states that if the conditions at retrieval (testing) are the same as the conditions at retention (learning) the skill fade will be decreased. The recall or knowledge retention is also increased if the test and learning environment are similar as the trainee has more environmental cues to draw upon when encoding and recalling the information. The richness of the retrieval cue and absence of irrelevant cues reduces the cue noise thereby increasing the ability to retrieve and recall information.

Importantly the physical fidelity of the training device may be less important than the functional fidelity. If the training does not accurately represent the process of the task to be used in the real world, the visual cues are useless (Grinsley, 1969 cited in Arthur et al., 1998).

3.1.7 Evaluation Criteria

Evaluation criteria do not affect skill fade they are only the ruler by which skill fade is measured. Arthur et al. nonetheless included them in their meta-analysis; thus it has been included here for completeness.

Evaluation criteria can be based around four different criterion measures. These are: reactions (trainee’s feelings or impressions), learning (learning outcomes of the training), behaviour (on-the-job performance), and results (related to organisational objectives, e.g., reduced costs/absenteeism and company profits). Behaviour and results criteria can be subdivided into objective and subjective.

Arthur et al.’s meta-analysis was limited to learning and behaviour criteria as the other two criteria do not lend themselves to investigations of skill decay or retention. Behavioural criteria see better skill retention results than learning criteria; this could be due to the type of tasks they are used to measure, on-the-job/natural tasks, as opposed to learning which would see more artificial/laboratory-based tasks.

3.1.8 Instructional Strategies and Training Method

Many media and strategies can be used to facilitate the training of skills. The most common forms of instruction or training include, on-the-job training and the lecture method. Not much attention has been given to training and instructional methods in the skill fade literature, the method of training was usually omitted from the reports. Therefore, Arthur et al. were unable to perform a meta-analysis investigating this area.

Nonetheless, they reported that the limited research indicates that the type of training method or instructions given affect the knowledge retention. The example given by Arthur et al. concerned the training of intellectual skills where programmed instruction[2] was found to lead to better knowledge retention than "platform-based, lock-step[3]" instruction (Farr, 1987 as cited in Arthur et al., 1998).

3.1.9 Individual Differences - Ability

Individuals with higher abilities consistently show less skill fade than their less able counterparts. It is not known if individuals with higher ability retain knowledge better than individuals with less ability or if they retain more information and/or skills during the training period. There is evidence to suggest that this is because the lower ability learners forget larger chunks of abstract, theoretical material than higher ability individuals. Additionally it has been seen that overlearning has a negative effect on skill fade, therefore, if a task is taught for a set time instead of to a task success level, retaining information quicker could lead to an element of overlearning.

[2] Programmed instruction is self taught learning from a text book or computer

[3] Platform-based lock-step is learning at a forced pace, step by step via a computer system.

4 Paper 2: Healy et al. (1998): Long-Term Retention of Knowledge and Skills

Healy et al. (1998) conducted numerous original studies investigating eight areas affecting the acquisition and long term retention of knowledge and skills. The aim of the team was to produce recommendations for effective training. Healy et al. felt their research was distinguished from previous research in five ways.

1. They aimed to improve performance after the retention period rather than assuming better retention from optimised performance during training. With this in mind, they aimed to identify training conditions that allowed performance to remain long after training.

2. Healy et al. used retention periods of weeks, months and even one to two years.

3. A combination of two experimental procedures, structural and analytic. Using a structural approach Healey et al. aimed to identify and describe the elements of different skills. They assessed the skill components for their retention characteristics by refining existing experimental methods.

4. They conducted comparable experiments over a range of skills with the aim of eliciting the stable training guidelines for general tasks or specific tasks.

5. Instead of looking at retention from the perspective of accuracy, they reviewed retention as a function of the percentage of subjects who retained the accuracy criteria as a function of delay.

From their research, Healy et al. found three classes that optimise long term retention. The three classes relate to:

1. Optimising the conditions of training,

2. Optimising the learning strategy used, and

3. Achieving automatic levels of processing.

All three classes are discussed in more detail in sections 4.1 to 4.3.

4.1 Class One - Optimising Conditions of Training

Healy et al. identified three general guidelines for optimising training conditions:

4.1.1 Contextual interference

An example of contextual interference is random sequences of tasks as opposed to fixed or predicted sequences. In the experiments conducted by Healy et al. contextual interference increased long term retention of knowledge. It was presumed that the

increased practice in retrieving the appropriate response to the stimulus improved retention.

4.1.2 Training Parts of the Task Versus the Whole Task

Here, Healy et al. recommend focusing on components that can be trained to full competency in the constraints of the training period and to avoid trivial components or components that are common to everyday life, e.g., visual search tasks.

4.1.3 The "Generation Effect"

The Generation Effect holds for memory of facts and skills. This is where the trainee generates the answer as opposed to reading it.

4.2 Class Two – Optimise the Strategies Used

The second class advises training of the tasks should be designed to encourage deliberate retrieval from memory to promote efficient encoding strategies and better retention of information.

