Using Spatial Context to Support Prospective Memory in Simulated Air Traffic Control

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Using Spatial Context to Support Prospective Memory in Simulated Air Traffic Control

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Objective: The aim was to examine whether prospective memory error and response costs to ongoing tasks in an air traffic control simulation could be reduced by providing spatial context.

Background: Prospective memory refers to remembering to perform an intended action at an appropriate point in the future. Failures of prospective memory can occur in air traffic control.

Method: For this study, three conditions of participants performed an air traffic control task that required them to accept and hand off aircraft and to prevent conflicts. The prospective memory task required participants to remember to press an alternative key rather than the routine key when accepting target aircraft. A red line separated the display into upper and lower regions. Participants in the context condition were told that the prospective memory instruction would apply only to aircraft approaching from one region (upper or lower). Those in the standard condition were not provided this information. In the control condition, participants did not have to perform the prospective memory task.

Results: In the context condition, participants made fewer prospective memory errors than did those in the standard condition and made faster acceptance decisions for aircraft approaching from irrelevant compared with relevant regions. Costs to hand-off decision time were also reduced in the context condition. Spatial context provided no benefit to conflict detection.

Conclusion: Participants could partially localize their allocation of attentional resources to the prospective memory task to relevant display regions.

Application: The findings are potentially applicable to air traffic control, whereby regularities in airspace structure and standard traffic flows allow controllers to anticipate the location of specific air traffic events.

Keywords: task interference, multitasking, workload, memory, attention, time sharing

INTRODUCTION

Prospective memory (PM) refers to remembering to perform an intended action at an appropriate point in the future. Failures of PM are not uncommon and can have dramatic consequences in work settings, such as aviation, medicine, and process control (Dismukes, 2008; Gawande, Studdert, Orav, Brennan, & Zinner, 2003). Shorrock (2005) reported that 38% of memory errors in air traffic control (ATC) in the United Kingdom involved a failure to complete an intended action. We know little about the cognitive processes underlying PM in work contexts such as ATC that would allow development of procedures to prevent such errors.

Loft and colleagues (Loft & Remington, 2010; Loft, Smith, & Bhaskara, 2011) recently applied theories and methods from the basic PM literature to ATC simulations in which individuals are required to monitor displays of dynamically changing air traffic patterns. Two crucial findings emerged. First, participants were slower to perform concurrent ATC tasks when they needed to remember to perform PM tasks compared with when they did not. Such costs to ongoing tasks in operational settings may potentially increase workload or error or decrease efficiency. Second, participants sometimes did not remember to perform PM tasks, suggesting that they found it difficult to maintain their intent to remember or to recognize PM task events.

The current study examined whether we could reduce PM error and costs to ongoing tasks in an ATC simulation if individuals were informed about which display regions to expect PM related air traffic events. Spatial context is particularly relevant to ATC, where knowledge of airspace structure and standard traffic flows often allows controllers to predict which air traffic events will occur in which display regions (Histon & Hansman, 2002). There is
also precedent in the basic literature to suggest that the use of task context can benefit PM performance.

**Prospective Memory Error and Costs to Ongoing Tasks**

En route controllers are responsible for ensuring the safe and efficient movement of aircraft. Controllers monitor dynamic displays and perform tasks such as accepting and handing off aircraft as they enter and exit their sector, responding to pilot requests, advising pilots on weather, and tracking aircraft movement efficiency (Durso & Manning, 2009). Controllers interleave these tasks with ongoing monitoring for aircraft pairs that will violate minimum separation standards (conflict detection; Loft, Bolland, Humphreys, & Neal, 2009). In juggling these multiple tasks, controllers are prone to forms of PM error familiar in laboratory experiments (Dismukes, 2008; Shorrock, 2005). One such error is when controllers fail to substitute an atypical intended action for a routine action. For example, a controller may intend, but fail, to assign incoming 767 aircraft an altitude of 350 instead of the routine altitude, 340.

PM errors in simulated ATC were studied by Loft et al. (2011; Loft & Remington, 2010; also see earlier work by Vortac, Edwards, Fuller, & Manning, 1993; Vortac, Edwards, & Manning, 1995), who had participants accept aircraft, hand off aircraft, and prevent conflicts. The PM task required participants to deviate from routine acceptance procedures for target aircraft that met certain criteria. Specifically, participants were required to press 9 instead of A when accepting target aircraft. Participants made slower acceptance decisions for nontarget aircraft (slower to press A after selecting an aircraft) when they held intentions to deviate from acceptance routine. Furthermore, participants made slower aircraft hand-off decisions (slower to press H after selecting an aircraft), missed marginally more conflicts, and were slower to detect conflicts. In short, the presence of the PM task led to a degradation of the concurrent non-PM tasks.

