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Checklist Memory Items

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EUROPEAN AVIATION SAFETY AGENCY

Checklist Memory Items

A preliminary analysis and review in respect of the Safety Recommendation issued by the Danish Accident Investigation Board in response to the serious incident involving aircraft OY-CIM on 13 Sept. 2011.

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Abstract

As part of its investigations into 'Serious incident to Avions de Transport Régional ATR72-212A, Registration OY-CIM at Copenhagen Airport, Kastrup (EKCH), Denmark on 13 September 2011', the Danish Accident Investigation Board made the following Safety Recommendation within its preliminary report:

'To promote an internal debate (e.g.: dedicated working group, workshop, etc.) to carefully evaluate the pros and cons of a continuously increasing of memory items introduced in the implementation or review of the emergency procedure, mainly when to be applied in a critical phase of flight'.

This document seeks explore those elements considered pertinent to this recommendation in support of an on-going internal debate.

Contents

1. Introduction

Similarly to many other human processes and interfaces, as a fundamental constituent of human nature, human memory is vulnerable to error. Whilst the vast majority of memory errors occurring on the flight deck will be captured by system defences *before* any negative consequences arise, history is scattered with numerous instances of this nature that have proved fatal.

Memory items (alternately known as recall or immediate action items) may be described as 'an action that must be taken in response to a non-routine event so quickly that reference to a checklist is not practical because of a potential loss of aircraft control, incapacitation of a crewmember, damage to or loss of an aircraft component or system, which would make continued safe flight improbable' [FAA, 1995]. As such, in the event of an emergency situation arising, memory items should be accomplished *from memory alone* before the checklist is called for or read.

Flight crews are trained to respond to specific emergencies by use of these memory-based checklists. The checklists are committed to memory as part of the training programme. Pilots are trained to memorise the immediate actions and carry them out without reference to the checklist. However, studies have demonstrated that the normal functioning of human memory may be impaired under stressful situations. Consequently, it is therefore essential that this factor be taken into account during the design of checklists with memory items.

While the purpose of this paper primarily refers to the human capacity for an increase in memory items, and therefore primarily relates to the retrieval of this information which will be stored in the long-term memory, it is necessary to assess other categories of memory, and the relationships existing between them, so as to ensure that conclusions arising remain in context. It shall begin with a preliminary overview of human memory, including those generally accepted theories pertaining to its processes and a review of existing literature relevant to the task; the paper will subsequently go on to assess these findings within an aviation context with particular regard to the Safety Recommendation issued on behalf of the Danish Accident Investigation Board further to its investigations into the incident arising on 13 September 2011.

2. Human memory

When considering the effects of stress upon human memory, for the purposes of this paper, it is first necessary to undertake a review of those generally accepted theories of memory structure to which the stress-related study findings have been applied. It should be acknowledged, however, that the information contained within this chapter is a non-exhaustive review of current literature and is merely intended to support the overall purpose of this paper.

According to Goldstein (2008), 'memory is the processes involved in retaining, retrieving and using information about stimuli, events, ideas and skills after the original information is no longer present'. Herman Ebbinghaus is widely considered to be the first man to have studied the human memory using a scientific approach. From his findings, he classified three distinct categories of human memory: sensory, short-term and long-term. This theory continues to hold a certain amount of credence to this day although a lack of definitive evidence has led to the development of a number of other theories also being proposed and which shall be discussed later in this section.

2.1.1. Sensory Memory

Sensory memory may be regarded as the first level and shortest element of human memory, capable of retaining information for only very brief periods of time. It utilises the five senses to retain impressions of sensory stimuli further to the cessation of exposure. Sensory memory's limited duration is based upon the rapid degradation of sensory registers, it has been proposed that its length will typically comprise a period of between 1/5 and 1/2 of a second. While research undertaken by George Spurling during the 1960's suggests that the capacity of sensory memory is approximately 12 items, others have suggested that the capacity may actually be much greater.

Whereas much of the information entering our sensory memory will degrade, that which we intend to utilise must be encoded. To successfully encode information, it is necessary to provide the stimuli with attention. When this process is achieved, this specific information will pass through to the short-term memory.