4.3 Class Three – Achieve Automatic Retrieval

The third class concerns guidelines aimed at achieving automatic retrieval from memory. Healy et al. identified that extensive practice is necessary for direct retrieval of information. However, Healy et al. also found that for some tasks, even after extensive practice mediators still affect automaticity.

5 Paper 3: Summers et al. (1998): Predicting Skill Fade and Procuring Performance

Summers et al. (1998) start by introducing the psychological concepts of skill fade, within which all the factors affecting it belong. These psychological concepts include: Skill Acquisition, Skill Loss, Skill Maintenance, Skill Re-acquisition and Skills Transfer and section 5.1 summarises this. Summers et al. then review the literature and present models for predicting skill fade, these are summarised in 5.2 and 5.3 respectively. Section 5.4 presents Summers et al.'s work on procuring training, the primary focus of Summers et al.'s work.

5.1 Psychological Concepts

5.1.1 Skill Acquisition

Skill acquisition is the level of learning an individual achieves, following training, in order to be able to complete a task. Summers et al. report that the primary areas affecting skill acquisition are:

- Motivation to Learn;
- Ability to Learn;
- Prior Knowledge.

These areas are described in more detail below.

5.1.1.1 Motivation to Learn

An individual's motivation to learn is affected by their self belief that they are able to acquire the knowledge, the belief of the trainer in their ability, the student's interest in the subject matter, the desire to achieve more, fear of the consequences for not achieving the necessary results, how necessary the training is for their work and how important their work is to them.

5.1.1.2 Ability to Learn

Summers et al. report that ability, general intelligence, is "the most consistent and reliable predictor of learning …" They go on to say that the individual will learn, apply in new or similar situations and retain knowledge better if they thoroughly understand the underlying principles.

5.1.1.3 Prior Knowledge

Where an individual has prior knowledge they have a context in which to put new information, making what they are learning more meaningful. Prior knowledge also means that the individual's skills may already be automatic which reduces cognitive workload allowing them to concentrate on the new aspects of the task.

5.1.2 Skill Fade

As mentioned above skills decay over a period of non-use. Some skills, however, decay less. One such skill is riding a bike - probably due to the level of automaticity needed to prevent falling off. Tasks which are less predictable and more complex, possibly involving analysis and decision making, require a different approach to simple repetitious practice, for example improving the level of understanding of the underlying principles to increase the knowledge retention.

Summers et al. speculate if apparent skill loss is due to poor learning rather than forgetting the information. That is, the information is stored in long-term memory but the individual is unable to recall it. Summers et al. postulate that it is due to ineffective structuring of the information during the skill acquisition. They suggest that students are trained with a better association between information to assist them with recall.

5.1.3 Skill maintenance

Skill maintenance is the process of preventing skills from deteriorating below an acceptable performance level.

5.1.4 Skill Re-acquisition

Skill re-acquisition is the concept relating to the re-training of a skill that has deteriorated below an acceptable criterion. The greater the skill loss the greater the effort required to bring the individual up to proficiency. Summers et al. state that the considerations for skill re-acquisition include: the nature, timing, amount and frequency of training. The nature of the training may simply be to remind the individual of the information. The timing is concerned with operational requirement, e.g., a sudden war, and the criticality of the skill to operational requirements and the availability of the necessary facilities. The amount of training is related to the level of skill loss, task difficulty, the level of skill proficiency required and the purpose for the training.

5.1.5 Skill Transfer

Skill transfer from the training environment and system to the real environment and system is thought to be facilitated through the fidelity of the training to the conditions where it will be used (Baldwin and Ford (1988), cited in Summers et al. (1998)). To transfer these skills to the battle field the trainees should be trained to a level where unexpected conditions do not affect performance. There are two primary ways of preparing troops for the unexpected and these depend on the skills being used:

1. Consistent Skills – usually psychomotor skills, require that they are trained to automaticity so they can not be affected by unexpected stimuli

2. Complex Skills – usually cognitive skills, require the individual is trained to a level where they have an excellent grasp of the underlying principles.

5.2 Literature Review

The Summers et al. paper includes McGuinness et al.'s (1995) tabulation of their findings from a literature review on the topics relating to skill fade. McGuinness et al.'s tabulation puts their review of the literature into broad categories proposed by Hurlock and Montague (1982). These categories are Task Characteristics, Learning Factors, Post Learning Activities, Job Conditions and Personal Characteristics. For completeness the table is included below, however, it is not felt the information adds anything additional to Arthur et al.'s summary of the literature (See Table 1).