These costs to ongoing tasks are consistent with theoretical approaches to PM (Burgess & Shallice, 1997; Smith, 2003) and human error (Norman, 1981; Reason, 1990) that claim that attentional or working memory resources are required to remember to perform PM tasks. Despite costs to ongoing tasks, participants sometimes failed to deviate from routine, suggesting that participants found it difficult to either maintain PM goals or recognize targets (Smith, 2003, 2008).

Is there a way to reduce PM error rates while also reducing the disruptive effects to ongoing tasks? There is some evidence that providing a temporal context moderates PM demands. In the basic literature, reductions in PM error (Cook, Marsh, & Hicks, 2005; Nowinski & Dismukes, 2005) and ongoing task costs (Marsh, Cook, & Hicks, 2006) were observed when participants were informed which upcoming blocks of trials were relevant to the PM task. In ATC simulations, the flashing of an external aid indicating when target aircraft needed acceptance provided sufficient temporal context to reduce PM error and costs to ongoing tasks (Loft et al., 2011). In contrast, static aids that did not alert participants of the presence of target aircraft provided no benefit. Temporal context is likely to be effective because it allows participants to predict when best to allocate resources to the PM task to detect targets.

**The Current Study**

We examine whether PM error and ongoing task costs in simulated ATC can be reduced by the provision of spatial context that allows participants to determine where best to allocate attentional resources to the PM task. We manipulate the regions of airspace from which participants expect target aircraft to approach. This manipulation was motivated by controllers’ reports that specific aircraft events often occur at specific sector locations (Histon & Hansman, 2002). For example, the controller who intends to assign incoming 767 aircraft an alternative altitude may benefit by knowing that 767 aircraft typically approach from the south. In contrast to the provision of temporal context, participants need to maintain resources to the PM task for the entire ATC trial. However, we may find reduced PM error and ongoing task costs if participants can localize (focus) the allocation of these resources to PM relevant display regions.
Participants monitored an ATC display screen (Figure 1). When aircraft were within 5 miles of the sector, the aircraft icon flashed for acceptance. Participants accepted aircraft by clicking the aircraft icon then pressing A. When aircraft exited the sector, the aircraft icon flashed for hand-off, and participants handed them off by clicking the aircraft icon, then pressing H. Participants prevented potential conflicts by changing aircraft altitude. Some participants were required to press an alternative key rather than the routine key when accepting target aircraft with certain flight information, and this task served as the PM task.

As shown in Figure 1, a horizontal line separated the display into upper and lower regions. Two slightly amended versions of each trial (air traffic scenario) were created. On upper trials, the target aircraft entered the sector from flight paths from the upper region of the display, and on lower trials, from the lower region. All other air traffic scenario details in the alternate upper and lower versions of each trial were identical.

The context group was given PM instructions. Half the participants were told that the target aircraft would approach for acceptance only from the upper region. These participants were presented upper trials, and the upper region was relevant whereas the lower region was irrelevant. The other half of participants were told that target aircraft would approach only from the lower region. These participants were presented lower trials, and the lower region of the display was relevant whereas the upper region was irrelevant.

The control group was not given PM instructions and was required to make the routine acceptance response for all aircraft. Half these participants were presented upper trials, and we dummy coded the upper region as relevant and the lower region as irrelevant. The other half were presented lower trials, and we reversed the dummy coding.

Figure 1. A screenshot of the ATC-lab Advanced program. The running score (95 points) is presented on the right-hand side of the display, and the time (1:14) is presented at the bottom of the display. Directly below the running score box is the horizontal line that separated the air traffic control display into upper regions and lower regions.
The standard group was given PM instructions but was not told the regions from which target aircraft would approach. These participants were presented a counterbalanced mixture of upper and lower trials. For upper trials, the upper region was dummy coded as relevant and the lower region was irrelevant. For lower trials, the reverse dummy coding was employed.

