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Prospective Memory in Aviation and Everyday Settings

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On the morning of August 31, 1988, Flight 1141, a Boeing 727, was moving slowly in a long taxi queue for departure from Dallas-Fort Worth, Texas. Because of the delay, the crew shut down the number three engine to conserve fuel. When the flight was fourth in line for takeoff, the crew restarted the engine and began running the checklists used to confirm that the airplane's systems were properly set. While they were running the checklists the air traffic controller unexpectedly told them to move up past the other airplanes to the runway, and 30 seconds later the controller cleared Flight 1141 to take off. The crew rushed to complete preparations for takeoff. When the flight engineer, who was reading the checklists aloud, called out the item for verifying that wing flaps and leading edge slats were set to the takeoff position, the first officer quickly responded "Fifteen, fifteen, green light," indicating that the inboard flaps and outboard flaps were correctly set to 15 degrees and that the green light indicating the slats were deployed was illuminated.

In fact, however, the crew had forgotten to set the flaps and slats to the takeoff position, which is essential for large airplanes to generate enough lift to climb at takeoff speeds. Unfortunately the configuration warning system, which should have alerted the crew when the throttles were advanced that the airplane was not properly configured for takeoff, failed to activate because of a mechanical failure. The airplane accelerated normally and began to climb from the runway, but then stalled, crashing a few thousand feet beyond the end of the runway. The airplane was destroyed by the impact and resulting fire; 12 passengers and 2 crew members were killed, and many others were injured seriously.

Accident investigators attribute most airline accidents primarily to crew error (Boeing, 2005). Between 1987 and 2001, 27 major airline accidents occurred in the

United States in which crew error was found to be a causal or contributing factor. In 5 of these accidents, inadvertent omission of a normal procedural step by pilots played a central role (National Transportation Safety Board [NTSB], 1988, 1989, 1995, 1997, 2001). Two accidents, including Flight 1141, involved failing to set flaps and slats to takeoff position. The other three involved failing to set hydraulic boost pumps to the high position before landing, causing the landing gear to not extend on command; failing to turn on the pitot heat,[1] causing erroneous airspeed indications on takeoff; and failing to arm the spoilers before landing, which combined with other errors and a wet runway to prevent the airplane from stopping before the end of the runway.

Perhaps I should reassure readers at this point that airliners are not raining from the sky. About 1 flight in 1.14 million departures worldwide results in an accident with fatalities or hull loss, and the accident rate for developed countries is around 1 in 5 million departures (Boeing, 2005). However, maintaining the aviation system at such a high level of reliability requires constant effort as the skies become more crowded and new challenges emerge. Because more than half of airline accidents are attributed to crew error (Boeing, 2005), it is crucial to identify the types of errors pilots make, to analyze the causes of those errors, and to avoid simplistic assumptions about the reliability of human performance (Dismukes, Berman, & Loukopoulos, 2005; Dekker, 2002).

Many factors beyond the scope of this discussion played a role in each of the five accidents already mentioned, but at the heart of each was failure by highly experienced pilots to remember to perform a fairly simple procedural step that they had executed successfully on thousands of previous occasions. Also noteworthy is that in each case the memory lapse by one pilot was not detected by the other pilot in the cockpit and was not discovered when the crew ran the associated checklist.

In this chapter I review several studies that enabled my research group to characterize the nature of prospective memory task demands in flight operations, and then compare these findings to those of a diary study of everyday prospective memory tasks, which share some features with many flight tasks. From these studies it is clear that real-world prospective memory tasks have aspects that have not yet been well explored in laboratory studies, and it seems likely that these aspects contribute to much of the variance in performance. Field studies and diary studies are by their nature rather phenomenological, and cannot resolve questions about underlying cognitive processes. Thus my discussion of cognitive issues involved in these real-world tasks is of necessity quite speculative, but this speculation points to new research issues with both practical and theoretical implications. Finally, I discuss a laboratory study we conducted as a first attempt at studying some of those implications empirically.

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[1] Pitot tubes provide atmospheric pressure readings for altimeters. These tubes are mounted on the outside of the aircraft and are heated to prevent freezing, which would cause erroneous readings.

AVIATION STUDIES

Airline operations lend themselves to study of skilled human performance of complex tasks because detailed written procedures, in the form of flight operations manuals (FOMs), guide almost every aspect of flight from before starting the engines to shutting them down after landing. The procedures are designed to ensure that crew actions are correct, safe, and efficient, and to provide standardization so that crew members who have never flown together (which is often the case in large airlines) can readily coordinate their actions. Also facilitating research is that a fair degree of consensus exists among aviation experts about what constitutes appropriate or inappropriate action in specific situations.