Table 1. The Tabulation of Skill Retention Review

Training Factor	Element	Summary Findings
Task Characteristics	Psychomotor Procedural Cognitive Social/Communication Continuous; Discrete	• We lack a common metric for retention, across different types of task. • Differences in retention may be attributable to task type (e.g. procedural, cognitive) or how tasks are organised. • Analysis of a skill in terms of its individual components is critical if the objective is to identify which components are relatively vulnerable to decay or relatively stable over time. • The majority of research has been for psychomotor skills. There is very little corresponding work on complex cognitive skills.
Learning Factors	Learning, overlearning and retention	• Long term retention of task competence can be improved by increasing the level of original learning. • Criterion by which the level of 'mastery' is being tested needs to be clearly defined to differentiate between learning and overlearning, particularly during the original learning phase. • 50% overtraining would appear to be the maximum amount required to promote retention of task mastery. • For maintaining optimal performance for cognitive tasks, the interval between training and performance should be no

Training Factor	Element	Summary Findings
		longer than three weeks. • High contextual interference during training, in relatively simple tasks, produces longer term retention. This effect is particularly noticeable with those who tend to have an impulsive style of problem solving. • Skills which have become highly automated during training, using consistent mapping and extensive practice show negligible decay over periods of non practice.
	System knowledge – conceptual and operational knowledge	• Operational knowledge is beneficial for the acquisition of skill in relatively complex procedural tasks. • Conceptual knowledge aids retention if it allows the trainee to infer the exact procedures to perform a complex task and the trainee is explicitly shown strategies for how to apply that knowledge.
	Feedback	• Feedback on elements of a trainee's performance on the whole task has been found to be more effective than segmented feedback. • Augmented feedback has been found to increase skill acquisition where task-inherent cues are either scarce or difficult to interpret, but this should <u>decrease</u> towards the end of the training. • Feedback with a slight delay interval is more effective than immediate feedback, if it allows the trainee to acquire error-detection capabilities. • Distributed training schedules have been found to enhance retention. The optimal amount, length and timing of the sessions is dependent on: the complexity of the task, the type of knowledge or skills to be taught, and the age and abilities of the students.
Post-learning activities	Re-learning and refresher training	• Test trials have been found to promote retention and be effective as a means of refresher training, providing performance ability has not dropped below acceptable levels. • Low cost options such as mental rehearsal and simulators with low physical fidelity are considered to be

Training Factor	Element	Summary Findings
		adequate for the refresher training of cognitive and procedural tasks, as long as there is sufficient relevant representation of task elements. • Refresher training sessions should be provided at intervals approximately equal to expected retention intervals. • Refresher training sessions can be just as effective at expanding time intervals as that provided by constant time intervals.
Job Conditions	Retention and Transfer	• Optimal retention can be expected when the retention test requires the operator to duplicate the same mental operations as were originally employed for skill acquisition. • Extreme environmental conditions have been reported as damaging recall. • Considerable differences between operational conditions and the original training conditions show degraded performance. • Physiological and psychological stress can both impede performance.
Personnel Characteristics	Ability, experience, age, sex and motivation	• Trained individuals exhibit equivalent rates of forgetting, regardless of difference in their levels of ability. • High ability trainees reach greater proficiency levels sooner, significantly affecting their retention rates by overlearning and/or their better understanding of the material. They will also relearn more quickly. • Previous scores on skill tests were found to be the strongest predictor of skill loss. • Age, sex and motivation do not substantively affect skill retention rates.

Table 2, below, shows Summers et al.'s summary of the literature review and how the component parts fit within the psychological factors listed above.

Table 2. Factors Effecting Skill Retention and Their Relevance to the 5 Psychological Factors (Comments in the Table are made by Healy et al.).

Psychological Factors	Retention Characteristics	Comments
Skill acquisition	Training factors; post training activities and personnel characteristics.	Personnel characteristics are the strongest single predictor of skill acquisition.
Skill loss	Task characteristics; learning factors; post learning activities; job conditions; personnel characteristics.	Better levels of proficiency which more able trainees are likely to have acquired are, in turn, reflected in better retention rates. Task complexity is the single most important factor in skill loss.
Skill maintenance	Task characteristics; learning factors; post learning activities; job conditions; personnel characteristics.	Competence in complex tasks drops significantly after 6 months. In order to maintain proficiency levels some form of refresher training can be introduced within this time scale. A low cost option such as low physical fidelity simulation has been found to be effective.
Skill re-acquisition	Task characteristics, learning factors; post learning activities; personnel characteristics.	Higher initial proficiency levels generally equate to faster skill re-acquisition. Suggested options are: - to select high ability individuals for initial training in complex tasks; - to train lower ability individuals to higher levels; - to ensure higher skill maintenance.
Skill transfer	Task characteristics, learning factors; job conditions; personnel characteristics.	Factors affecting skill transfer are: - level of physical and psychological fidelity; - level of organisation involved in the individual's mental model for complex procedural tasks; - automation of simple psycho-motor tasks.

5.3 Modelling Skill Fade

Summers et al. (1998) then summarise Quantitative Skill Fade Models including: Sticha, Knerr and Goldberg (1983), Rigg and Gray (1981) Goldberg and O'Rourke (1989) and the US Army Research Institute's (ARI) Task Classification System (TCS). This model looks at predicting unit efficiency on a task and is not meant for individual performance.