The provision of spatial context should allow participants to restrict PM cognitive operations to specific regions of airspace. For example, the delay in time taken to press the A key after selecting aircraft for acceptance may indicate that individuals check the PM status of aircraft (Loft & Remington, 2010). If spatial context is used effectively, there would be less need to perform these checks in PM-irrelevant regions, and we should find an interaction between group and context for aircraft acceptance decisions. Specifically, the context group should make faster acceptance decisions for aircraft approaching from irrelevant regions compared with relevant regions.

In contrast, no differences are expected in acceptance decisions as a function of region for either the standard or the control group. Participants in the context group could reduce PM error by allocating more resources than the standard group to aircraft approaching from relevant regions. It would be more impressive, however, if the context group, when compared with the standard group, showed reduced PM error and reduced acceptance decision time for aircraft approaching from irrelevant regions without increased acceptance decision time for aircraft approaching from relevant regions.

Any net reduction in PM resource allocation required from the context group for accepting aircraft may also lead to reduction in costs to aircraft hand-off and conflict detection. We also manipulated the airspace regions in which aircraft involved in conflicts approached the sector, and from which aircraft were handed off, to examine whether any such reductions in cost were context specific. An additional question we examined that had not previously been addressed by Loft et al. (2011; Loft & Remington, 2010) concerned whether PM demands also cause a delay in the time taken to select the icon of aircraft flashing for acceptance or hand-off.

**METHOD**

**Participants**

The 144 undergraduates, 80 females and 64 males, from the University of Western Australia, participated in return for course credit or AUS20. The participants had a mean age of 20.3 years. For the experiment, 48 participants were randomly assigned to each condition.

**ATC-lab\textsuperscript{advanced} Task and Materials**

The ATC-lab\textsuperscript{advanced} task (Fothergill, Loft, & Neal, 2009) is illustrated in Figure 1. The sector was designated by the light gray polygon. Aircraft were represented by circles, and leader lines indicated direction of flight. Aircraft data blocks displayed call sign, speed, type, and altitude. A horizontal red line was presented through the middle of the display. At the start of each trial, aircraft appeared on flight paths and then proceeded along flight paths before crossing sector boundaries and exiting the screen. New aircraft continued to enter throughout the trial. Aircraft positions were updated every second.

Aircraft icons were black when they first appeared on screen (Aircraft C9 in Figure 1) and then flashed orange (C41) when they were within 5 miles of the sector. To accept aircraft, participants clicked on the aircraft icon and pressed A, after which the aircraft turned green (C79). Aircraft icons flashed blue when ready to exit the sector (C91). To hand off aircraft, participants clicked on the aircraft icon, then pressed H, and the aircraft then turned white (C13). Participants had 20 s to accept or hand off aircraft after they flashed. Conflicts were scripted whereby aircraft would simultaneously violate 5 miles lateral and 1,000 feet vertical separation. Figure 1 shows that the individual had changed the altitude of C15 from 310 to 340 to avoid a conflict with C35. Aircraft C69 will conflict with C87 (i.e., the aircraft will violate separation if not intervened). If participants failed to prevent a conflict, the aircraft pair turned yellow, indicating that the minimum separation was violated, and returned to green when separation was reestablished.
Training

There were eight 5-min training trials (Loft et al., 2011; Loft & Remington, 2010). At the start of each trial, 14 aircraft were presented at varying stages of transition. Per trial, 15 aircraft were accepted and 9 aircraft handed off. We scripted three conflicts to occur in each trial. We presented three other events whereby aircraft traveling at different altitudes were scripted to converge at less than 5 miles lateral separation.

Test Phase

There were four test blocks with two 5-min trials each (Loft et al., 2011; Loft & Remington, 2010). Instructions were presented on the display at the start of each block. These instructions informed the control group to continue to perform ongoing tasks. The PM groups were additionally instructed to remember to press 9 instead of A when accepting aircraft with call signs >88, altitudes >440, speeds >48, or types <400. PM groups held only one of these intentions per block. At trial commencement, 13 aircraft were presented at varying stages of transition. Per trial, 18 aircraft were accepted; of these, 9 approached the sector from the upper region and 9 from the lower region. In each trial, two or three aircraft were target aircraft. In each trial, 10 nontarget aircraft were handed off; half of these exited the upper region and half the lower region. We scripted four conflicts to occur in each trial, none of which involved target aircraft. We manipulated the region in which aircraft involved in potential conflicts approached. In most cases, one of the aircraft involved in the conflict was already accepted into the sector and thus was not relevant to the PM task. It was the second member of the conflict pair that approached from either the upper or lower region and needed acceptance. We presented three other events whereby aircraft traveling at different altitudes were scripted to converge at less than 5 miles lateral separation.