2.1.2. Short-Term Memory

After information has successfully passed from the sensory memory into the short-term memory, it shall be held there for a short period of time. Though significantly longer than the duration that which information is held within the sensory memory, studies suggest that information held within the short-term memory is also subject to spontaneous decay if continual efforts to maintain it are not upheld. It has been suggested that information may be stored in short-term memory for up to approximately 30 seconds, although others have

suggested that the maximum duration may indeed be greater than this at around a maximum duration of around one minute. If items are to be held within the short-term memory for periods longer than this, a conscious effort must ensue which may be achieved by means of verbal repetition, thus allowing the item(s) to 're-enter' the short-term memory.

In his 1956 paper *'The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information'*, George Miller presented his observations pertaining to the short-term memory capacity of young adults. From his research, Miller concluded that, on average, it was possible to store approximately seven (plus or minus two) items of information. This may be increased, however, by a process known as 'chunking'. It should also be considered that the value of seven that was determined within Miller's study may vary by population demographic, with seven instead representing the average number of items that can be held for the participants undertaking his study.

The importance of chunking information is significant, particularly with regard to the scope of this paper. By chunking information into meaningful categories, the individual in question may enhance their ability to remember items. This tendency is prevalent in the performance of memory tasks, a common illustration being the ability to recall telephone number sequences – it is easier to retain and recall such numbers when they have been broken down into smaller blocks e.g. '8-6-2-5-9-7' may be recalled with greater ease if it were chunked as '862-597'. As such, while the average person will maintain a memory capacity of 7+/-2, the individual may expand the number of items they may recall by chunking the information and thus allowing for a much greater capacity.

Similarly to that of sensory memory, if items held within short-term memory are to be retained, the items held must be processed further. Items may be transferred to long-term memory by various means, namely repetition, assigning meaning to or associating this information with that which has been previously acquired. As such, information relevant to that which is already stored (in the long-term memory) will be more readily retained as it has greater meaning and relevance to the individual.

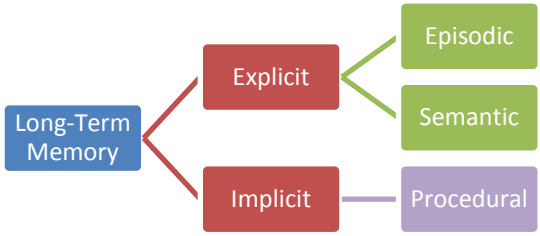
2.1.3. Long-Term Memory

Further to the consolidation of the information contained within the short-term memory, items are transferred into the long-term memory and may be stored semantically. Although the process is not fully understood, it is generally accepted that new information enters the long-term memory further to a process of neural network formation whereby new circuits are created. New information pertaining to existing knowledge may require existing neural networks to altered or strengthened.

The process of forgetting long-term memories occurs when the strength of existing connections within neural circuits degrade or when newer networks interfere with those that are older.

Long-term memory may be further broken down into two separate divisions, explicit (declarative) and implicit (procedural), which are determined in accordance with the type of the information itself. Both divisions may be sub-divided once more, in accordance with the following diagram:

Fig.1: The theoretical structure of long-term memory



2.1.3.1. Explicit Memory

Explicit memory refers to that information relating to facts and events and, in accordance with Figure 1, may be broken down further into the subsets known as *episodic* and *semantic* memory.

Episodic memory pertains to those memories of particular events. Through conscious effort, the individual may reflect upon those specific events having previously taken place throughout his or her lifetime. According to Conway (2009) recollections utilising episodic memory encompass nine distinct properties, namely:

- Contain summary records of sensory-perceptual-conceptual-affective processing.
- Retain patterns of activation/inhibition over long periods.
- Often represented in the form of (visual) images.
- They always have a perspective (field or observer).
- Represent short time slices of experience.
- They are represented on a temporal dimension roughly in order of occurrence.
- They are subject to rapid forgetting.
- They make autobiographical remembering specific.
- They are recollectively experienced when accessed.

In contrast to episodic memory, semantic memory is utilised to store one's knowledge of the external world and, as such, will therefore comprise facts, meanings and concepts and may be accessed quickly and without apparent effort on behalf of the individual. While semantic memories may typically arise from episodic memories, it should be noted that this is not mandatory; its contents may therefore be applied to wider situations.

2.1.3.2. Implicit Memory

While explicit memory refers to those memories of 'what', implicit memory refers to memories of 'how' e.g. motor skills. Implicit memories require no conscious effort on behalf of the individual, instead actions are carrier out somewhat automatically, a primary example being one's ability to ride a bike.