We have recently completed three studies that enable us to describe the kinds of prospective memory tasks that commonly occur in flight operations, to identify the forms of error that occur, and to speculate about the causes of those errors. The first was an ethnographic study in which we collected information about normal flight operations on Boeing 737 aircraft (Dismukes, Loukopoulos, & Barshi, 2003; Loukopoulos, Dismukes, & Barshi, 2003). One author observed 60 normal flights by 36 crews from two major airlines by sitting in the cockpit jumpseat and taking notes. (In the Boeing 737 the jumpseat is between and behind the two pilots' seats.) The other two authors participated as pilots in one airline's flight simulation training for first officers. We also analyzed FOMs and participated in classroom training to characterize how pilots were ideally expected to execute procedures. We searched the Aviation Safety Reporting System's (ASRS) extensive database of voluntary reports from pilots to find examples of prospective memory errors and other errors associated with concurrent task demands.

In a second study we analyzed the NTSB reports of the 19 major U.S. airline accidents between 1991 and 2001 in which crew error played a central role, and attempted to determine the task, cognitive, and organizational factors contributing to those errors. (This study and the ethnographic study address many crew performance issues beyond prospective memory that are not discussed in this chapter.)

The third study sampled 20% of all ASRS reports from airline pilots over a 12-month period to obtain descriptions of any type of memory error (Nowinski, Holbrook, & Dismukes, 2003). A startling finding of this study was that, of the 75 reports with sufficient information to clearly identify a memory failure, 74 involved prospective memory rather than retrospective memory. This is not necessarily evidence that prospective memory errors are more common than retrospective errors—the frequency of reporting of different types of error to ASRS reflects factors beyond the frequency of occurrence. Pilots are motivated to submit ASRS reports in part because submission provides immunity from prosecution for the reporter's errors, so pilots are more likely to submit reports about the kinds of error that might get them in trouble. However, this finding does suggest that prospective memory errors are more consequential, more frequent, or more memorable than retrospective memory errors.

On reflection, it would not be surprising if experts are more vulnerable to prospective memory errors than to retrospective memory errors. The high level of experience and proficiency of airline pilots greatly reduces their vulnerability to retrospective memory errors, but may provide less protection against prospective memory errors, and may even increase vulnerability in certain situations, discussed later in this chapter. Operational procedures provide safeguards, such as checklists, to support performing intended actions, but these safeguards are themselves vulnerable to inadvertent errors of omission. In several airline accidents, crews that were distracted, interrupted, or overloaded forgot to begin or to resume a checklist.

By combining the findings from these three studies we began to get a picture of prospective memory demands in the cockpit. We have categorized these demands into five general situations that differ in terms of the associated cognitive demands. The situations are illustrated with examples in the following discussion.

Episodic Tasks

These tasks correspond to the type of prospective memory task most commonly studied in laboratory paradigms. In these situations the pilot must remember to perform at a later time some task that is not habitually performed. For example, an air traffic controller might instruct a crew to report passing through 10,000 feet (altitude) while the airplane is descending through 15,000 feet, a task that would require the crew to hold the instruction in memory for perhaps 5 minutes as the airplane descends. The way pilots typically perform this type of task seems to combine aspects of both event-based and time-based prospective memory. Although the condition for executing the intended action is ostensibly framed in terms of an event—passing through 10,000 feet—to know that the airplane has reached this altitude requires the crew to monitor an altimeter as it winds down during descent, similar to monitoring a clock. During descent pilots are occupied with diverse flight tasks that divert their attention from the altimeter, so awareness of time probably plays a role in the altitude task. With experience, some pilots may develop scanning routines in which they perform several steps of an ongoing task and then switch attention to the altimeter, in which case the ongoing task steps may serve as event-based cues for monitoring. Also, all of the ongoing tasks are part of the overarching goal of managing the flight path, and this context may provide associative cuing that helps the pilots remember to check the altimeter (see Cook, Marsh, & Hicks, 2005; Nowinski & Dismukes, 2005, for context effects).

The window of opportunity for executing a deferred intention and the nature of the cues signaling that opportunity in real-world situations are far more variegated than in most prospective memory laboratory paradigms. (See Ellis's [1996] discussion of retrieval context.) In the laboratory the prospective memory target cue uniquely defines the opportunity to respond and is usually presented in a discrete trial, in most cases lasting only a few seconds. In contrast, consider an aviation situation in which the crew decides to defer setting the flaps to takeoff position until they reach the end of the taxi rather than at the usual time (for reasons explained later). The window of opportunity here is defined not by a single perceptual cue but by a constellation of cues that must be interpreted as a set to recognize that the time has come to set the flaps. When the crew reach the end of the taxi they begin performing the last preparations for takeoff and may not consciously frame their situation as "we are at the end of the taxi." Also, the crew's ongoing tasks at this point may or may not direct attention to happenstance cues associated with the intention, for example, the flap handle.

Habitual Tasks

Crews perform many tasks in the course of a flight, and many tasks involve multiple steps. Most of the tasks and many of the intermediate steps of the tasks are specified by written procedures, and are normally performed in the same sequence. Thus, for experienced pilots, execution presumably becomes largely automatic and does not require deliberate search of memory to know what to do next. Pilots do not need to form an episodic intention to perform each task and each action step—rather the intention is implicit in the action schema for the task, stored as procedural memory. It would be uncommon for a pilot to arrive at work thinking "I will lower the landing gear today when I turn onto final approach" (and it would be rather alarming if a pilot found this necessary).

