Chapter 16

Prospective Memory, Concurrent Task Management, and Pilot Error

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In 1991, a tower controller at Los Angeles International airport (LAX) cleared a commuter aircraft to position and hold on runway 24L while she worked to clear other aircraft to cross the other end of the runway. There were several communications delays because one of the other aircraft was on the wrong radio frequency. Visibility was poor at twilight because of haze and glare. The controller's workload was considered moderate by air traffic controllers, although laypeople might consider it quite busy. The controller forgot to clear the commuter aircraft to take off and cleared another aircraft to land on 24L, which it did, destroying both aircraft and killing 34 people.

Similar errors by pilots have also led to major accidents. In 1994, an airliner ran off the runway at LaGuardia airport after the crew rejected the takeoff at high speed because they observed anomalous indications on their airspeed indicators. The National Transportation Safety Board (NTSB) determined that the anomalous indications occurred because the crew failed to turn on the pitot heat, a normal procedural step that keeps the pitot input to the airspeed indicators from freezing in cold, wet weather. Two previous major airline accidents occurred in the 1980s when the crews forgot to extend wing flaps and slats to takeoff position, a normal procedural step required before takeoff. More recently, in 1996, an airliner landed gear-up in Houston when the landing gear failed to extend because the crew forgot to set the hydraulic pumps to the high position, which was part of the normal procedure for preparing their type of aircraft for landing. Obviously, multiple factors were at play in each of these accidents, but a central aspect of each accident was the failure of the crew to execute a simple procedural step that they had performed many thousands of times during previous flights.

In everyday life we are all susceptible to forgetting to perform intended actions. These everyday lapses are mainly annoying and sometimes embarrassing, but in the operational world memory lapses can be fatal, as these accidents testify. Memory lapses during airline flight operations are particularly striking because the airline industry has erected elaborate safeguards against errors, including written standard operating procedures, checklists, and requirements for the captain and first officer to cross-check each other's actions.

Prospective memory—remembering to perform an action that cannot be executed when the intention is formed—is a fairly new but rapidly growing topic in cognitive psychology (see reviews by Brandimonte and colleagues [1996] and Ellis and Kvavilashvili [2000]). Prospective memory is distinguished by three features: (1) an intention to perform an action at some later time when circumstances permit; (2) a delay between forming and executing the intention, typically filled with activities not directly related to the deferred action; and (3) the absence of an explicit prompt indicating that it is time to retrieve the intention from memory—the individual must "remember to remember." This third feature distinguishes prospective memory from traditionally studied retrospective memory. (Arguably, prospective memory has some similarity to implicit memory, which is a form of retrospective memory.) Typically, if queried after forgetting to perform an action, individuals can recall what they intended to do. If the LAX controller had been asked what she planned to do with the holding aircraft, she almost certainly would have been able to report her intended sequence of actions. Thus, the critical issue in prospective memory is not how we retain the content of our intentions, but how we remember to perform those intentions *at the appropriate moment*, and why we sometimes fail to remember. What would have helped the controller remember to clear the commuter aircraft to take off *before* she cleared the second aircraft to land?

Aided by new laboratory paradigms, researchers are beginning to elucidate the cognitive processes underlying prospective memory, although many questions remain unanswered. The most common paradigms are variations of a procedure developed by Einstein and McDaniel (1990): Experimental participants are given an *ongoing task*, such as evaluating the pleasantness of a series of words displayed on a computer screen, and are told that if they encounter a particular word (or set of words or class of words) they should take a specified action, such as pressing the slash key on a keyboard. This second task is the *prospective memory task*. This particular type of prospective memory task, which we will call *episodic*, has been studied extensively in recent years; however, in this chapter we present evidence that this paradigm represents only one of several types of prospective memory situations encountered in the real world.

