Chapter 28

Prospective Memory in Air Traffic Control

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Introduction

The air traffic control (ATC) environment is characterised not only by the necessity to remember past activities to support ongoing operations but also the requirement to remember to perform activities in the future (Neal, Griffin, Paterson, & Bordia, 1997). Controllers make frequent use of this type of memory; they frequently cannot execute a control action immediately either because the current situation does not allow it or their workload is too great (Neal, Griffin, Paterson, & Bordia, 1997). Successfully completing an intended action in the future depends on a type of remembering that has been labelled *prospective memory* (Harris, 1984). The objective of this paper is to overview the theoretical prospective memory literature, present a new experimental task for examining prospective memory, and outline potential general applications to en route air traffic control (ATC).

Prospective Memory and Air Traffic Control (ATC)

A recent survey of ATC related errors by the NASA Ames Research Center revealed that a high percentage of these errors involved failures to execute deferred actions (Freed & Remington, 1999). A specific incident that illustrates the importance of prospective memory occurred at Los Angeles International Airport in 1991. A controller cleared an aircraft to hold in takeoff position and shortly afterward directed another aircraft to land on the same runway, without clearing the first aircraft to takeoff beforehand (National Transportation Safety Board, 1991). On the surface, the accident was simple: the controller forgot about the action required for the plane that was on the runway because of intervening attention to other aircraft she was managing. This forgotten to-be-performed action represents a failure of prospective memory. Despite its importance this type of memory has received relatively little attention in the ATC literature.

The current paper reviews the current state of knowledge regarding prospective memory. Experimental studies have identified a range of general factors that affect the likelihood of prospective remembering. These include: (a) the characteristics of memory cues, (b) the length of the retention interval and the amount of mental rehearsal on the to-be-performed action, and (c) the nature and workload of concurrent activities (Mantyla, 1996).

Key Findings from the Prospective Memory Literature

One of the factors that affect prospective memory is the nature of the memory cue that is used. Information is stored in memory in the form of associations between events or objects. For example, when we have breakfast we store a memory trace that represents what we ate, together with information about where we ate it, the time of day, and any unique events that may have occurred. In order to retrieve information from memory, we need to use a retrieval cue that is associated with the information that we have stored. For example, when trying to remember what we had for breakfast, it is possible to use time of day and location to cue the retrieval of this information.

Prospective remembering is difficult because the environment has to spontaneously cue the retrieval of the intention to perform an action. Three types of memory cues have been identified by researchers: event-based, activity-based, and time-based cues (Einstein & McDaniel, 1990).

Event-based cues are located in the environment. Here people remember to perform an action when some external event occurs. For example, if I intend to invite a friend over for dinner next time I see him, this intention is cued when that friend walks into my office. Activity-based cues are also located in the environment, with individuals remembering to perform an action after finishing some previous activity. For example, if I intend to take some medication after dinner, this intention is cued when I finish my dinner. A time-based cue simply refers to the passage of time. Here the action is performed at a certain time or after a period of time has elapsed. For example, if I decide to take the garbage out at 8am in the morning I am relying on time to act as retrieval cue.

Research has shown that time-based cues are significantly less effective than event-based cues (Einstein & McDaniel, 1990; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). This is thought to be the case because time-based cued tasks rely on self-initiated processes and do not contain externally presented cues to signal the correct time for the initiation of the action (Einstein & McDaniel, 1990). Time-based cued tasks require participants to monitor elapsed time and initiate the prospective memory action on their own. No research to date has directly examined the effectiveness of activity-based cues.

A second factor affecting prospective memory is the retention interval. The retention interval refers to the amount of time between deciding to do something and the correct time for performing the intended action. Prospective memory performance is facilitated by relatively short retention intervals. Research suggests that the amount of rehearsal that an individual carries out during the retention interval can affect prospective memory (Koriat, Ben Zur, & Nussbaum, 1990; Vortac, Edwards, & Manning, 1995). Rehearsing the action during the retention interval in terms of both what has to be done and the correct time at which it should be performed enhances prospective memory.

The degree to which an event-based cue prompts a particular idea (something to be done) varies with its characteristics (Einstein & McDaniel, 1990; McDaniel & Einstein, 1993). A specific characteristic that facilitates prospective memory performance is the distinctiveness or salience of the memory cue in the environment. For example, if I intend to take medication before going to bed I am more likely to remember to do so if the medication box is a bright colour and/or placed on a bedside draw containing no other items.