This raises the question of whether performing habitual tasks should be considered a form of prospective memory—certainly habitual tasks differ substantially from episodic tasks in the way intentions are encoded. We come down on the side of including habitual tasks as a special form of prospective memory for largely practical reasons. When individuals forget to perform a habitual task, they generally report having intended to perform the task, and consider not having done so a failure of memory. Regardless of how we label these memory failures, it is important to study them: It is noteworthy that all five of the memory failures resulting in accidents described earlier involved habitual tasks.

Remembering to perform habitual tasks seems quite reliable normally—individuals in aviation and in everyday life perform enormous numbers of habitual activities with few complaints—but performance is undermined if normally present cues are for some reason removed. Apparently execution of habitual tasks depends heavily on cuing (Meacham & Leiman, 1982), an aspect shared with event-based episodic tasks. For example, at a given airline, the procedure may be for the captain to call for flaps to be set for takeoff immediately following completion of the after engine start checklist and before starting to taxi. Setting the flaps occurs as part of a habitual sequence of actions, and the captain is normally prompted to remember to call for the flaps by the strong association in memory with completing the preceding checklist. Further, the context of the perceptual environment of the ramp area outside the cockpit is associated with setting flaps, and recent research reveals that context can support retrieval of intentions (although this has not been studied with habitual tasks; Cook et al., 2005; Nowinski & Dismukes, 2005).

What happens, however, if the crew must defer setting the flaps until after taxi to prevent freezing slush on the taxiway from being thrown up on the flaps? The cues that normally trigger crews to set the flaps are no longer present—this action is now out of sequence, temporally separated from completion of the after engine start checklist and removed from the normal environmental context provided by being at the ramp. By deferring the task of setting the flaps, the crew has essentially changed a habitual task to an episodic task. They may not realize that this increases their vulnerability to forgetting and may not elaborate encoding of the intention or identify or create specific cues as reminders.

An even more insidious vulnerability of habitual tasks occurs when external circumstances remove a cue that normally triggers execution of a task. For example, a highly experienced airline captain reported landing his private airplane gear-up. The captain's own analysis was that he had developed the habit of lowering the landing gear as he entered the downwind leg of the landing pattern when the runway passed under the wing (in visual rather than instrument conditions). On this occasion he made a rare visual straight-in approach to the airport and thus the runway never passed under the wing, removing the cue that normally prompted him to lower the gear. This suggests that the captain relied on automatic retrieval of the action, rather than consciously monitoring for the opportunity to lower the gear. We suspect that pilots rely heavily on automatic retrieval of habitual actions because otherwise the volume of action steps required to operate an airplane during busy periods would be overwhelming.

Although the distinction between episodic and habitual tasks goes back to the early days of prospective memory research (Ellis, 1996; Meacham & Leiman, 1982), few empirical studies have addressed habitual tasks, and those few have not examined tasks as deeply engrained and situation dependent as those of experts performing highly practiced tasks (Einstein, McDaniel, Smith, & Shaw, 1998). It would be useful to know more about the factors determining retrieval of individual steps by experts performing habitual concurrent tasks. Is retrieval driven by a single cue or interaction of multiple cues? How do cues interact with the expert's action schema and goal structures? How do automatic and conscious processing interact? Performance on event-based prospective memory tasks in the laboratory has been shown to improve when importance of the prospective tasks is emphasized, presumably because participants shift their strategy for allocation of attention (see, e.g., Kliegel, Martin, & McDaniel, 2004). Given the extensive role of habitual procedures in the work of experts in many domains, it would be worthwhile to explore the role of importance in habitual prospective memory tasks. For example, even though pilots are quite cognizant that omitting certain procedural steps could have fatal consequences, the successful execution of those steps many thousands of times over years of experience may remove the sense of threat. Combined with sometimes heavy task loading, this may undercut pilots' incentive to carefully monitor execution of procedures that can be performed in a largely automatic fashion (Dismukes et al., 2005).

Atypical Actions Substituted for Habitual Actions

Circumstances sometimes require crews to modify a well-established procedural sequence. If the modified procedure resembles the normal procedure, differing only in a single step, the crew is vulnerable to unintentionally reverting to the normal procedure unless they carefully monitor execution when the step is to be substituted. For example, departing from a particular runway at a certain airport, crews might almost always be given a standard instrument departure (SID) procedure that requires them to turn left to 300 degrees on reaching 2,000 feet.

Through long experience the sequence of actions to execute this procedure would become habitual. If on one occasion a crew is directed before takeoff to modify the SID to turn to 330 degrees instead of 300, the crew would need to form an episodic intention to continue their turn to 330. Crews are quite busy with multiple attention-demanding tasks during early departure; when the crew levels the airplane at 2,000 feet and sets the cockpit automation to start a left turn they are vulnerable to setting 300 degrees out of habit instead of 330, without noticing the error. Reason (1990) discussed memory errors of this sort as *habit intrusions*. The idea is that cues that normally trigger the habitual action are so strongly associated that the habitual action is often retrieved and executed automatically instead of the intended action if the individual does not consciously supervise the process.