Summers et al. looked to validate the model. Their findings were heavily constrained by participant drop out and varying levels of exposure to the test material during retention. The varying levels of exposure to their test material effectively made statistical testing impossible. Nonetheless, two findings emerged. First they found that qualitative explanations of the task improve retention by increasing meaningfulness; this finding is supported by the literature. Second, also supported by the literature, they found that higher scores in the theory test led to higher scores in the practical test, which, they conclude shows that a higher level of operational/functional understanding assists in retaining detailed procedural tasks.

5.4 Organisational Recommendations

Summers et al. discuss a skill-based framework showing the steps involved in accurately identifying, recruiting, planning, administering and retaining skills. The model is shown in Figure 1. The model is of a training process that starts with early analysis of the new equipment and its users; from this a Training Needs Analysis (TNA) is conducted. The TNA identifies the areas that need new or changes to training or user selection criterion. The areas identified in the TNA then influence the psychological functions and factors. The results from an initial training program are recorded and feed back into the relevant earlier steps. At the bottom of the diagram, in parallel to the model, there is a line relating the steps of training with economy, efficiency and effectiveness.

Summers et al. then consider the organisational considerations in procuring training. Procurement is concerned with the most cost effective way of utilising effective training resources to achieve the necessary trained levels, where the training levels are proportional to the operational effectiveness.

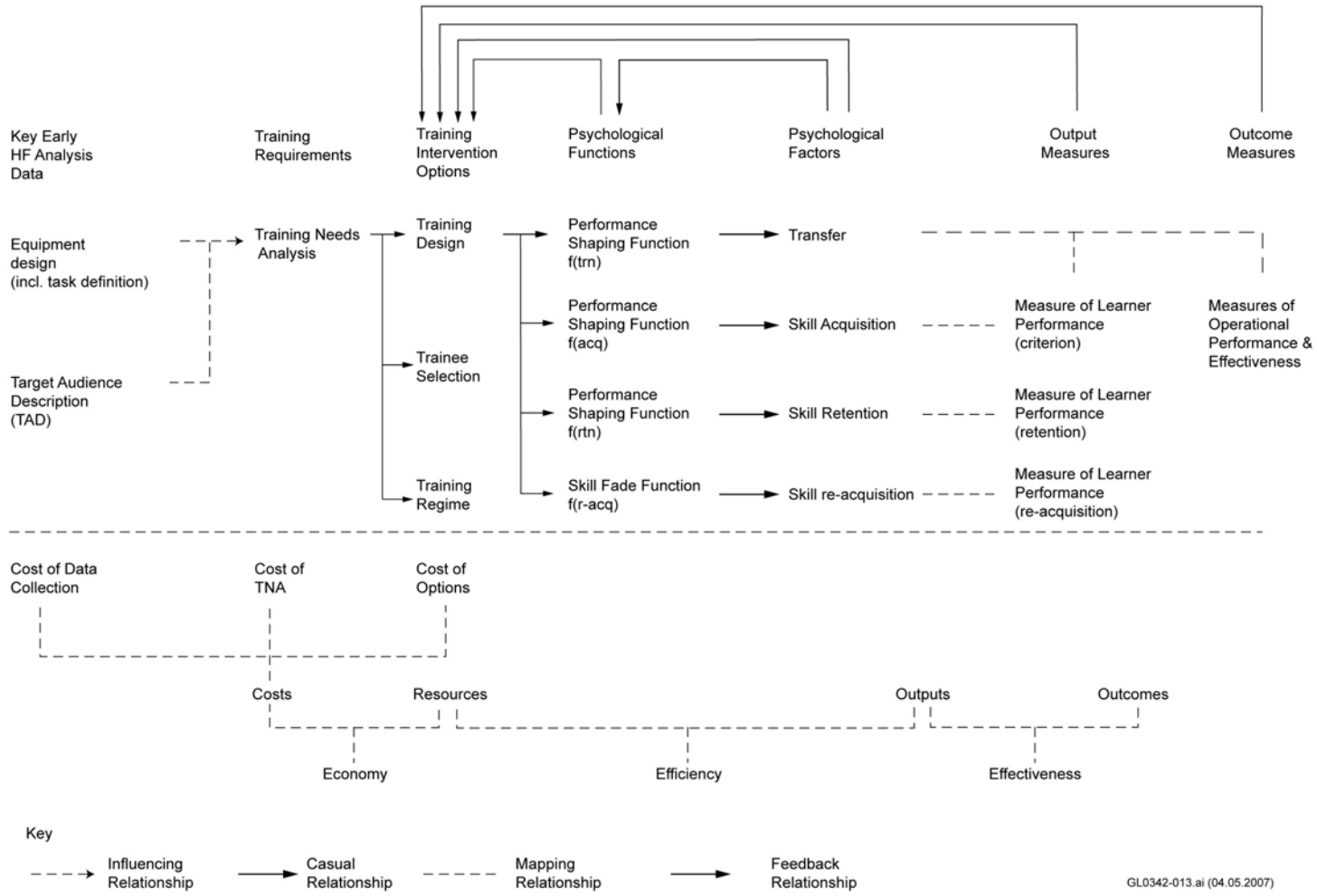

Figure 1. Model showing the stages of Identifying, Recruiting, Planning Administering and Retaining skills