The nature of concurrent activities being performed during the retention interval has been found to influence prospective memory (Brandimonte & Passolunghi, 1994; Ellis & Nimmo-Smith, 1993; Marsh & Hicks, 1998). In particular, concurrent tasks requiring high levels of attention, planning, and monitoring hinder prospective memory. Purely visual, phonological, and auditory tasks have been found to have little effect. The relationship between prospective memory and concurrent activities is considered to be particularly relevant to ATC. Controller's must plan and execute multiple tasks while attending to simultaneous changes in the environment. In addition, these tasks contain differential levels of workload. In general, high workloads have lead to higher decrements in prospective memory than low workloads (Marsh & Hicks, 1998).

Limitations

The prospective memory literature, to date, has used a number of different methodologies. A number of studies have been conducted in naturalistic settings using everyday tasks such as telephoning the experimenter (West, 1988) and mailing postcards to the experimenter at a certain data (Meacham & Leiman, 1982). These studies have been criticised for not allowing strict control or assessment of the memory strategies that people use nor any control over compliance. For this reason, recent research efforts have shifted to the laboratory. The dominant paradigm used was pioneered by Einstein and McDaniel (1990). This paradigm requires subjects to remember to respond (i.e., press a key) to particular words during a word recall task. Subjects are presented with a list of words to remember and recall at a later point in time. Before the commencement of the task they are given instructions to hit a key on each occasion they see the word TIGER presented to them. The measure of prospective memory is the number of times subjects remember to press the response key to this word.

This paradigm has led to substantial improvements in our understanding of prospective memory. However, it very difficult to generalise these results to complex applied environments such as ATC where operators must plan the execution of multiple concurrent tasks in the face of considerable uncertainty. Under these conditions no single mental operation determines behaviour. We believe that in order to understand prospective memory in domains such as ATC researchers must deal directly with the source of human error in a dynamic, multitasking environment. What is needed is an experimental paradigm that requires participants to perform a dynamic task, which involves competing demands on attention, while also allowing tight control over conditions. The use of such a task also allows the precise specification of the variables influencing error and the quantification of the probability of different error types under different conditions. In the following section we describe the development of one such task.

ATC Laboratory Task

The laboratory paradigm that we have developed is a simplified two-dimensional ATC task. It is designed so that naïve experimental participants can learn to perform the task to an adequate standard within 2 hours of practice. In order to

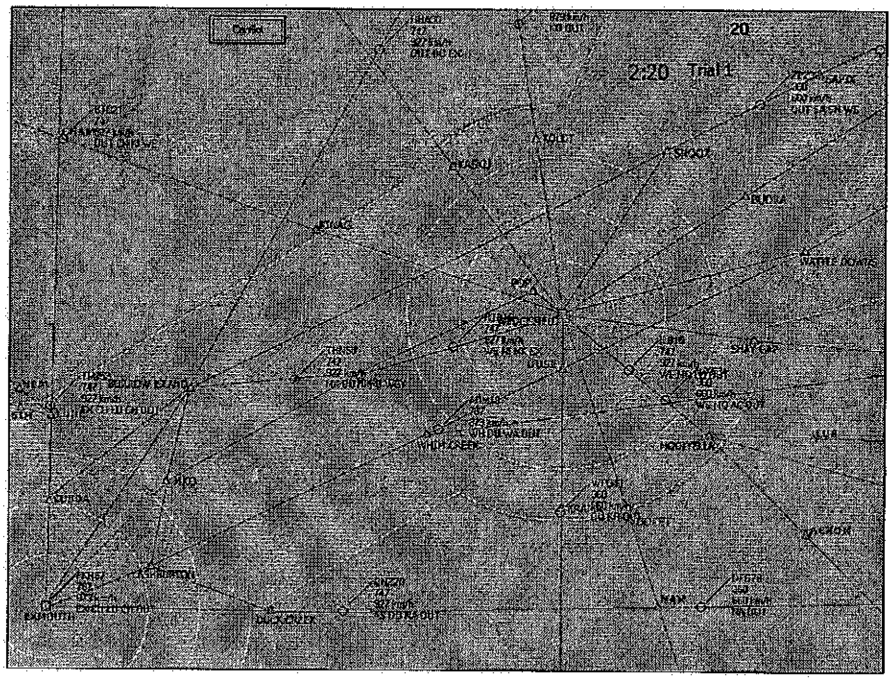

Figure 28.1 **The ATC task.** Small circles symbolise aircraft. Each aircraft has a light strip attached to it that displays the call sign of the aircraft, the type of aircraft (747, 767, 360), the speed of the aircraft and the designated route

meet this requirement, altitude has been eliminated from the display and aircraft fly on fixed flight paths. The participants have control over the speed of the aircraft and their job is to ensure that the aircraft do not violate a 5 nautical mile separation standard.