In summary, each test trial contained certain scripted target aircraft, nontarget aircraft, conflicts, and aircraft scripted to converge at less than 5 miles lateral separation but to maintain vertical separation. Trials were paired to form four test blocks. For the PM groups, a particular PM task was presented in each test block (i.e., call sign >88, altitude >440, speed >48, or type <400). These PM tasks were always fixed to the same test block. The presentation order of test blocks was counterbalanced.

We created two versions of each trial. On upper trials, the two or three target aircraft approached from the upper region, and on lower trials, from the lower region. All other air traffic details in the alternate upper and lower versions of each trial were identical. Half the participants in the context group were presented upper trials (upper region was relevant and the lower region irrelevant). The other half were presented lower trials, and the context coding was reversed. Half the participants in the control group were presented upper trials and half lower trials. The standard group was presented a counterbalanced mixture of upper and lower trials (i.e., on some test trials, target aircraft approached from upper regions, and on some trials, from lower regions). Dummy coding of context was applied to upper and lower trials for the control and standard groups.

Procedure

Participants were instructed on how to accept aircraft, hand off aircraft, and prevent conflicts. When participants accepted or handed off aircraft, they were awarded 10 points. Failure to do so within 20 s resulted in the loss of 10 points, and these aircraft were accepted or handed off automatically by the simulator. Participants also received between 10 and 40 points depending on how fast they prevented conflicts. If participants failed to prevent a conflict or intervened unnecessarily, 40 points were deducted. Training trials were randomized. At test, all groups were instructed to continue performing ongoing tasks, and the PM groups were given additional instructions. The control and standard groups were told to ignore the red line. In contrast, the context group was instructed on how the red line served a PM function.

Instructions were presented on the display before each test block that reiterated earlier verbally presented instructions. For the PM groups, these on-screen instructions also specified the
target aircraft (e.g., call sign >88). The instructions also reminded the context group of the region from which target aircraft would approach. After completion of each test block, the PM conditions were asked to recall the target aircraft and PM response key.

**RESULTS**

A 3 (group: control, standard, context) × 8 (training block) ANOVA revealed that training scores obtained on each trial increased across training, $F_{\text{linear}}(1, 141) = 42.11, p < .01$. There was no effect of group and no interaction, $F$s < 1. For the test trials, we included upper versus lower region as a variable. There were no main effects or interactions for this variable (smallest $p = .19$), and for brevity, we collapsed across it in the analyses reported next.

**PM Performance**

During the postblock questionnaires, 97% of PM instructions were recalled, with no differences between groups ($t < 1$). Thus, any differences in PM errors between groups cannot be attributed to differences in failure to encode or retain PM instructions. A PM error was defined as the substitution of a routine aircraft acceptance response for a PM instructed response. All target aircraft were accepted, either correctly (9) or incorrectly (A). The context group ($M = .12, SD = .15$) made fewer PM errors than the standard group ($M = .21, SD = .22$), $t(94) = 4.74, p < .05$. False alarms (i.e., pressing 9 for nontarget aircraft) were rare (1% of nontarget aircraft), $t < 1$.

**Ongoing Task Performance**

We analyzed ongoing task performance by examining aircraft acceptance time, aircraft hand-off time, and conflict detection accuracy and response time. A series of 3 × 2 mixed ANOVAs were conducted, with group (control, context, standard) as the between-subjects factor and region (relevant, irrelevant) as the within-subjects factor.

**Aircraft acceptance.** We first measured the time to select the icon of aircraft flashing for acceptance ($M = 2.45$). There was no main effect of region ($F < 1$), no main effect of group, $F(2, 141) = 1.67, p = .19$, and no interaction, $F < 1$.

![Figure 2. Acceptance decision time as a function of group and region. Error bars represent standard errors.](https://sagepub.com)

We then obtained acceptance decision times by calculating the time taken to press A after the individual had clicked the icon of an aircraft flashing (Loft et al., 2011; Loft & Remington, 2010). We excluded target aircraft and also nontarget aircraft that were flashing for acceptance when target aircraft were flashing (Loft et al., 2011; Loft & Remington, 2010). We trimmed response times by excluding acceptance times greater than 10 s (Ratcliff, 1979). Acceptance decision times are presented in Figure 2. There were main effects of group, $F(2, 141) = 13.91, p < .01$, and region, $F(2, 141) = 28.08, p < .01$. The PM groups made slower acceptance decisions than did the control group. The main effects were qualified by an interaction between group and region, $F(2, 141) = 17.11, p < .01$.