Our research group is attempting to link real-world prospective memory phenomena with the emerging picture of underlying cognitive processes. Our approach is congruent with the approach that Chris Wickens (1992) has pioneered for many years. We believe that understanding human performance of complex real-world tasks requires converging evidence from several very different types of research methods. This chapter examines findings from ethnographic studies, analyses of accident and incident reports, and laboratory studies, all of which we attempt to pull together in a theoretical framework grounded in cognitive psychology. Well-controlled laboratory studies are essential to understand cognitive processes underlying human performance, but taken by themselves often miss important phenomena and major sources of variance in the real world. Field studies (ethnographic observations and analyses of accident and incident reports) identify crucial phenomena and the influence of task, individual, organizational, and social factors, and raise theoretical issues that might not be apparent from laboratory studies alone. Working back and forth between field and laboratory studies enriches both approaches.

FIELD STUDIES

Airline operations lend themselves to the study of skilled human performance and human error because these operations are highly standardized, with formal written operating procedures that cover almost every aspect. Because most aspects of flight operations are explicitly scripted, we can readily observe deviations from what is prescribed. In addition, a fair degree of consensus exists among subject matter experts over what actions are appropriate or inappropriate in most normal situations.

We conducted three studies that helped us to identify the kinds of tasks involving prospective memory in airline flight operations and the most common forms of associated error. An ethnographic study focused on a particular aircraft type to allow in-depth analysis (the Boeing 737—one of the most commonly used airplanes in the transport industry). We reviewed written operating procedures, participated in classroom and flight simulation training at two major airlines, and observed a large number of flights from the cockpit jump seat (Dismukes, Loukopoulos, & Barshi, 2003; Loukopoulos, Dismukes, & Barshi, 2003). A second study analyzed NTSB reports for the 19 major US airline accidents attributed to crew error between 1990 and 2001 (Dismukes, Berman, & Loukopoulos, 2005), and a third study sampled 20% of all air carrier reports submitted to the Aviation Safety Reporting System (ASRS) over a 12-month period to obtain reports involving any type of memory error (Nowinski, Holbrook, & Dismukes, 2003).

From these studies (which also address topics beyond prospective memory), we concluded that prospective memory demands in cockpit operations emerge during five types of task situations:

1. *Episodic tasks*. During these situations, pilots must remember to perform at a later time some task that is not habitually performed at that time. For example, an air traffic controller may instruct a crew to report passing through 10,000 feet while the crew is still at 15,000 feet, creating a delay of perhaps 5 minutes. Another example occurs when circumstances force pilots to perform a habitual task out of its normal sequence. Most laboratory research on prospective memory has focused on these types of episodic tasks.
2. *Habitual tasks*. Crews perform many tasks and many subtask steps during the course of a normal flight. On the order of a hundred action steps are required just to prepare a large aircraft for departure. Most of these steps are specified by written procedures and are normally performed in the same sequence. Thus, execution of tasks becomes highly habitual for experienced crews. For example, flaps are normally set to takeoff position after the engines have been started and before taxiing to the runway. Pilots do not have to form an episodic intention to perform each of these action steps; rather, the intention to perform each step is *implicit in the action schema* for the task, stored in procedural memory. Pilots do not have to form an explicit intention in advance each time they must set the flaps.

   One might argue whether performing highly habitual tasks fits the definition of prospective memory. Although habitual tasks differ substantially from episodic tasks, we include them as a form of prospective memory because the individual must retrieve the action to be taken when circumstances are appropriate without receiving any explicit prompt to retrieve the memory item. Individuals who forget to perform habitual tasks typically report that they intended to perform the task.
3. *Atypical actions substituted for habitual actions*. Circumstances sometimes require crews to deviate from a well-established procedural sequence. For example, through long experience departing from a certain airport, a crew would come to know that the standard instrument departure procedure (a written instrument procedure) requires them to turn left to 300 deg upon reaching 2,000 feet. This would become habitual for the crew. If on rare occasion a controller told them to turn to 330 deg instead of 300 deg, the crew would have to form both an episodic intention to turn to 330 deg and an intention to inhibit their habitual response of leveling the wings at 300 deg. Reason (1984) discussed memory errors in such situations as *habit capture*.
4. *Interrupted tasks*. Interruptions of procedures occur fairly frequently, especially when crews are at the gate preparing the airplane for departure. Flight attendants, gate agents, mechanics, and jump seat riders frequently interrupt the pilots as they work to complete preflight procedures. Pilots may try to finish the immediate task they are working on before addressing the person interrupting them, or they may suspend the ongoing task to handle the interruption. In either case, attention is diverted at least momentarily by the intrusion, and pilots must remember to resume where they left off. A common form of error is to move on to the next task in the normal procedural sequence, failing to return to and complete the interrupted task.
5. *Interleaving tasks*. Pilots must often "multitask," interleave two or more tasks concurrently, somewhat like a circus performer twirling plates on poles. For example, first officers must sometimes reprogram the flight management system while the airplane is taxiing to the runway (perhaps because the original runway or the original departure clearance has changed). But during taxi, the first officer is also responsible for other tasks, including monitoring the course of the taxi (to catch potential errors by the captain), handling radio communications, and—depending on the airline—various other tasks. If the reprogramming can be accomplished with a few keystrokes, the first officer may do this all at one time. But if the reprogramming takes longer, it is necessary to interleave performing some programming steps with performing other