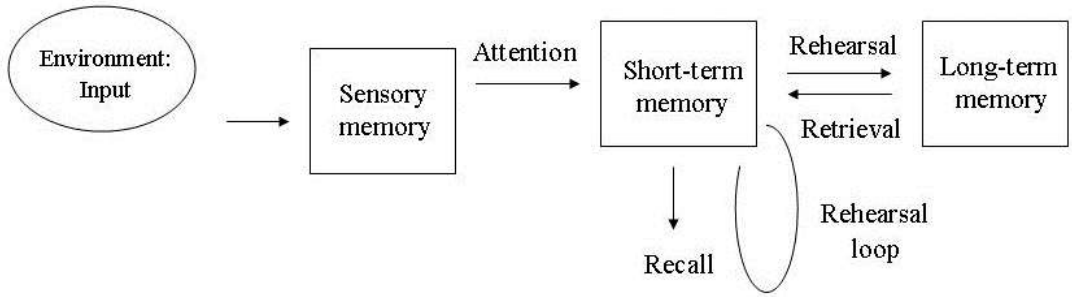
2.2. Memory Models

Whilst for the most part it is generally accepted that separate and distinct categories comprise the basic constituents of human memory, the manner in which they work i.e. the structure of human memory continues to stimulate debate amongst psychologists. The subsequent models reflect two of those theories:

2.2.1. The Multi-Store Model

The Multi-Store Memory model was put forward by Richard Atkinson and Richard Shriffin in 1968. It pertains to the three (sensory, short-term and long-term) memory stores discussed previously, the relationship between which being as follows:

Fig. 2 The Multi-Store Model



Source: McLeod, S. A.

2.2.2. The Working Memory Model

Baddeley and Hitch argued that Atkinson and Shriffin's model, particularly with regard to short-term memory, was too simplistic. Instead they offered an alternative theory to replace short-term memory, which, in accordance with their

own theory, was now to be known as *working memory* due to the significantly greater emphasis placed upon the structures and workings of this area.

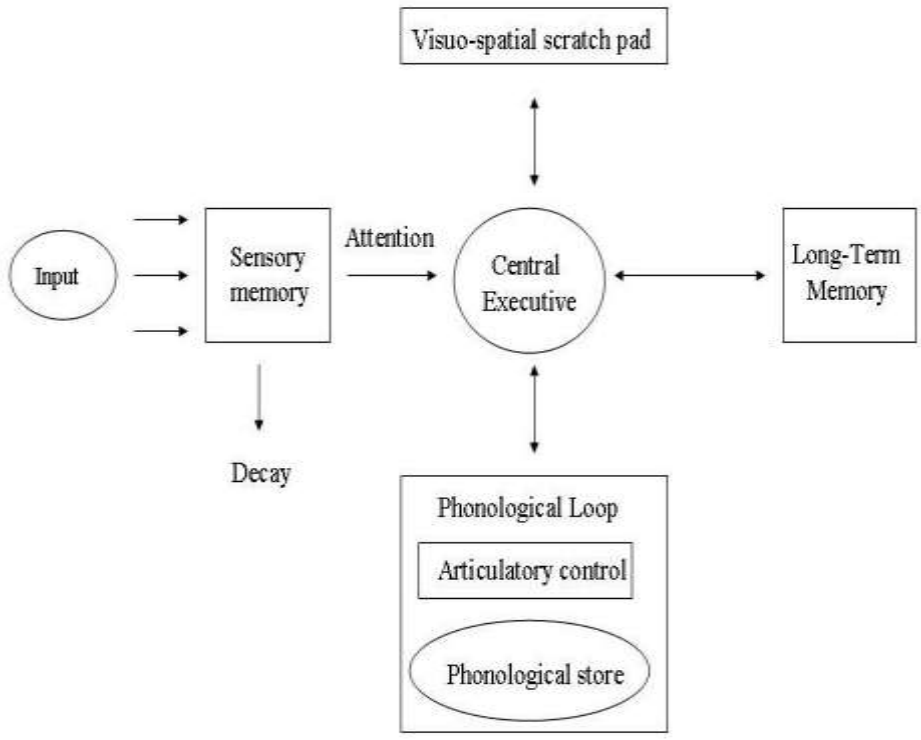
While the Multi-Store Model suggests that short-term memory is comprised of one single store, the Working Memory Model (1974) instead suggests that short-term memory is of significantly greater complexity than this. Baddeley and Hitch propose within their theory that 'working memory' is comprised of several systems dependent upon the nature of the information itself. Working memory is comprised of a central executive and two sub-systems known as the phonological loop and the visuo-spatial sketchpad.