Planned comparisons revealed that there was no difference in acceptance decisions between irrelevant and relevant regions for either the standard or control group, $F$s < 1. However, the context group made faster acceptance decisions for aircraft approaching from irrelevant regions ($M = .39$) compared with relevant regions ($M = .55$), $F(1, 47) = 35.47, p < .01$. In the context group, 90% of participants made faster acceptance decisions for aircraft approaching from irrelevant compared with relevant regions. However, the context group ($M = .39$) still made
slower acceptance decisions than the control group (M = .31) in irrelevant regions, F(1, 95) = 4.53, p < .05. There was no difference in acceptance decision time between the context group and standard group in relevant regions, F < 1.

**Aircraft hand-off.** We measured the time to select the icon of aircraft flashing for hand-off, but there were no main effects or interactions (M = 2.16), Fs < 1. We then obtained aircraft hand-off decision times by calculating the time taken to press H after the individual had clicked the aircraft icon of an aircraft flashing (Loft et al., 2011). We used the same criteria for excluding aircraft and the same data-trimming techniques as for acceptance time. Hand-off decision times are presented in Figure 3. There was a main effect of group, F(2, 141) = 6.09, p < .01. There was no main effect of region and no interaction between group and region, Fs < 1. Planned comparisons indicated that the standard group (M = .52) made slower hand-off decisions than the control (M = .35), F(1, 94) = 11.32, p < .01, and the context (M = .39) groups, F(1, 94) = 5.58, p < .05. There was no difference in hand-off decision time between the context group and control group, F < 1.

**Conflict detection.** The proportion of conflicts missed on each test block and conflict detection response times are presented in Figures 4 and 5. There was a marginal effect of group on conflict misses, F(2, 141) = 2.58, p = .08. There was no effect of region and no interaction between group and region, Fs < 1. Conflict detection false alarms were made when participants changed the altitude of aircraft not in conflict. Participants made 0.43 false alarms per block, with no effects approaching significance (F < 1). For conflict detection times, there
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was a main effect of group, $F(2, 141) = 3.69, p < .05$. There was no main effect of region and no interaction between group and region, $F$s < 1. Planned comparisons indicated that both the standard ($M = 56.17$), $F(1, 94) = 4.06, p < .05$, and context ($M = 58.16$), $F(1, 94) = 7.55, p < .01$, groups were slower to detect conflicts than the control group ($M = 49.59$). There was no difference in conflict detection time between the context group and standard group, $F < 1$.

**GENERAL DISCUSSION**

To our knowledge, this study is the first demonstration in the literature that spatial context can reduce PM error and ongoing task costs and extends the work of Loft et al. (2011) by demonstrating that nonflashing (static) aids that provide diagnostic information concerning the presence of target aircraft can be beneficial. The costs to acceptance decisions, hand-off decisions, and conflict detection for the PM groups compared with control group provide replications of Loft et al. (2011; Loft & Remington, 2010) and are consistent with theories that claim that attentional resources are required for PM (Burgess & Shallice, 1997; Smith, 2003).

The context group made faster acceptance decisions for aircraft approaching from irrelevant compared with relevant regions. This finding indicates that the allocation of resources to the PM task can be at least partially localized to relevant display regions. The reduction in PM error and cost to acceptance in relevant regions was not accompanied by increased costs in relevant regions for the context group compared with the standard group. In addition, the context group made faster hand-off decisions than did the standard group. In fact, there was no significant cost to hand-off decisions for the context group compared with the control group.

The time taken to select aircraft was not slowed by PM demands. The task requirement of clicking on the icons of aircraft flashing for acceptance or hand-off may produce a set for attention that is captured involuntarily by flashing aircraft (Folk, Remington, & Johnston, 1992). Such a task that requires minimal resources is likely to be less sensitive to changes in resource allocation associated with PM goals.

In contrast, the increased time taken to decide to press $A$ after selecting a nontarget aircraft for acceptance is suggestive that individuals checked the PM status of aircraft. Checking could also account for the slowing of hand-off decisions if participants checked which key press to make (i.e., $A$, $H$, or 9 key) following the selection of any flashing aircraft icon.