> cockpit duties, switching attention back and forth. It is easy for pilots to become preoccupied with one attention-demanding task (for instance, if a programming glitch occurs) and forget to interrupt themselves to check the status of other tasks frequently enough. (Dismukes, Young, & Sumwalt, 1998)

The ASRS study revealed a startling finding: Of the 75 reports with sufficient information to identify a memory failure clearly, 74 involved prospective memory, rather than retrospective memory (Nowinski et al., 2003). We cannot conclude from this that prospective memory failures occur more often than retrospective memory errors. The frequency of reporting of various error types reflects factors beyond the frequency of occurrence. For example, pilots are motivated to submit ASRS reports in part because submission provides immunity from prosecution for the reporter's errors; thus, pilots are more likely to submit reports about the kinds of error that might get them in trouble. However, this finding suggests that prospective memory errors are more consequential, more frequent, or more memorable than retrospective memory errors, or combine some of these three aspects. The high level of expertise of airline pilots greatly reduces their vulnerability to retrospective memory errors, but that expertise appears to provide less protection against prospective memory errors, and indeed may contribute to some forms of prospective memory error, as discussed further in later sections of this chapter. Flight operating procedures are designed to safeguard against crew errors, but in the case of prospective memory tasks, the safeguards are themselves vulnerable to errors of omission.

Although our discussion focuses on aviation operations, we have conducted other studies revealing that comparable prospective memory tasks occur in everyday life situations (Holbrook, Dismukes, & Nowinski, 2005), and other workplace settings are very probably similar in prospective memory demands.

A THEORETICAL PERSPECTIVE

Phenomenologically, these five prototypical prospective memory situations seem quite diverse, but we argue that they share some cognitive features and can best be understood within a common conceptual framework. To make that argument requires a theoretical perspective on the cognitive processes underlying prospective memory, and this perspective can in turn help us to understand the nature of vulnerability to prospective memory errors and point to countermeasures to reduce vulnerability.

Several theoretical accounts of prospective memory have been published in recent years (e.g., McDaniel & Einstein, 2000; Smith, 2003). In some accounts a stored intention is retrieved from memory automatically when the individual notices some cue associated in memory with the intention. This has been called the *automatic* view (Guynn, McDaniel, & Einstein, 2001; McDaniel, Robinson-Riegler, & Einstein, 1998). A cue can be a specific physical stimulus or combination of stimuli in the external environment (I remember to take the cookies out of the oven when I hear the timer go off), or an internal event such as a thought or a state (I remember to go grocery shopping when I think about a recent meal or when I feel hungry). Two critical features determine the effectiveness of a cue. The cue must have a strong enough association to the intention (either through rehearsal or previous experience) to bring the intention to mind when the cue is encountered, and the cue must be present within the window of opportunity for performing that intention. A cue to remind pilots to extend the flaps for takeoff is not effective if it appears after takeoff.