Kvavilashvili and Ellis (1996) argued that habit intrusion errors of this sort are not truly prospective memory errors, which they would restrict to situations in which no intention is retrieved at all. (In habit intrusion the habitual action is retrieved and executed inappropriately.) Regardless of nomenclature, it seems important for prospective memory researchers to investigate errors in execution of habitual tasks. Highly practiced tasks make up much of the work of experts, and it seems that errors of omission in these practiced tasks occur mainly when normal cues are removed (as when habitual tasks are deferred) or when an atypical action step is substituted for a habitual step. The latter may suffer from a double vulnerability. Not only must the pilot remember a new, episodic task; the intended action must also compete for retrieval with the habitual action, which is strongly associated in memory with cues present in the environment or generated by preceding actions.

Interrupted Tasks

Interruptions of cockpit procedures are quite frequent, especially when crews are at the gate preparing the airplane for departure (Dismukes, Young, & Sumwalt, 1998; Latorella, 1999; Loukopoulos et al., 2003). Flight attendants, gate agents, mechanics, and jumpseat riders require the pilots' attention as the pilots perform a fairly long sequence of procedural steps before starting the engines. Interruptions are so abrupt, salient, and common that pilots may do little if anything to encode an explicit intention to resume the interrupted task. After the interruption is over, a common error is to go on to the next task, forgetting to complete the interrupted task. In many cases the perceptual cues available in the cockpit do not provide a salient indication of the status of the interrupted task, and the perceptually rich environment of the cockpit is associated with many tasks that remain to be done at this point. If the pilot thinks to ask, "What was I doing when I was interrupted?" he or she may remember the interrupted task, but sometimes this question is not asked, and the pilot simply responds to the next task demand.

We speculate that source memory confusion may play a role here (Johnson, Hashtroudi, & Lindsay, 1993). Having performed cockpit preparation tasks thousands of times previously (and perhaps on earlier flights the same day), a specific instance of performing the interrupted task may not be very distinctive in memory from the many times it has been completed. Further, the memory of having started the interrupted task may lead to the belief that it has been accomplished, and this may help trigger initiation of the next task in the sequence.

Interleaving Tasks and Monitoring

While performing ongoing tasks pilots are often required to monitor the status of other tasks. Some tasks, such as the requirement to report passing through an altitude, previously discussed, involve monitoring for an event that is known *will* occur. In other situations, pilots must monitor for events that occur infrequently, if at all. For example, when flying in visual meteorological conditions, pilots must scan outside the cockpit windows for other airplanes that might be on a conflicting path. This may seem a topic of more interest to attention researchers than memory researchers, but in fact pilots report becoming preoccupied with ongoing tasks and forgetting to monitor the status of other tasks for dangerously long periods (Dismukes et al., 1998). The problem is probably greatest when high workload preempts limited resources: Bargh and Chartrand (1999) argued that conscious control of behavior (which monitoring presumably requires at least to some extent) is a very limited resource. However, lapses in monitoring also occur in low and moderate workload situations in which enough time exists to switch attention back and forth between the ongoing task and monitoring and to perform both tasks adequately.

In a flight simulation study, pilots' scanning outside the cockpit increased substantially when potentially conflicting airplanes started appearing, but returned to near baseline levels minutes after the last airplane appeared (Colvin, Dodhia, & Dismukes, 2005). We speculate that it is difficult to maintain the monitoring task goal in working memory when the result of each inspection of the monitored scene reveals that no event has occurred. In this sense the monitoring aspect of the pilots' dual tasks somewhat resembles vigilance tasks (Parasuraman, 1986). Apparently humans are wired to allocate attention heavily toward sources of high information content, and thus have difficulty maintaining monitoring for low-probability events, even when those events may have high consequences (see Wickens, Goh, Helleberg, Horrey, & Talleur, 2003, for a model of attention allocation among tasks). However, this sort of monitoring differs from traditionally studied vigilance tasks in that the pilot must interrupt an ongoing task and shift attention to the thing being monitored. When the pilot goes too long without shifting attention, the monitoring task may slip from working memory, and then must somehow be retrieved, just as in other types of prospective memory situation. This conclusion is supported by a study in which Einstein et al. (2005) found that the level of monitoring declined over the course of the experiment. (The level of monitoring was inferred from the cost to response time of an ongoing task.)

Much of prospective memory laboratory research has focused on stimulus-driven responding, and only a few studies have addressed monitoring as a prospective memory task. Park, Hertzog, Kidder, Morrell, and Mayhorn (1997) required participants to remember to make a response at either 1-minute or 2-minute intervals while performing an ongoing working memory task. Participants were allowed to check elapsed time during the intervals. Monitoring performance was worse with 2-minute intervals, suggesting difficulty maintaining the monitoring task in working memory.