The **central executive** controls and coordinates the sub-systems, allocating specific information to each (dependent upon its context). It is also the area of human memory that is responsible for completing cognitive tasks such as mental arithmetic and problem solving.

The **visuo-spatial sketch pad** is the sub-system responsible for storing and processing information that is presented within a visual or spatial form. As such, the visuo-spatial sketch pad is used for navigational purposes.

The **phonological loop** is the sub-system that is used for storing and processing information within spoken or written formats. The sub-system may be sub-divided once again into two separate systems:
- the phonological store
- the articulatory control process

Fig 3. The Working Memory Model (1979)



Source: McLeod, S. A.

N.B. Baddeley updated the Working Memory Model in 2000 through the addition of an additional component between the central executive and long-term knowledge. The component was named the **episodic buffer.**

3. The effects of stress on memory

Based upon the afore mentioned theories pertaining to the structure of, and inter-relationships within, human memory, it can be ascertained that the primary memory store to be considered for the purposes of this research is long-term memory and, more specifically, its relationship with working memory (for the purpose of memory item retrieval and action implementation).

A large number of psychological studies have been conducted with respect to the implications of stress on memory function. For the purposes of this paper, the literature review undertaken has primarily focussed on the retrieval of memories under stress-induced situations.

Cortisone, a glucocorticoid, is a hormone released by the adrenal gland in response to stress. Extensive evidence has been found to suggest that stress, and consequentially glucocorticoids, maintain an influence on cognitive function. According to Dickerson and Kemeny, the release of cortisol is presumed dependent on the elicitation of feelings of threat and vulnerability (Dickerson and Kemeny, 2004).

3.1. Memory retrieval and stress

While much of the early research focussed on the effects of stress and the acquisition of and long-term storage of new information; de Quervain et al., however, sought to establish the effects of stress on memory retrieval, results indicating that glucocorticoids also affect memory retrieval mechanisms in rats (de Quervain et al, 1998).

Seeking to continue their research with respect to human memory, de Quervain et al. subsequently demonstrated a relationship between cortisone treatments and memory retrieval in healthy adults. The administration of cortisone at acute-stress levels 'specifically impaired retrieval of declarative long-term memory for a word list' (de Quervain et al, 2000). The researchers conclude that it would seem probable that 'elevated glucocorticoid levels may induce retrieval impairments in such stressful conditions as examinations, job interviews, combat and courtroom testimony' (de Quervain et al, 2000).

Wolf et al. verified the research of de Quervain et al. The research also indicated that the recall of words could be associated with the emotional nature of the material itself, results suggesting that negative words were more significantly impaired than those that were neutral. However, it was also apparent that the recall of autobiographical memories was the most severely impaired by cortisol (Wolf et al., 2004).

The results from the research undertaken by Buchanan et al. would imply that the release of cortisol is the primary factor associated with impaired memory

retrieval, as opposed to stressful experience alone. In consideration of the work undertaken by Elzinga and Roelofs (2005), Buchanan et al. concluded that only those participants exhibiting a cortisol response the stressor had lower cognitive performance (Buchanan et al.,2006). Buchanan et al. also cite substantial evidence to imply that stress is associated with the prefrontal cortex region of the brain. Functional neuroimaging studies suggest that both working memory and declarative memory retrieval may be associated with activity in this area of the brain. Buchanan et al. conclude that, in conjunction with the results of Elzinga and Roelofs (2005), it may be suggested that both 'working memory and long-term memory retrieval mechanisms are similarly impaired in stressful situations involving the release of cortisol' (Buchanan et al., 2006).

3.2. Memory and aviation

As discussed at the outset of this document, aviation is not exempt from the limitations of human nature. In the paper 'Human Memory and Cockpit Operations: An ASRS Study', Nowinski et al. present their research with respect to this area.

According to Nowinski et al., the majority of memory errors commonly experienced fall into one of two categories, namely retrospective memory error or prospective memory error. A retrospective memory error may be considered to be an unsuccessful attempt to retrieve information from memory whilst a prospective memory error can be considered to be a situation in which an intention is forgotten. Prospective memory requires retrieval at a specified time, i.e. the individual must remember to remember.