A competing theoretical perspective, which has been dubbed the *strategic* view, is that retrieval requires individuals to monitor for an opportunity to perform a delayed task (Smith, 2003; also, see the discussion in McDaniel and Einstein [2000]). This monitoring makes demands on limited cognitive resources. The critical difference between the two theoretical perspectives is that they predict different effects of a delayed task on ongoing task performance, and different effects of ongoing task difficulty on prospective memory performance. The strategic view posits that the monitoring required to identify the window of opportunity for a prospective memory task requires cognitive resources that must be shared with the ongoing task. Therefore performance on an ongoing task should always be affected to some degree by a prospective memory task, and, likewise, performance on the prospective memory task should decline when the ongoing task is particularly difficult and resource demanding. In contrast, the automatic view suggests that performance on the ongoing task is not necessarily affected by the presence of a deferred intention. Also, some authors have assumed that the demands of the ongoing task should not affect automatic retrieval of intentions; however, we argue that these demands could impair retrieval if they prevent individuals from attending cues associated with the intention or reduce the extent to which those cues are processed. We believe the automatic view suggests that prospective memory performance should vary directly with the extent to which the ongoing task directs attention toward relevant cues when they appear. McDaniel and Einstein (2000) combined the two perspectives in their multiprocess framework, arguing that individuals sometimes use automatic processing and sometimes use strategic processing, depending on the nature of the prospective memory task.

Neither the proponents of the strategic view nor the proponents of the automatic view have provided a detailed account of the cognitive processes that might be involved in the retrieval of intentions. Both views have been presented exclusively in terms of episodic intentions. The *associative activation* model of Nowinski and Dismukes (2005) is an elaboration of the automatic view that also provides a framework for examining all five types of prospective memory situation. This model posits that in most situations, after forming an intention, individuals turn their attention to other tasks. The intention resides in long-term memory and is retrieved when the individual processes cues associated with the intention. Thus, retrieval is dependent on the presence of adequate cues and may or may not occur during the window of opportunity for intended execution of the deferred task. Even if the ongoing task does not direct attention to cues that were encoded to define the window of opportunity for execution, other cues associated with the intention may trigger retrieval. Retrieval may also occur at other times that are not appropriate for execution because associated cues are present. For example, one might form an intention to ask a colleague for a copy of his paper when seeing him, but might also be reminded of this intention while reading another paper related to his.

Our model posits that automatic retrieval processes are always at play, however individuals may, in some situations, supplement those processes with some strategic process, such as monitoring for opportunities to execute intentions (although it seems unlikely that in most real-world situations individuals could perform ongoing tasks adequately and monitor for cues related to intentions for long periods, especially because at any moment individuals have various and diverse intentions stored in memory). At the heart of this model is a simple system consisting of (1) only two separate information stores (focal attention and long-term memory), (2) activation mechanisms that allow memory representations to move within and between those stores, and (3) an associative network of representations through which activation is delivered to and distributed among those representations. Our formulation draws directly from the ACT-R cognitive architecture developed by Anderson and colleagues. See Anderson and Lebiere (1998) and Cowan's (1995) framework for integrating attention and memory processes. Like Cowan, we do not consider working memory a separate store, but rather treat it as a small subset of highly activated items in long-term memory.

Deferred intentions are a form of goal; however, unlike some theorists, such as Goschke and Kuhl (1993) and Anderson and Lebiere (1998), we argue that goals have no special status in cognitive processes, and we treat goals simply as memory representations consisting of actions to be executed under specified conditions. Retrieval of deferred intentions follows the same rules and involves cognitive processes underlying retrieval of other types of memory items. Thus, our account of retrieval of deferred intentions is couched within an existing framework of memory retrieval.

Following the ACT-R framework, we posit that items are stored in long-term memory in associative networks, and that items that have been encountered together form links through which activation can spread. Retrieval of an item from memory occurs when the representation receives sufficient activation to pass some threshold and enters awareness. The activation of an item at any given time is the sum of activation from two sources. The first, *baseline activation*, is determined by history. It increases with rehearsal of an item and with the frequency of retrieval, and it decreases with the length of time since the item was last retrieved. The second type of activation, *source activation*, is determined by the proportion of attentional resources directed to a cue at a given moment. The source activation received by a given item spreads to its associates, is distributed among them, and in turn spreads from them to their associates. The level of activation spread from one item to another is proportional to the strength of association between the two items. Source activation is a limited resource, thus the amount of activation reaching a given item in memory is inversely proportional to the number of competing associates.