Summers et al. surmise that using the model in Figure 1, combined with the knowledge of the factors affecting skill fade, it is possible to populate the model with useful data. The model can then be used to inform its users of the best approach to their training program (following this work in 1998, however, no additional effort has been made towards populating the model and research remains disparate). Once the model is populated with work on skill acquisition, retention, decay, etc., the areas that are weak in offering useful information will become apparent and it will be possible to focus or redirect future efforts.

6 Skill Fade Literature Post 1998

The following section is a literature review of the research to occur post 1998 that affects skill fade. Key words were taken from the previous 3 papers and used to search "Google" and "Google Scholar" for recent publications on the area of skill fade. Where useful papers were found a search for other papers that had cited them was also made. Additionally searches of published papers from military research centres in Canada, Australia and the United States of America were also searched. Finally, authors who were responsible for relevant publications were contacted directly for more recent work that was unpublished or in-press.

Much of the research on skill decay and retention reviewed and analysed in Arthur et al.'s paper has stayed constant since 1998. This includes their findings on:

- The Retention Interval,
- Task Types,
- Method of Testing For Original Learning and Retention,
- Conditions of Retrieval and Similarity of Original Learning, and
- Retention Contexts.

There are recent findings that affect those presented in the Arthur et al. paper, these include:

- Findings on overlearning, 6.1.2, will lead to a paradigm shift in the belief that it is the most significant determinant of skill retention;
- Research on Individual Difference has grown to show that if trained to criteria, less able individuals suffer skill fade to the same degree as more able individuals, 6.1.6.1.

The remaining sections, 6.1.1, 6.1.3, 6.1.4 and 6.1.5, outline important recent findings, aimed at reducing skill fade.

6.1 Recent Research Findings

6.1.1 Repeated Retrieval "The Testing Effect"

Early work showed that repeated study followed by testing, e.g. Study, Study, Study, Test (SSST) produces generally equivalent results to repeated testing e.g. Study, Test, Test, Test (STTT), Tulvin (1968) cited in Karpicke and Roediger (2007). New work by Karpicke and Roediger (2007) showed the study group, SSST, initially recalled slightly more than the test group. However this difference diminished after a number of cycles[4]. Karpicke and Roediger (2007) conducted 2 experiments to explore the testing factors that affect long-term retention. Both experiments looked at the retention of lists of words. Their first experiment used three groups: a standard STST group, a study group SSST and a test group STTT. The learning phase took the subject through 5 cycles and they were given a final recall test 1 week later. In this final recall test the subjects had 10 minutes to recall as many words as possible.

The results of the final recall test showed from the first minute, the study group recalled fewer words than the other two groups; however, the standard group recalled 4% more words than the test group by the end of the ten minute test. Even though the study group studied the list of words 15 times and the test group only studied the list of words 3 times, the test group recalled more words in the final recall test. The implication of this is that testing needs to be included regularly during study to ensure long-term retention when recalling information.

Experiment 2 produced results that have implications for the information included in and structure of study and testing to ensure long-term retention. Karpicke and Roediger investigated the effects of four different learning conditions. In the first condition subjects were put in a STST condition, studied and aimed to recall all the words on the list. In the second condition subjects were put into a SSTT group and again asked to study and recall all the words on the list. The hypothesis was that test facilitated studying on the following study trial. The other two conditions explored how different types of studying and testing affected long term retention; here a dropout condition was used. There were two variations of the dropout condition; subjects either: a) studied only items not recalled in the previous test but were still asked to recall the whole list of words when tested, STS_NT[5], or b) neither studied nor recalled items previously successfully recalled in the test condition STS_NT_N[6].

One week later, subjects were asked to recall all the items on the list. The results of the final test showed that subjects in the STST and STS_NT condition recalled the highest

[4] Repeated testing encouraged knowledge retention at the next study phase and the phenomenon is known as the Potentiating Effect, Izawa (1971)

[5] S_N denotes studied only non-recalled items

[6] T_N denotes were asked to recall only items not previously recalled. Asked to recall items only from the previous study list.

number of words, showing that additional study of successfully recalled words does not increase long-term retention. The implication of this finding could lead to shortening of training programmes or, at the very least, more efficient structuring of training time. Both groups performed higher than the SSTT group indicating that the feedback from tests promotes retention. All three of the conditions above, unsurprisingly, out performed the STS_NT_N. Asking the subjects to recall the information more regularly, as in the STS_NT condition, produced 100% more recalled words than the STS_NT_N. Karpicke and Roediger's findings, listed below, are two new recommendations included in the updated Healy et al. classes:

- successfully recalled information can be dropped from future **study**, and
- dropped information should be included in future **testing.**

More recent work by Pashler et al. (in press) has shown that covert retrieval practice also enhances learning. The implications of this are that if a student continues to practice in their head between study periods their learning will be enhanced. Pashler et al.'s finding on covert practice is included into the first of Healy et al's classes as a new recommendation: encourage mental practice and rehearsal.