The six-element task developed by Shallice and Burgess (1991) and adapted for prospective memory studies by Kliegel and colleagues (Kliegel, McDaniel, & Einstein, 2000) shares some features with cockpit monitoring tasks. The six-element task requires participants to remember to switch tasks on their own as a function of how far they have progressed on the current task, rather than remembering to switch when a prearranged cue is perceived or at a predetermined interval. Similarly, many cockpit monitoring tasks also require pilots to remember to switch attention periodically from an ongoing task, without the benefit of any specific cue. In both the six-element task and cockpit tasks, the individual's perception of passage of time presumably plays a role, although the mechanisms of this are not understood (see Cicogna, Nigro, Occhionero, & Esposito, 2005, for theoretical speculation about mechanisms of time-based prospective memory).

Many interesting research questions about performance of monitoring tasks of this sort invite study. When the goal of monitoring slips from working memory it eventually reappears—its reappearance triggered by the passage of time, happenstance cues, the context of the cockpit environment, performance of steps of the ongoing task, or something else altogether. What is the relation of the goal and action structures of the ongoing task and the monitoring task? What role does task importance play when monitoring for low-probability, high-consequence events? Do individual differences and situational factors such as fatigue and stress affect monitoring performance? Could pilots and other individuals learn techniques to reduce vulnerability to lapses in monitoring?

EVERYDAY PROSPECTIVE MEMORY

Our ethnographic study revealed the structure of prospective memory situations in the cockpit, but too few errors were observed for analysis. Review of accident and incident reports provided plentiful examples of errors, but did not provide access to the pilots involved. We recently completed a diary study of everyday prospective memory to explore the structure of these real-world tasks, to compare them to aviation prospective memory tasks, and to take advantage of individuals' ability to report the nature of their intentions (Holbrook, Dismukes, & Nowinski, 2005). Eight participants, all with at least some graduate-level training in psychology and familiarity with prospective memory concepts, were used on the assumption that these individuals would be better able to recognize and describe prospective memory situations than untrained individuals. We recognize that our participants' reports are undoubtedly colored by their theoretical perspectives.

Participants were asked to record at least one prospective memory task in which they succeeded or failed each day for a week. Each participant received a digital voice recorder and worksheets with questions to elicit a detailed description of the intention, prior experience performing this type of intention, how the intention was encoded, length of retention interval, whether the intention came to mind during the retention interval, and the window of opportunity for executing the intention. Voice recorders were used to make brief notes at the time the intention was retrieved; these notes helped participants fill out the worksheets at the end of the day.

Sixty-nine worksheets were collected, describing 29 successes and 40 failures to perform an intended action during the intended period. The types of intention reported fell into four categories: event-based episodic (e.g., buy toothpaste while at a drugstore), time-based episodic (e.g., take car to garage before 5 p.m.), habitual (close top of bottle of contact lens solution), and multiple component. The last category consists of intentions with multiple intended actions grouped under a superordinate goal, such as going to a store to buy several items. Failing to pick up one item of several might be viewed as a failure of the retrospective component of prospective memory in some situations, but in other situations it seemed clearly a problem with the prospective component. For example, one participant reported going to a store to buy an item, then thinking of additional items while at the store and buying those items, but forgetting to buy the item originally intended. Perhaps picking up the unplanned items induced a sense of having completed the intention and triggered the action schema of going to the cash register.

No habit intrusion errors were reported in this sample, although these were reported in the larger sample of another study of everyday tasks not discussed here. No failures of interleaving tasks or monitoring were reported, which may indicate that this type of task is less common in everyday affairs than in aviation or that monitoring failures are less likely to be noticed.

It is not likely that the relative proportion of successes and failures or the numbers of each type of prospective memory task reported in this study represent actual exposure. For example, success at habitual tasks, such as brushing one's teeth, are so common as to seem trivial, and were almost certainly underreported. Thus our analysis focuses on interrelations among variables described next.

Participants were asked to indicate which of four statements best described their encoding of each intention. Table 19.1 shows that most intentions were encoded in ways that did not fully specify the window of opportunity for executing the intention and did not identify specific cues that might be encountered to trigger retrieval of the intention. Intentions for which more specific information was encoded were more likely to be remembered (r = .34). (All correlations reported

TABLE 19.1 Extent of Encoding

Level of Encoding	No.	%
You did not think very much about the intention, just assumed you would remember to perform it.	16	23
You made a "mental note" to perform your intention, but didn't think specifically about how, where, or when you would perform it.	24	35
You thought about how or where you would perform your intention but did not identify exactly when you would perform it.	23	16
You developed a specific plan for how, where, and when you would perform your intention.	35	24

TABLE 19.2 Retention Interval

Retention Interval	No.	%
Less than 1 hour	15	22
1 to 12 hours	28	41
12 to 24 hours	7	10
More than 24 hours	19	28

here were statistically significant.) Also, intentions that were rated as more important were encoded more completely ($r = .32$) and were remembered better ($r = .26$). Participants were more likely to create a cue to help them remember intentions they considered important ($r = .24$).

The retention interval ranged from 30 seconds to 3 weeks (Table 19.2). The length of most retention intervals makes it seem unlikely that individuals could continuously and actively monitor for the opportunity to execute the intention. No participant reported monitoring for cues in his or her narrative descriptions, which is consistent with reports from other diary studies (e.g., Kvavilashvili, 2005; Marsh, Hicks, & Landau, 1998; Sellen, Louie, Harris, & Wilkins, 1997). This does not rule out the possibility of some sort of unconscious monitoring or, alternately, of individuals being in a state of heightened retrieval sensitivity (Mäntylä, 1993).