The content of focal attention is in a constant state of flux, and once a cue exits attention, source activation to its associates in memory decays rapidly. However, decay is not instantaneous, and we speculate that this allows source activation received by a memory item from a series of associated cues passing through attention to be summated over brief intervals. The item retrieved from memory at a given moment is the item with the highest total activation, baseline activation plus source activation received through associative links.

Prospective memory, by its nature, involves dual-task processing. Once an intention is delayed, retrieval of that intention must occur during progress of whatever task is ongoing. Thus, retrieval of intentions must compete with retrieval of memory items directly associated with the goals of the ongoing task. The ongoing task has an advantage in this competition as it guides attention to environmental information needed to achieve its goal. The overarching goal, when in focal attention, provides activation for retrieval of subgoals, and subgoals, when in focal attention, in turn provide activation to help maintain the overarching goal as well as to retrieve specific information relevant to the task. So how are deferred goals ever successfully retrieved when we are in the midst of performing ongoing tasks? We attempt to answer that question in the following section.

SOURCES OF VARIANCE IN PROSPECTIVE MEMORY PERFORMANCE IN THE REAL WORLD

Our theoretical account of prospective memory suggests that the probability of retrieval of an intention (at the desired time or otherwise) is determined by several factors, one of which is the effectiveness of cues associated with the stored intention that may be noticed and processed attentively. The effectiveness of a cue hinges on the level of activation delivered to the intention from the cue. Therefore, the strength of a cue's association to the intention, the number of intentions associated with that cue, and the number of intermediate links though which source activation must spread before reaching the stored intention should influence prospective memory performance. Direct and indirect experimental evidence supports these predictions. A number of studies have demonstrated a substantial effect of the strength of association between a cue and an intention—either by choosing cues with a strong *a priori* association to the intention (Mantyla, 1993; McDaniel & Einstein, 2000; Nowinski & Dismukes, 2005) or by encouraging participants to rehearse the association (Guynn, McDaniel, & Einstein, 1998; Passolunghi, Brandimonte, & Cornoldi, 1995; Taylor, Marsh, Hicks, & Hancock, 2004). Fewer studies have examined the effect of the number of associations to the cue on prospective memory performance, but McDaniel and Einstein (1993) demonstrated that words that were likely to have fewer associations, unfamiliar words such as *bole* and *monad*, were more effective prospective memory cues than more common words. Finally, several studies have demonstrated that cues associated only indirectly to an intention are less effective than are directly associated cues. These studies found that prospective memory performance was better when specific cues rather than general-category cues were used to define the conditions for executing intentions. For example instructions to participants might read: "Press the slash key when you see the word apple," versus "Press the slash key when you see the name of a fruit" (Cherry, Martin, Simmons-D'Gerolamo, Pinkston, Griffing, & Gouvier, 2001; Ellis & Milne, 1996). When a general-category instruction is used, cue activation must spread across two associative links from the specific target presented at retrieval to the category concept to the intention.

The encoding of an intention is another major factor influencing prospective memory performance. We suggest that intentions are encoded in a form similar to if-then statements, with the *then* part specifying what is to be done and the *if* part specifying the conditions under which the intention is to be executed. The diary study by Holbrook and associates (2005) found substantial variation in the way that individuals encoded intentions to perform everyday tasks. Often individuals encoded only a vague notion of the window of opportunity for executing an intention, and did not identify specific cues they were likely to encounter that could trigger retrieval of the intention at the appropriate time. For example, one might form an intention to go to the grocery store without specifying when to execute the intention. In these circumstances, retrieval depends on chance encounters with cues that have preexisting associations with the intention—for example, one might be reminded of the need to get groceries while eating lunch in the office cafeteria. The effects of variation in encoding of intentions have not been explored experimentally until recently. In most laboratory paradigms the instructions to participants specify a particular cue that narrowly defines the condition under which the prospective task is to be executed (e.g., encountering a particular word or category of word while performing the ongoing task of evaluating the pleasantness of a series of words). Later in this chapter we report an experimental study of interruptions in which encoding was manipulated and which supports the associative activation model.