6.1.2 Overlearning

In 1998, overlearning was solely defined as any period of training beyond success criteria. However, new research is looking at overlearning in two areas. The first is as defined in 1998. The second is the difference in quantity of information learnt in the same time frame e.g., 40 word pairs in 5 minutes as opposed to 20 word pairs in 5 minutes.

6.1.2.1 Overlearning Beyond Criteria

Arthur et al. reported that overlearning appears to be "… the single most important determinant of both skill and knowledge retention…" Recent work on overlearning is starting to indicate that this is not true. The effects of overlearning seriously diminish after a 1 week retention gap and it appears that after 3-4 weeks overlearners and underlearners have retained similar amounts of information. Additionally, the strategy of overlearning to increase the knowledge stored at one week is very costly. Rohrer et al. (2005) reported that overlearners who studied 4 times the period of underlearners only outperformed the underlearners by double.

Nonetheless, the effect of overlearning could be utilised by the military in preparing soldiers for combat occurring in a week or less. The overlearning, combined with the use of the knowledge or skills in the field (comparable to an ISI, see section 6.1.3), would mitigate against the drop seen in skills not used.

The recommendation to be carried forward from the latest overlearning literature is: if mobilisation of a group is required within a week and skills are not current, overlearning is an effective strategy.

6.1.2.2 Increased Information in the same Period

Roher et al. (2005) asked two groups of subjects to learn either 20 word-definition pairs or 10 word-definition pairs in the same study time (2 minutes). They were then given a test to establish initial learning followed by a retention test 1 or 4 weeks later.

The findings showed that the individuals learning the ten word-definition pairs, who had twice the study time, recalled a far greater proportion of their words after 1 week. This difference disappeared after 4 weeks and the number of words recalled by the 20 word group was greater than those recalled by the 10 word group. The implication of this finding is that where quantity is important in retention an individual would be better studying 50 words in 5 minutes and recall 20 than studying 20 words in the same time and recalling 15.

The practical application of this finding could be for personnel that need to learn a new language or primary words and a larger subset of secondary words. The recommendation, therefore, is: increased information can be used to increase the retention of secondary/tertiary information.

6.1.3 Inter-Study-Interval

Related to the Retention Interval (RI) is Interspaced Learning or Inter-Study-Interval (ISI). Cepeda et al. (2006) conducted two experiments aimed at exploring the optimum ISI for different Retention Intervals. Experiment 1 trained and tested 182 subjects on Swahili-English word pairs to a success criterion. They were then brought back for an ISI. The ISI was five minutes, 1, 2, 4, 7 or 14 days. During this second session the subjects were not trained to criteria, and 10 days following this second session subjects were given a final recall test. The results showed that the optimum ISI was 1 day after the initial training. The 1 day ISI saw a 34% more accurate recall in the final test than the 5 minute ISI and from the 1 day ISI to the 14 day ISI a gradual decrease in recall accuracy of 11% was observed.

The second experiment investigated if the 1 day ISI was optimum for a longer RI of 6 months. Experiment 2 trained 161 subjects on two different tasks, not-well-known facts and learning the names of unfamiliar visually presented objects. After the first study session the subjects were either brought back for an ISI of 20 minutes, 1, 7, 28, 84 or 168 day/s. The final test then took place 6 months after the second study session. The results showed the optimum ISI period for a 6 month retention test was 28 days for both tasks.

The results for both the 10 day retention period and 6 month retention period showed the optimum ISI/RI ratio to be 10% and 16% respectively. This result indicates that as the retention period increases so to does the ISI for optimum long term retention.

The recommendation to trainers is to structure an ISI for 10-20% of the Retention Interval. It is accepted that the RI is not always known. Cepeda et al.'s work shows it is better to have an ISI greater than 10% of the RI than less than 10%. Therefore, any estimate of the RI should be larger than expected to maximise on the benefits of an ISI.

6.1.4 Spacing of Learning

A recent study by Pashler et al. (in press) took two groups and trained them in a simple but unfamiliar mathematical principle, “The Principle of Combinatorics”. In this study one of two groups were either given all 10 problems in one session or half the problems in the first session and the other half one week later. A final test was given 1 or 4 weeks later. The results showed little difference in the two groups after one week but substantial effect after 4 weeks. The spaced learning group performed considerably better. This effect was not seen in perceptual categorisation learning. This study is similar to the ISI study; however, the studying was either all in one session or half the size and over a period of time. Effectively the ISI was 25% of the 4 week RI. Work continues in this area and it is felt that this study is currently too immature to derive a useful recommendation from.