Participants were asked to report spontaneous retrievals during the retention interval. Spontaneous retrievals were reported for 59% of successfully executed intentions and 33% of failures ($r = .26$), and multiple spontaneous retrievals were reported for 48% of successes and 18% of failures.

The window of opportunity for successfully executing intentions (retrospectively defined by participants when filling out the worksheets) ranged from 1 minute to 3 weeks (Table 19.3). Thus most of these everyday tasks provided a broad window of opportunity to execute the intention. In 51% of successful retrievals during the execution window, individuals reported that retrieval occurred when they noticed a happenstance cue, that is, a cue the individual had not identified when forming the intention. In some sense even the “failures” in our sample represent some level of success, because participants eventually retrieved the intention after the execution window had passed. Forty-eight percent of late retrievals were

TABLE 19.3 Window of Opportunity for Execution

Execution Window	No.	%
Less than 1 hour	23	33
1 to 12 hours	31	45
12 to 24 hours	3	4
More than 24 hours	12	17

reported to have been associated with noticing a happenstance cue. Thus happening to encounter unplanned cues may account for a major portion of the variance in performance of these everyday prospective memory tasks. Happenstance cues are more likely to be encountered, of course, when the window of opportunity for execution is broad.

In comparison, how effective were planned cues (those identified during encoding)? Participants reported encoding specific cues in 22 instances. The planned cues were actually encountered in only 14 of these 22 instances, and retrieval was successful in 8 of these 14 cases. Thus planned cues played a smaller role than happenstance cues in successful performance in this study.

Summing across this diary study (not all of which is reported here), I posit that several factors account for much of the outcome of executing intentions in everyday situations. The following factors are internal to the individual:

Intention is not explicitly specified at all—intention is *implicit*, as in habitual tasks and some interrupted tasks.
Intention is poorly specified—few details are encoded about opportunities for execution.
Cue is ineffective—individuals habituate to cues continuously present, cues are not sufficiently associated with the intention, cues have many other associations.

These factors are environmental:

Ongoing task demands direct attention away from cues.
Planned cues do not occur or are not encountered.
Happenstance cues are encountered.
Broad window of opportunity for execution.

Our subjective impression is that these factors also account for much of the variance in prospective memory performance in aviation settings, but we have not studied this directly. It is noteworthy that the experimental literature on prospective memory has not yet addressed many of these factors in any depth, perhaps in part because it is difficult to manipulate these factors in a controlled way in most existing laboratory paradigms. For example, a large number of experimental studies have explored the crucial role of cuing in event-based prospective memory (e.g., Brandimonte & Passolunghi, 1994; Ellis & Milne, 1996; McDaniel & Einstein, 1993; Meacham & Colombo, 1980; Richards & Krauter, 1999; Vortac, Edwards, Fuller, & Manning, 1993), but both our diary study and a recent diary study by Kvavilashvili (2005) suggest we should pay more attention to happenstance cues not encoded with the intention. Also, experimental studies have typically not explored how individuals encode intentions and what they encode in real-world situations. (However, Kliegel et al., 2000, did use the six-element task to look at participants' planning and adherence to their plans.) Our studies suggest self-initiated encoding varies considerably, partly as a function of the situation, and the implementation planning literature (Chasteen, Park, & Schwarz, 2001; Gollwitzer, 1999) reveals that prospective memory performance can be enhanced by more elaborate or more specific encoding. (This conclusion is supported by the interruption study described next.)

The factors identified in our studies have practical implications, such as pointing to ways to protect against prospective memory failures. One can also see interesting theoretical issues lurking within these sources of variance. For example, is self-encoding more effective than experimenter instructions (when content is comparable), analogous to the generation effect for retrospective memory (Slamencka & Graf, 1978)? By what mechanisms do spontaneous retrievals during the retention interval affect performance (Kvavilashvili, 2005)? Are individuals more sensitive to noticing happenstance cues when retaining an intention to which those cues are related (see Mäntylä, 1993)? Do stored intentions alter how individuals allocate attention, consciously or nonconsciously, while performing ongoing tasks? Are the goal structures for ongoing tasks and prospective memory tasks independent or do they interact, and if so how?

AN EXPERIMENTAL STUDY OF INTERRUPTIONS

Our group is attempting to develop experimental paradigms that would allow exploration of the factors identified in our studies of prospective memory in aviation and everyday settings. We have developed a paradigm that allows us to study how some of these factors play in interrupted tasks. Interruptions are a major source of errors of omission in cockpit operations (Dismukes et al., 1998) and in aviation maintenance (Hobbs & Williamson, 2003), and interruptions may contribute to errors of omission in other domains, such as medicine (Gawande, Studdert, Orav, Brennan, & Zinner, 2003), although this has not been studied explicitly in other domains. Several experimental studies have found that interruptions contribute to delays, impaired retrospective memory, and errors of commission after the interrupted task resumes (Edwards & Gronlund, 1998; Speier, Valacich, & Vessey, 1999; Trafton, Altmann, Brock, & Mintz, 2003), but interruptions have not been studied as a form of prospective memory task until recently.