IMPLICIT INTENTIONS

Our studies of interruptions and habitual tasks in the cockpit have led us to conclude that intentions are sometimes implicit rather than explicit. In episodic situations, individuals explicitly form an intention to perform an action at some later time when conditions become appropriate. But interruptions of real-world tasks sometimes occur so quickly and forcefully that individuals do not think explicitly about the need to resume the interrupted task after the interruption. In these situations, we argue that an intention does exist; however, it is implicit in the individual's original plan to execute the interrupted task. If queried, the individual is likely to say that they do intend to complete the interrupted task, or if they forget to complete it, they are likely to say they intended to do so. When individuals do not form an explicit intention to resume an interrupted task, they may be especially vulnerable to forgetting because they do not encode specific cues likely to be encountered after the interruption that can trigger retrieval of the need to go back to the interrupted task.

Implicit intentions are also involved in highly practiced tasks that are always performed in a particular situation—for example, setting flaps to the takeoff position after starting the engines and before taxiing to the runway. Pilots do not need to think in advance of each flight "I must remember to set the flaps," thus no explicit advance intention is formed for each episode of setting the flaps. However, we argue that the intention to set the flaps exists implicitly as part of the action schema for preparing the aircraft for flight. Normally, highly practiced tasks such as this are performed with great reliability, but they become vulnerable to inadvertent omission if the cues that normally trigger execution of an action are absent.

For the sake of discussion, let us suppose that a captain normally calls for the flaps to be set when the engine after-start checklist is completed. Performing the checklist is strongly linked in procedural memory to the next action, calling for flaps to be set. Contextual cues from the environment at the airport gate may also contribute to remembering to set the flaps. Nowinski and Dismukes (2005) reported an experiment in which contextual cues enhanced the effectiveness of primary cues in a prospective memory task. But what happens if the crew must defer setting the flaps until after taxi because of freezing slush on the taxiway? The cues that normally trigger crews to set the flaps are removed. This action is now out of sequence, temporally separated from completion of the after-start checklist and is removed from the normal environmental context provided by being at the gate. Unless the pilots form an explicit intention to set the flaps at a specific point and identify or create cues to remind them, they become vulnerable to forgetting to perform this essential action.

Cues that normally trigger habitual action can also be removed for reasons other than crew actions. For example, Nowinski and colleagues (2003) found that landing without a clearance at a controlled airport was one of the prospective memory errors most frequently reported by airline pilots. Normally, crews are instructed to switch radio frequencies and contact tower immediately by approach control, and crews apparently come to rely on this prompt. However, approach controllers on occasion tell crews to delay switching to tower frequency until reaching a specified distance from the airport. Nowinski and colleagues (2003) found that 12 of the 13 reports citing an incident of landing without clearance occurred under these circumstances in which the normal prompt to change frequency immediately did not occur.

INTERLEAVING TASKS

Our model predicts that any prospective memory situation in which the ongoing task does not direct attention to cues strongly associated with the intention is vulnerable to error. Interleaving two or more attention-demanding tasks is an important example of this situation. Pilots are required to monitor the state and path of the aircraft and the actions of the other pilot while performing other tasks, and monitoring is considered an essential defense against threats to safety and crew errors (Sumwalt, Thomas, & Dismukes, 2002, 2003).

Although task switching has been studied extensively in fundamental research on attention mechanisms (Pashler & Johnston, 1998), much less research has been conducted to determine the cognitive mechanisms involved when individuals attempt to interleave tasks in real-world situations. In contrast to typical laboratory paradigms for studying attention mechanisms, many real-world situations do not provide strong environmental cues for both tasks being interleaved, and switching between tasks occurs relatively slowly—typically on the order of minutes. In these situations, individuals cannot maintain the intention to check the status of other tasks continuously in focal attention, and thus must somehow retrieve that intention to interrupt the ongoing task periodically. Pilots report becoming preoccupied with one attention-demanding task, such as reprogramming the flight management computer, and forgetting to check the status of another task, such as monitoring the progress of the taxi by the captain (Dismukes et al., 1998; Loukopoulos et al., 2003).