One of the difficulties of studying prospective memory in a natural setting is that the researcher can never be sure if and when the participant forms an intention to carry out an action, and does not know how the participant has encoded this intention in memory. In this task, we overcome these problems by embedding a prospective memory task in a primary ATC task. The primary ATC task requires participants to monitor evolving air traffic control scenarios on a radar-like screen in order to detect and prevent aircraft separation standard violations. The prospective memory instruction asks participants to remember to carry out a particular action in the future. Figure 28.1 presents the ATC task interface.

The factors reviewed in this paper, that have been found to affect prospective memory in word recall tasks, can be examined using the ATC task to determine their influence on prospective memory performance in a more complex dynamic setting. For example, if the participants are instructed to change the speed of a particular aircraft, we can manipulate the type of memory cue presented. We could ask to them to change the speed: (a) in five minutes (time-based cue), (b) when the aircraft reaches a nominated waypoint (event-based cue), or (c) after resolving a nominated conflict. In addition to the nature of the retrieval cue, it is also possible to manipulate the length of the retention interval, the opportunity for rehearsal (by representing the instructions), and the nature and workload of the intervening events (concurrent activities being performed).

Implications

One of the key features influencing the safety of computerised systems is the design of the Human-Computer-Interface (HCI). The HCI of a system consists of the physical mechanisms by which the operator interacts with the machine, as well as the procedures the operator follows. Findings from the literature have increased our knowledge of the psychological processes responsible for remembering to carry out previously planned actions. These findings give rise to some general applications for the design of human-computer-interfaces, applications that may help reduce the likelihood of prospective memory error. The new ATC task presented in this paper provides a sound setting for empirically examining these applications. Some starting points are listed below.

- Event-based cues are more effective reminders to perform an action. This is the case because time-based cues require the individual to monitor and initiate the action on their own. Human-computer systems should provide cues to signal the execution of to-be performed actions. These cues should be as distinctive as possible. Moreover, the system should draw operators' attention to events that will cue memory to perform actions.

- Prospective memory performance is enhanced with shorter retention intervals and when the individual rehearses the content and correct time for the intended action. The designers of human-computer systems could consider ways to encourage operators to rehearse information pertaining to the intended actions.
- The nature of concurrent tasks and workload appears to affect the likelihood of prospective memory error. Designers need to consider the likely variation in both the nature of tasks being performed and general workload in the task, paying particular attention to peaks and troughs in workload.

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References

Brandimonte, M. A., & Passolunghi, M. C. (1994). The effect of cue familiarity, cue-distinctiveness, and retention interval on prospective memory. *The Quarterly Journal of Experimental Psychology, 47*(a), 565-587.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 717-726.

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 996-1007.

Ellis, J. A., & Nimmo-Smith, I. (1993). Recollecting naturally-occurring intentions: A study of cognitive and affective factors. *Memory, 1*(2), 101-126.

Freed, M., & Remington, R. (1999). *A Conceptual Framework for Predicting Error in Complex Human-machine Environments* (Tech. Rep.). NASA.

Harris, J. E. (1984). Remembering to do things: A forgotten topic. In J. E. Harris & P. E. Morris (Eds.), *Everyday Memory, Actions, and Absent-mindedness* (pp. 71-92). New York: Academic Press.

Koriat, A., Ben Zur, H., & Nussbaum, A. (1990). Encoding information for future action: Memory for to-be-performed tasks versus memory or to-be-recalled tasks. *Memory & Cognition, 18*, 568-578.

Mantyla, T. (1996). Activating actions and interrupting intentions: Mechanisms of retrieval sensitization in prospective memory. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 93-114). Hillsdale, NJ: Erlbaum.

Marsh, R. L., & Hicks, J. L. (1998). Event-based prospective memory and executive control of working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 336-349.

Meacham, J. A., & Leiman, B. (1982). Remembering to perform future actions. In U. Neisser (Ed.), *Memory Observed: Remembering in Natural Context* (pp.327-336). San Francisco: W.H. Freeman.

National Transportation Safety Board. (1991). *Aircraft Accident Report* (NTSB/AAR-91/08). Washington, DC: US Government Printing Office.

Neal, A., Griffin, M., Paterson, J., & Bordia, P. (1997). *Human Factors Issues: Performance Management in the Transition to a CNS/ATM Environment* (Final Report: Airservices Australia). Brisbane: The University of Queensland, Centre for Organisational Psychology.

Vortac, O. U., Edwards, M. B., & Manning, C. A. (1995). Functions of external cues in prospective memory. *Memory, 3*(2), 201-219.

West, R. L. (1988). Prospective memory and aging. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical Aspects of Memory: Vol. 2* (pp. 119-125). Chichester, England: Wiley.