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Dodhia and Dismukes (2005) hypothesized that individuals forget to resume interrupted tasks for three reasons. First, the salient intrusion of interruptions often diverts attention quickly, undercutting encoding of an explicit intention to resume the interrupted task. If no explicit intention is encoded, then remembering to resume will depend on noticing happenstance cues that remind the individual of the status of the interrupted task and of the original motivation to undertake that task. In this case one might say that an *implicit* intention to resume exists. Even if the individual does explicitly think at the moment of interruption of the need to resume the interrupted task, encoding is likely to be abbreviated, conditions for resuming may be poorly specified, and cues indicating the opportunity to resume may not be encoded. This situation may somewhat resemble that presented by a paradigm reported by Einstein, McDaniel, Williford, Pagan, and Dismukes (2003) in which participants retrieved a deferred intention but had to defer executing the intention for a short period in which they continued an ongoing task. Even a 15-second delay in execution of the retrieved intention reduced performance substantially. The need to execute the retrieved intention after a short delay is essentially a new prospective task. Perhaps participants underestimated the difficulty of retaining the retrieved intention for such a period and did little to encode or rehearse this new prospective task after the initial intention was retrieved.

A second reason individuals may forget to resume interrupted tasks is that, after the end of an interruption, individuals are often presented with new task demands and opportunities that capture their attention, giving them little time to interpret the end of the interruption or to process cues that might remind them of the implicit or explicit intention to resume the interrupted task. A third reason is that 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 to resume (implicit or explicit) was encoded. The end of an interruption is not a simple perceptual cue, but a state of affairs that requires interpreting diverse perceptual cues to recognize. Although the individual may process these diverse cues as part of the ongoing task, he or she may not frame the situation as "this is the end of an interruption," unless consciously monitoring for this event. Rather, the individual may frame the situation only as the transition from one task to another, or may not even consciously frame the situation at all, simply responding to the flow of demands posed by a series of tasks. This third hypothesis goes beyond the issue of how individual cues are processed and suggests that how individuals frame the ongoing task might have an effect on retrieval, a sort of metacognitive influence. This idea is partially related to the concept of transfer-appropriate processing and to the finding that changes in conceptual context (McGann, Ellis, & Milne, 2002) or semantic context (McDaniel, Robinson-Riegler, & Einstein, 1998) between encoding and testing impair retrieval of intentions.

We designed an experimental paradigm to investigate these three hypotheses. Participants were required to answer a series of questions resembling the Scholastic Aptitude Test, arranged in blocks of different types of question (e.g., analogies, vocabulary, math). They were instructed that when blocks were occasionally 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 and before continuing to the next block in the series. Five of the 20 blocks were interrupted. In the baseline condition these occasional interruptions were abrupt: The screen with the question participants were currently working on was suddenly replaced before the question could be answered with a screen with a different type of question, and the background color of the screen changed.

After the last question of the interrupting block was answered, 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 incomplete block that was interrupted. Without receiving any explicit prompt, participants had to remember to return to the interrupted block at this time by pressing a key. Participants in the baseline condition frequently forgot to resume the interrupted task (discussed later) and instead continued with the next block in the series after the interruption. These failures to return to the interrupted block were due to memory failures, rather than to misunderstanding 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 individual participants.

The first experiment included three manipulations, conducted across participants. To address the first hypothesis, that the sudden intrusion of an interruption discourages adequate encoding of an intention to resume the interrupted task, we used an encoding reminder condition in 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 .48 to .65, which was highly significant statistically (as were the results of all other manipulations discussed here). It was not clear whether the encoding reminder manipulation improved performance because of the explicit reminder or because of the 4-second delay before participants had to start performing the interrupting task. Therefore we included 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 .65. We interpret this result as indicating that a short 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 remember to resume the interrupted task. Providing an explicit reminder to resume the interrupted task apparently does not provide any additional advantage over the pause.

This experiment also included a manipulation to address the second hypothesis, that individuals sometimes forget to resume an interrupted task because interruptions are often quickly followed by other task demands that attract attention and prevent the individual from fully processing and interpreting environmental conditions and retrieving 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 other 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 might make them less likely to think about the implications of a new block of questions being loaded (implicitly signaling that the interrupted task should be resumed rather than starting the next block). To address this we created a retrieval pause condition in which the delay between all completed blocks, including the delay after interruptions, was increased to between 8 and 12 seconds. (No delay occurred in the onset of the interruption, as in the baseline condition.) During the delay between blocks a countdown clock displayed the remaining time to the next block so it would be obvious to participants that they had plenty of time before new task demands would begin. This manipulation increased performance to .88, supporting the idea that individuals fail to resume interrupted tasks in part because their attention is sometimes quickly diverted to new task demands arising after interruption's end.