We suggest that interleaving may be accomplished in one of two ways. First, individuals may attempt to remember to interrupt the ongoing task after some period of time has passed. However, because they cannot consciously monitor the passage of time continuously while performing the ongoing task, and because the ongoing task often directs gaze away from the other task or tasks to be monitored, it is not clear how individuals retrieve the intention to switch attention to the other task. (See Cicogna and coworkers (2005) and Logie and associates (2004) for theoretical discussions.) What is clear is that individuals are more vulnerable to forgetting to perform time-based prospective memory tasks than they are when performing prospective memory tasks in which salient physical cues are available (Holbrook et al., 2005; Einstein & McDaniel, 1996).

Second, we speculate that in practice individuals do not depend entirely on time cues to perform time-based prospective memory tasks such as interleaving. Rather, retrieval of the intention to switch tasks may be prompted by happenstance noticing of cues associated (to some degree) with the intention, and this prompting may be facilitated by the environmental context. Also, individuals may implicitly learn rules of thumb to help them remember to switch tasks; for example, first officers might learn to limit the number of actions taken to program a flight management computer before looking up to check taxi progress. Either of these two possibilities converts the time-based prospective memory task to an event-based task. However, both processes seem rather haphazard, and performance is not likely to be highly reliable.

AN EXPERIMENTAL STUDY OF INTERRUPTIONS

We describe here an experimental study that illustrates some of the issues discussed in this chapter and provides support for our theoretical account of some of these sources of errors of omission in prospective memory. Interruptions by external agents are a major source of errors of omission in cockpit operations (Dismukes et al., 1998), maintenance (Hobbs & Williamson, 2003), and everyday tasks (Holbrook et al., 2005), and presumably contribute to errors in other domains, such as medicine (Gawande, Studdert, Orav, Brennan, & Zinner, 2003), although these other domains have not been studied extensively.

The associative activation model suggests that individuals may be vulnerable to forgetting to resume interrupted tasks in large part because of three reasons. First, the salient intrusion of many interruptions quickly diverts attention and discourages encoding explicit intentions and identifying cues to resume the interrupted task. If no explicit intention is encoded, then remembering to resume the interrupted task will depend on noticing happenstance cues that remind the individual of the status of the interrupted task and the implicit intention of completing all tasks. Even if an intention is explicitly encoded, the conditions for resuming the interrupted task are likely to be framed only as "after the end of the interruption." Individuals are often not in a position to identify and encode specific perceptual cues likely to be present at the end of the interruption. Second, cues indicating the window of opportunity for resuming the interrupted task at the end of the interruption may not closely match the form in which the intention (implicit or explicit) to resume the interrupted task is encoded. The end of the interruption is not a perceptual cue but a state of affairs that requires cognitively interpreting diverse perceptual cues to recognize. If the individual does not consciously monitor for the end of the interruption, the diverse perceptual cues may fail to trigger recognition that the interruption has ended. Third, the end of interruptions in real-world situations is often followed immediately by other task demands that may not allow the individual sufficient time to process and interpret environmental conditions fully signifying that the interruption is over or to retrieve the associated intention (Holbrook et al., 2005; Loukopoulos et al., 2003). Furthermore, activation from environmental cues associated with these other task demands may support retrieval of the goals associated with these task demands preferentially over retrieval of the goal to resume the interrupted task.

Dodhia and Dismukes (2005) designed an experimental paradigm to investigate these three themes. Experiment participants were required to answer a series of questions resembling the Scholastic Aptitude Test, arranged in blocks of different question types (e.g., analogies, vocabulary, math). They were instructed that when blocks were interrupted by the sudden onset of a different block of questions they should remember to return to the interrupted block (after completing the interrupting block) before continuing to the next block in the series. During the baseline (control) condition, these occasional interruptions were abrupt—the screen with the question participants were currently working on was suddenly replaced with a screen with a different type of question, and the background color of the screen changed.

After the end of the interrupting block, a screen appeared for 2.5 seconds with the message "Loading next section" (this screen also appeared between all blocks that were not interrupted) and then the next block of questions appeared without any reference to the interrupted block. Without receiving any explicit prompt, participants had to remember to return to the interrupted block by pressing a key. Participants of the baseline condition frequently forgot to resume the interrupted task and instead continued with the next block in the series after an interruption. The proportion of successful resumptions of the interrupted task was 0.48. These failures to return to the interrupted block were the result of memory failures, rather than a misunderstanding of the task requirements, as shown by participants' correct description of task requirements when debriefed after the experiment and by the distribution of errors among the five prospective memory trials for each participant.