6.1.5 Feedback

Recent work by Pashler et al. (in press) has shown that following a one week Retention Interval, immediate feedback of the correct answer, after a wrong answer has been given, shows a 5 fold increase in likelihood of a Luganda-English word pair being correctly recalled in the final test. Other forms of feedback, simply stating the individual has given the wrong answer reaps little benefits. Pashler's study shows that not providing corrective feedback is always harmful. They also found that as long as the right answer is given, even with little confidence, withholding feedback has no effect.

Pashler et al. also investigated the timing of feedback on a one week Retention Interval and found that delayed feedback was better than immediate feedback. This could be because delayed feedback allowed spaced practice.

The recommendation to training personnel is: provide feedback to erroneous answers.

6.1.6 Individual Differences

6.1.6.1 Ability

Additional research since 1998 has shown there is no direct relationship between ability and task retention when individuals are trained to criteria. Lance et al. (1998) cited in Stothard and Nicholson (2001) showed aptitude moderated retention for some tasks, but not others. Ability is thought to interact with the training which affects the learning levels thus affecting the overall skill performance and retention.

The implications of these findings are that for tasks that are difficult to recruit for, less able staff can be used if the time is available to train them. Note that the effect of training to criteria on abstraction has not been investigated.

6.1.6.2 Motivation

Motivation has been linked strongly with learning and therefore affects retention. In addition, emotional states such as self belief, self doubting, trainer belief and doubting in the trainee have been linked with performance and could also affect retention.

Trainees should be selected for their motivation for the role they will be carrying out. Trainers should not communicate any belief that the trainee is not capable.

6.1.6.3 Prior Knowledge

Prior knowledge or experience of subject mater provides a foundation upon which new knowledge can be built. The learner has a cognitive model or concept into which the new information can be placed or built upon. Additionally some of the existing skills or knowledge may already be automatic allowing the trainee to concentrate on learning the aspects of the task which are new.

In conflict with the above findings is Nembhard et al.'s (2000) work. Here, Nembhard et al. found that those people who have greater prior knowledge of a task, experience greater negative learning episodes and tend to forget more easily in breaks from using their skills. It is thought, that the prior knowledge held by the subjects was in conflict with the new tasks being learnt and therefore had to be unlearnt while the new knowledge was being learnt.

6.1.7 Additional Research in Learning

There are many aspects of learning that have not been included in this report as their effect on skill decay and retention has not been explicitly investigated. Nonetheless, for completeness it is important for the reader to understand that while the relationship between learning and skill decay may not have been directly investigated their effect is still relevant.

7 Updating Healy et al.'s Three Classes

Using the additional findings discussed in section 6 it is possible to add to the three classes discussed by Healy et al.:

1. Optimising Conditions of Training;
2. Optimising the Training Strategy;
3. Reaching Automaticity.

The three classes are updated in sections 7.1, 7.2 and 7.3 respectively.

7.1 Optimising Conditions of Training

The first stage in Healy et al.'s classes "optimising conditions of training" had three guidelines:

1. Contextual Interference;
2. Training parts of the task versus the whole task – focusing on components that can be fully trained and avoiding unnecessary training of components common to every day life;
3. The Generation Effect – encouraging students to generate their answers for memory facts and skills.

Considering the more recent research and by including the stable findings from Arthur et al. it is now possible to update the guidelines of this first class. Six additional guidelines should be added, they are:

- Recruit Motivated Trainees - While the recruitment process is not directly explored in this research, motivation of individuals has been shown to be important in the learning process which directly affects retention. Students should be chosen for their motivation in the subject matter or job function.
- Self-belief and trainer belief in the student are positively correlated to skill acquisition. Confidence building techniques should be incorporated into the training feedback for those students who lack self-belief.
- Train to Criteria - Students where possible should be trained to criteria ensuring that those less able individuals reach the same level of competency. Once this competency level is attained skill fade will be the same for all abilities.[7]

[7] Note that although the skill fade is very similar, it is has not been shown that less able individuals are able to generalise as well as individuals with a high ability.

- The One Week Gap – Ensure skills are used with in a week of training. Where this is not possible, an ISI (described below) should be used.

- Inter-Study-Interval – If the Retention Interval (RI) is known, include an Inter-Study-Interval (ISI) of 10-20% of the RI from the point of the inter-study. For example, a student receives training but is not expected to use the skill for 11 months. The ISI should take place a month or two months from the original training, which is 10-20% of the RI from the ISI.

- Mental Practice and Rehearsal – Encourage mental practice and rehearsal inside and outside the classroom.

- Feedback - Fear of erroneous mental practice does not appear necessary providing feedback is given to the errors (currently no longer than a week after the mistake).