A second experiment, conducted within participants, addressed the third hypothesis, that individuals are vulnerable to forgetting to resume interrupted tasks because the diverse cues indicating the end of an interruption do not provide a simple match to the encoded intention and must be integrated for the individual to interpret their significance. As before, participants were interrupted on five blocks; two of these blocks were interrupted in the manner of the baseline condition, but for three of the blocks the "Loading next section" screen that appeared after the interruption also included the message "End of interruption." This message increased performance from the baseline condition of .52 to .88, supporting our hypothesis.

Although more studies will be required to fully elucidate the cognitive mechanisms underlying these effects, this interruption study demonstrates that hitherto unexplored sources of variance in real-world prospective memory studies can be studied in controlled laboratory paradigms. The sources of variance we hypothesize for interruptions may also apply in other prospective memory situations. For example, in many real-world situations individuals may fail to elaborate an intention or the conditions for execution—someone might have a fleeting thought at night to call a colleague the next day but not encode conditions for execution in detail. One interpretation of the improvement in performance associated with forming implementation plans (Gollwitzer, 1999) is that planning provides better matching between the encoded intention and cues that may occur during the window of opportunity for execution (Chasteen et al., 2001).

Also, in many real-world situations the window of opportunity requires interpretation of diverse cues to frame the situation as the window of opportunity. In the preceding example, you might frame the window for calling the colleague as "when in my office tomorrow." If asked the next day, you would certainly report being aware of being in your office, but until asked you might not consciously frame your situation that way. Of course individual perceptual cues within the office are associated with the concept of office and thus should provide some associative cuing, at least indirectly. Indeed, the office provides many cues, so in one sense the opportunities for reflexive retrieval are large. However, the point here is the lack of direct correspondence between how the intention was encoded—as an abstraction not depending on any single perceptual cue—and how the individual frames the ongoing situation in the office. Most likely the individual's stream of consciousness will revolve around the tasks being performed rather than an explicit frame of "Now I am in my office." We can only speculate how this might affect prospective memory processes, as most laboratory studies have used simple perceptual cues—mainly words and pictures—as targets to signal the opportunity to execute deferred intentions. Some experimental studies have used more complex situations to define the window of opportunity, for example, asking participants to remind the experimenter to look up some data after the end of the experiment, but the effects of using more complex situations, and the underlying cognitive processes, have not been explored systematically (see discussion in Kvavilashvili, 1992).

The difference between using single perceptual cues and more complex situations as conditions for retrieving intentions may be somewhat analogous to the difference between using single targets and conjoint targets in visual search (Triesman & Gelade, 1980). When searching for a target that differs from distracters only in a single dimension, the target appears to "pop out" automatically, but when the target is defined by conjunction among two or more variables, individuals must search serially and effortfully. By analogy, individuals may be able to retrieve intentions automatically and fairly reliably if the opportunity for retrieval is defined by a simple perceptual cue and if the ongoing task directs their attention to this cue. But if the opportunity for retrieval is defined by conjoint occurrence of several cues, relying on automatic retrieval may be much less reliable. (West & Craik, 1999, used a conjoint prospective memory target in which both words of a pair had to be either green or uppercase, but this study was directed to other issues.)

CONCLUSION

Field studies of prospective memory in everyday settings and in the tasks of expert professionals reveal dimensions and sources of variance not fully explored by existing laboratory paradigms. These field studies are by their nature rather phenomenological and cannot resolve questions about underlying cognitive processes, but they do suggest fruitful avenues for experimental research. They also raise theoretical issues that might not be identified in experimental studies that eliminate some of the real-world sources of variance. Finally, field studies are a necessary precursor to developing practical measures to improve prospective memory performance, pointing to sources of variance that may affect prospective memory performance substantially in various real-world situations and that might be manipulated usefully. Also, one must understand the structure of tasks and goals in specific real-world situations to assess whether potential countermeasures are likely to be practical.

Only well-controlled experimental paradigms can resolve issues hinted at by field studies and elucidate the underlying cognitive mechanisms. Prospective memory research has progressed to the point that it is now useful to develop new paradigms to explore the more complex aspects of prospective memory. For example, Kvavilashvili's (1998) word substitution paradigm provides a way to study habit intrusion errors, the six-element task (Kliegel et al., 2000) can be used to explore retrieval of intentions in the absence of explicit cues, and our paradigm can be used to study interruptions.

Many other topics in prospective memory would benefit from new paradigms. Expertise plays a large role in many real-world prospective memory situations and thus warrants experimental study. In contrast to most laboratory paradigms, the world is rich in perceptual stimuli related to individuals' diverse intentions, and individuals often maintain multiple goals, waiting for appropriate opportunities to pursue them. Retrieval of intentions may depend on happenstance cues as much or more as on encoded cues. Opportunities for executing goals are often defined by the conjunction of multiple conditions, rather than by simple perceptual stimuli. Priming experiments (e.g., Mäntylä, 1993) and context experiments (Cook et al., 2005; Nowinski & Dismukes, 2005) suggest that multiple cues may interact to trigger retrieval in ways that have not yet been fully explored. It might also be useful to study what factors belatedly prompt retrieval of intentions that were not executed when intended—this might point to ways to help individuals detect and recover from prospective memory errors before the opportunity is lost completely. Opportunities for research abound!

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