To address our first hypothesis—that the intrusion of a sudden interruption discourages adequate encoding of an intention to resume the interrupted task—we implemented an *encoding reminder* condition during which the interruption began with a 4-second text message "Please remember to return to the block that was just interrupted." This manipulation increased the proportion of resumptions from the baseline condition of 0.48 to 0.65, which was highly significant statistically (as were the results of all other manipulations, discussed later). It was not clear whether the encoding reminder manipulation was effective at improving performance because of the explicit reminder or because of the additional 4-second delay before participants had to start performing the interrupting task. We therefore performed an *encoding pause* manipulation in which participants saw only a blank screen for 4 seconds at the beginning of the interruption. This manipulation also improved performance to 0.65. We interpret these results to indicate that a pause before starting to perform an interrupting task allows individuals time to recognize the implications of being interrupted and to encode information that helps them to remember to resume the interrupted task. The explicit reminder to resume the interrupted task apparently did not provide any additional encoding advantage.

We also addressed our second hypothesis that individuals are likely to forget to resume interrupted tasks because they do not encounter explicit cues signaling the end of the interruption. During the *retrieval reminder* condition, participants received a message "End of interruption" for 2.5 seconds while the next block was loading. This message appeared above the "Loading next section" message that appeared during all conditions. This manipulation increased the proportion of interruptions resumed to 0.90.

Finally, we addressed our third hypothesis, that individuals sometimes forget to return to an interrupted task because the end of interrupting tasks is often quickly followed by other task demands that do not allow the individual time to process and interpret environmental conditions fully and to retrieve the intention to resume the interrupted task. One might imagine that the "Loading next section" message that appeared for 2.5 seconds after the end of interrupting blocks (and between all blocks) would give participants enough time to reflect on whether they should do anything else before starting the block after the interruption. However, we suspected that this short pause, coupled with the message that the next section was about to start, might orient participants toward mentally preparing to start the next section and make them less likely to think about the implications of the start of a new block of questions. Thus we created a *retrieval pause* condition during which the delay between the end of the interrupting task and the beginning of the next block was increased to 8 to 12 seconds, and a countdown clock appeared to display the remaining time to the next block. This manipulation was intended to make clear to participants that they had plenty of time before new task demands would begin. Resumption performance increased to 0.88, supporting the idea that people fail to resume interrupted tasks in part because their attention is quickly diverted to new task demands arising after interruptions end.

CONCLUSION: IMPLICATIONS AND COUNTERMEASURES

The results of this experimental study of interruptions are consistent with the associative activation model, although of course much more empirical research is required to validate such a broad conceptual framework. Equally important, these results suggest practical ways individuals can reduce their vulnerability to forgetting to resume interrupted tasks. Individuals may be able to improve performance by (1) pausing when interrupted to form an explicit intention to resume the interrupted task and to identify cues that may be available to remind them after the interruption and (2) pausing after completing all tasks to ask which task should be performed next, which may not necessarily be the most salient task. We are currently conducting experiments to determine whether individuals can implement these two techniques, after being given only general instructions, without reminders on each trial from experimenters.

More broadly, we suggest that individuals may improve their prospective memory performance by (1) deliberately encoding information about environmental cues that may be encountered during the window of opportunity for executing deferred intentions, (2) by creating salient cues they will be likely to encounter at the appropriate time, (3) by making and consulting lists of deferred intentions, and (4) by periodically pausing to search memory for deferred intentions.

Although a relatively new topic in cognitive psychology, prospective memory is clearly of great importance for safe, effective human performance in many real-world situations. Continued theoretical and experimental studies are needed to elucidate the cognitive mechanisms underlying prospective memory, particularly to address questions about the form in which intentions are encoded, how intentions are retrieved, and how prospective tasks interact and compete with ongoing tasks. However, we hope that investigators will not forget that we must also study prospective memory in diverse real-world situations to identify the full range of phenomena and sources of variance that theoretical and experimental studies must attempt to explain.

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