7.2 Optimising the Learning Strategy

The second class, optimising the learning strategy used, stated that the training of the tasks should be designed to encourage deliberate retrieval from memory, thus promoting efficient encoding strategies and better retention of information. Recent work by Karpicke and Roediger means that this class can now be developed, further increasing the efficiency of training. Karpicke and Roediger showed that once knowledge and skills have been successfully tested they can be dropped from further study but should be included in further testing.

Additionally, to increase knowledge and skill retention, Arthur et al. highlighted the importance of similarity between the way the task is trained and used and the environment the task/skill is trained and employed in. Therefore, Healy et al.'s second class can now be updated to include three guidelines:

- Encourage deliberate retrieval from memory - to promote efficient encoding strategies and better retention of information.

- Successfully tested material can be dropped from further study but should be continually tested for to increase long term retention.

- Optimise the similarity between the task functions and environment the individual is trained in and how and where they will be used.

7.3 Automaticity

Reading of the literature to date has provided no additional information to be added to the third class, guidelines concerning ways to achieve automatic retrieval. However, Summers et al. discussed automaticity and postulated that, as well as repetitive practice for consistent tasks, an increased understanding of the underlying principles is necessary for complex tasks. Healy continues her research and it is recommended that additional time is allocated to reviewing her subsequent work in more detail.

7.4 Updating and Progressing Summers et al.'s Model

The five psychological concepts outlined in the Summers et al. paper remain valid. Their review of the literature was summarised at a very high level and because of this the additional research presented above only further supports their approach. Nonetheless one amendment would be made to the "Post-learning activities" section of the table. Instead of recommending that refresher training be employed at a period equal to the RI, it is advisable that it is administered at a period 10-20% of the RI.

The model described in the Summers et al. paper again has remained stable due to its high-level description of the process.

8 Further Work

Work in the area of knowledge retention is continuing and producing some new and interesting results. To optimise the benefits of this work in the services it is recommended a comprehensive review of the tasks taught/used is carried out.

Using the continuing research and a better understanding of the tasks carried out in the services a best practice booklet can be produced for use by military HF and Training personnel. The booklet's aim would be to recommend approaches for optimising training to delay knowledge and skill decay.

To ensure the weaknesses and strengths of the booklet are known it is advisable that Summers et al.'s work be completed by populating their model with the research available to date. Through this population process we can identify the areas that are mature and immature allowing us to direct future research towards the weaker areas. Beyond a booklet, it would be beneficial to explore the benefit of a software package to assist in the successful design of the process and approach to efficient training programmes. The software could highlight the areas a trainer should and should not allot resources to, provide a best practice approach, provide a deeper understanding of the decision making process and provide monitoring of trained personnel's skills. The work initiated by Arthur et al. and added to here should facilitate this process. The work by Summers et al. and Healy et al. provides frameworks to build the software tool around.

Finally, automaticity for service personnel when completing tasks is extremely beneficial as it frees up cognitive workload for use on other tasks. A detailed investigation into the limitations of automaticity and best way of achieving it should be conducted.

During the search for literature many documents surrounding the area of skill fade were read. This reading led to identification of other areas for further work. These are shown in bullet point below:

- Investigate if automaticity can ever truly be achieved for all tasks. If not, what are the qualities of tasks that do and do not reach automaticity.
- Investigate the plausibility of modelling skill fade for different tasks to propose when task types should be retrained.
- Produce a model for estimating the time taken for a student to reach proficiency. The model could then be used to aid the decision to cut students from training.
- The generation effect – what is the best way of encouraging generation of answers in Computer Based Training?
- Much literature is written on training in digital environments. It is advisable that a detailed literature review of these findings should be conducted.
- Much literature is being written on the training of collectives and teams. A literature review of this topic would be beneficial.

- Investigate the development of transferable collective working techniques.

- Online gaming could be used to explore the following:

    - How strangers effectively create strategies to successfully complete missions after having just met. Findings from this research could be used to inform theories on how disconnected personnel could most effectively interact with each other if meeting in a war zone for the first time.

    - What do online gamers see as important to effective collaboration?

    - What do they see as hindrances to their communications or progress while on missions?

    - How do prolonged absences of team mates affect the team work and skill retention in the team?

    - Online gaming could also be investigated as an effective training tool for personnel across barracks and services.

- Is there a positive correlation between students with low self-confidence and recruits cut from the training program? Is the correlation high enough to warrant considering increasing student confidence?

- Earlier work by the ARI looked at how long it will take for skills to be *lost*, however the more recent work looks at how long it will take for skills to be *re-acquired*. In light of the recent work from Cepeda on ISI further work could review these earlier *skill loss* models and their predictive validity with the view of then including the work on ISI to recommend at which point follow-up training should occur to maintain optimum retention.

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11 Abbreviations and Acronyms

ARI	Army Research Institute
BATES	Battle Artillery Target Engagement System
HF	Human Factors
ISI	Inter-Study-Interval
RI	Retention Interval
TCS	Task Classification System
TNA	Training Needs Analysis

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