The risk of prospective memory errors can be significantly reduced when aviation operations are conducted in accordance with strict procedures which are overlearned. The majority of tasks to be performed on the flight deck have been overlearned to the extent that which an experienced pilot should very rarely make a retrospective memory error. Researchers analysed 75 memory-related occurrence reports from the ASRS database, only one of which pertained to an instance of retrospective memory failure whilst the remaining 74 reports reflected a prospective memory failure. Whilst it is evident from these findings that there are strong defences in place to guard against retrospective memory errors, the findings would suggest that the same cannot be said for prospective memory errors.

Based upon their findings, Nowinski et al., made the following recommendations to reduce pilot vulnerability to prospective memory errors:

1. *Recognize non-routine situations, namely interruptions, deviations from habitual actions, and deferred tasks, as potentially dangerous. If possible identify exactly when a deferred or interrupted task will be performed and what cues will be available. Create salient cues as reminders. If possible*

enlist the help of other crewmembers. At the very least, acknowledge the fact that a task is being deferred.

2. *Stick to established operating procedures as much as possible—they provide both obvious and subtle safeguards against forgetting.*
3. *Recognize monitoring as a critical task. Several airlines have formalized monitoring procedures for both pilots and have changed the designation of pilot not flying to pilot monitoring.*

4. Checklist memory items

In the event of an emergency situation, a set of specific actions, appropriate to the nature of the event, are required to be performed by the crew before they make reference to the printed checklist. Their use relates to situations in which the safety of the aircraft has been compromised. These actions, known as memory items (or recall/immediate action items), are committed to memory by each pilot as part of the training programme for each particular aircraft type and should be performed in response to the emergency situation immediately.

4.1. Checklist design

Barbara Burian, Human Factors specialists with the NASA Ames Research Center, has undertaken a number of research activities with respect to human factors and checklists. In her 2004 paper, she states '*emergency and abnormal checklists are essential tools flight crews use to respond appropriately to situations that can be very serious and time critical. Therefore, it is crucial that these checklists be complete, clear, and easy for the crews to use*'. In her research however, Burian acknowledges that only a few of the factors related to the design of emergency and abnormal checklists have been identified and discussed by research and operational communities. Burian goes on to highlight memory items as one of the areas having been previously addressed to a limited degree but still requiring further research (Burian, 2004).

Within its document 'Guidance on the Design, Presentation and Use of Emergency and Abnormal Checklists' – CAP 676, the UK CAA defines the term 'Memory Items' as '*Those actions normally resulting from an Emergency situation which must be performed immediately by the crew without reference to any checklist, but which, nevertheless, are included in the checklist for verification purposes'.* The document goes on to make reference to the limitations of human memory with respect to item recall of items and provides the following recommendations with regard to checklist design:

- *Memory items should normally be at the start of a drill.*
- *Memory items should clearly be indicated, e.g. by colour shading, or by `boxing'. An explanation in the OM or Philosophy Notes showing how these memory items are indicated should be included.*
- *The number of steps in a memory item should be kept to a minimum (preferably fewer than four and certainly no more than six for multi-crew operations; single pilot operations may require a greater number of steps).*
- *Simple mnemonics can be used as an aid.*

4.1.1. Checklist design compliance

The Checklist Audit Tool (CHAT) can be used to verify that the checklist complies with the best human factors practice. Whilst covering a large

number of aspects, with respect to Memory Items only, the tool provides the following material:

Attribute	**Comments**
Are the memory items listed at the beginning of the drill?	*Memory items should be carried out first and verified on the checklist. When they exist they must be the first set of action items.*
Are the memory items clearly distinguished from the other action items?	*It is recommended that the memory items be distinguished in some fashion - boxing, shading, line marking, numbering etc.*
Are there six or less memory items on a single drill?	*It is recommended that the memory items should be kept to a minimum - preferably four or less. Recall can be impaired under stressful situations.*

Source: CAA CAP 676

4.2. Checklists, memory and human error

As noted previously, there has been comparatively little research previously conducted with respect to checklist memory items themselves. However, further to their research activities, Burian and Geven have highlighted the following aspects being key factors in the recall of each checklist containing memory items:

1. Environmental cues
2. Number of items
3. Complexity of items
4. Situation e.g. time, threat distractions

Burian and Geven cite aborted engine starts and uncommanded roll/pitch/yaw as the events mandating the implementation of memory items checklists that are most susceptible to human error.