Spatial context allowed participants to make faster acceptance decisions in irrelevant regions and eliminated costs to hand-off decision time. The provision of spatial context may have partially freed participants from having to check the PM status of aircraft selected for acceptance in irrelevant regions and, more generally, decreased the complexity of aircraft response decision mappings related to any selected flashing aircraft.

Part of the cost to conflict detection could also be attributed to checking the PM status of aircraft. However, we found no evidence of decreased cost to conflict detection when one of the aircraft involved in a potential conflict approached from an irrelevant region. Moreover, both PM groups were slower to detect conflicts than the control group. It is possible that delays to detect conflicts arise because of slower or less extensive scanning of the display (Remington, Johnston, Ruthruff, Gold, & Romera, 2000) or decreased efficiency of aircraft trajectory prediction (Loft et al., 2009), either of which could be caused by net reductions in available processing resources and which may not have benefited from spatial context. It would be diagnostic for future studies to track participants’ scanning and fixation patterns to address this possibility. Conflict detection may benefit from spatial context if participants are provided more practice. However, Loft et al. (2011) reported that reductions in costs to conflict detection with the use of flash aids were present in the first block of test trials and did not further increase with practice. This finding suggests that the benefits of contextual aids can emerge with the level of task practice provided in the current study.

A further question concerns how participants in the context group, relative to the standard group, managed to reduce PM errors. The provision of spatial context may have increased the
encoding specificity of PM task goals (i.e., the overlap between encoding and retrieval contexts; Morris, Bransford & Franks, 1977; Tulving, 1983). It is likely difficult to monitor for low-probability target aircraft (Parasuraman, 1986), and attending to relevant regions may have associatively cued the PM task, increasing the likelihood that participants checked the PM status of aircraft (Nowinski & Dismukes, 2005). The increased encoding specificity may also have decreased PM errors that arose from difficulty in recognizing and verifying the presence of targets, despite the adequate allocation of attentional resources (Smith, 2003, 2008).

Operators in work contexts that monitor displays of dynamic traffic patterns, such as in ATC, are often required to substitute atypical intended actions for routine actions and can be vulnerable to forgetting (Shorrock, 2005). Holding PM intentions may also come at a significant cost to ongoing tasks. These costs, if replicated in the field, would require careful consideration because delays in the time taken to process aircraft or to detect air traffic events may increase controller workload. It is important, therefore, to determine whether our findings characterize ATC operations. Moreover, it will be important to determine how controllers and student participants differ in the deployment of attention or use of memory in approaching PM tasks.

 Nonetheless, there is good reason to believe that controllers already use spatial context and would further benefit if it were possible to establish a spatial context for PM. Controllers are extensively trained on each sector they monitor and control, and in doing so, they become sensitive to details of their airspace that affect routing decisions. Theories of strategic control propose that operators maintain acceptable workload levels by using strategies that minimize the control activity required to meet objectives (Loft, Sanderson, Neal, & Moiij, 2007; Sperandio, 1971). Airspace factors and operational constraints are key contributors to controller management strategies because they constrain the relationship between traffic factors and workload by shaping the evolution of air traffic and creating predictable air traffic patterns (Histon & Hansman, 2002).

Although current knowledge of such phenomena in field operations is largely based on anecdotal report, and would benefit from the converging evidence provided by experimentation in field settings (Dismukes, 2008; Wickens, 1992), it provides a basis for the conjecture that extensive training and experience controlling specific sectors would allow controllers to use spatial context to manage PM demands in operational ATC settings.

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**KEY POINTS**

- **Prospective memory** (PM) refers to remembering to perform an intended action at an appropriate point in the future. PM errors sometimes occur in air traffic control.
- Costs to ongoing tasks reported in previous studies were replicated; participants were slower to detect conflicts, accept aircraft, and hand off aircraft when they held PM intentions to deviate from aircraft acceptance routines.
- PM error and costs to ongoing tasks in an air traffic control simulation were reduced when participants were instructed which region of the display to expect target aircraft to approach.
- This study is the first demonstration in either the basic or the applied literature that the provision of spatial context can reduce PM error and costs to ongoing task activity.
- The findings are potentially applicable to air traffic control, whereby regularities in airspace structure and standard traffic flows allow controllers to anticipate the location of specific air traffic events.

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