4.3. Industry trends

With respect to industry trends and memory items, it is first necessary to once again consider the Safety Recommendation itself once more:

'To promote an internal debate (e.g.: dedicated working group, workshop, etc.) to carefully evaluate the pros and cons of a continuously increasing of memory items introduced in the implementation or review of the emergency procedure, mainly when to be applied in a critical phase of flight'.

An assessment of the available literature, in combination with the views of EASA experts and in addition to the feedback received from members of the European Human Factors Advisory Group, would suggest that, in contrast to the view of the Danish Accident Investigation Board which issued the recommendation,

memory items are not increasing either in terms of the number of items within the checklist itself or the number of checklists themselves. The advent of new technologies, such as the glass cockpit, has resulted in a reduction in memory items within checklists as compared to older aircraft.

4.4. Memory items criticisms

While the purpose of checklist memory item and the resultant benefits to the flight crew has been discussed previously within this document, memory items do face a number of criticisms:

1. Checklist memory items rely upon the flight crew to correctly identify the problem and provide a solution appropriate to that issue specifically.
2. Selection of an inappropriate checklist will lead to incorrect actions being taken.
3. Implementation of memory items does not allow for the analysis of the issue itself, thus implying the possibility for the problem to be exacerbated or attempts to solve the wrong problem.
4. Attention is drawn away from environmental stimuli, resulting in a reduction in cognitive processing.
5. By nature, human memory is subject to human error.

5. Conclusion and recommendations

5.1. Conclusion

Based upon the literature surveyed and in conjunction with the opinions expressed from key industry personnel with regard to the Safety Recommendation in question, as per paragraph 4.3, there is little empirical evidence to suggest that memory items are in fact increasing either in total number or in checklist length (i.e. number of items per list). However, it is also apparent from the literature review undertaken, that comparatively little research has been undertaken with reference to this area specifically.

Although overall research with regard to checklist memory item explicitly is lacking, a large number of studies have been undertaken with respect to the retrieval of memories under stressful situations. Due to the nature of the conditions in which memory items are designed to be utilised, the findings of these studies have significant implications for the design and implementation of checklists with memory items; in particular, the findings with regard to the capacity of memory should be considered at this time so as to ensure checklists are designed in respect of the optimal value identified. An elevation in glucocorticoid levels appears to be the most significant factor affecting the retrieval of both working memory and long-term memories; although this was not studied in a cockpit environment specifically, there is no reason to suggest that the findings would not apply within a cockpit environment also, providing that the event itself was stressful enough to stimulate the release of cortisol (a glucocorticoid).

In addition to the knowledge gained from the wider research activities in the area of human memory, the comparatively limited number of studies concerning memory and aviation undertaken do however provide valuable information with regard to checklist training activities, particularly in respect of potential prospective memory failures. The research undertaken by Nowinski et al. should be considered at this stage, with specific attention given to the area of prospective and retrospective memory. Also to be considered is the work undertaken by Dr Barbara Burian who has carried out what appears to be the largest amount of research in this area.

The Checklist Audit Tool (CHAT) provided by the UK CAA within CAP 676 is intended to promote best-practice in checklist design and includes specific guidance with respect to memory items within checklists. In absence of further guidance material, it is recommended that this tool be utilised to ensure that checklist design, including but not limited to memory items, complies with best-practice.

5.2. Recommendations for further research

The research undertaken in this paper incorporates a non-exhaustive review of the existing literature available. The major limitation during the paper's drafting has been a knowledge gap with regard to the in-depth functioning of human memory; this has not been aided by an overall lack in specific industry research activities with respect to checklist memory items and human psychology.

During this limited study, it is evident that, while non-specific in nature, a substantial body of research has been conducted within areas that can be considered pertinent to the area of memory items and checklists. In consideration of the large number of memory-related studies within non-aviation fields, it can be recommended that any subsequent research to be undertaken in consequence to the Safety Recommendation issued by the Danish Accident Investigation Board should be undertaken by an individual maintaining substantial experience within the field of human psychology and whom is able to extrapolate the findings of these studies into a commercial aviation context. Whilst primarily addressing the Recommendation itself, such results may ultimately have wider implications for checklist design and training practices.

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