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Abstract

Prospective memory is the ability to remember to perform acts in the future. Prospective memory is essential in the aviation domain because it supports a range of tasks including remembering to complete critical radio communications. A wide variety of literature reports that in the laboratory younger adults outperform older adults on many prospective memory tasks. In naturalistic settings however, older adults perform as well as or better than younger adults. It is suggested that lower working memory load from *on-going* background tasks, context cues and the habitual nature of the tasks are reasons for the improved performance by older adults in naturalistic settings. We tested this notion using a Cessna 172 aircraft simulator to examine radio communication task completion rates of 45 pilots (16 older and 29 younger participants). Individual measures of working memory were also collected. In contrast to the trends reported in the literature, we found that older pilots had significantly lower communication task completion rates than younger pilots in both the low and high working memory workload conditions. A multiple regression model identified age and working memory scores as the strongest individual predictors of prospective memory task performance in the low workload condition and working memory and recent pilot-in-command hours as significant predictors of performance in the high workload condition. Our results suggest that, even in a low workload condition, a naturalistic aviation context did not afford advantages to older pilots and that prospective memory task performance appears associated with age and working memory function.

Keywords: prospective memory; applied cognitive science; working memory; aging; aviation.

Introduction

Prospective memory refers to the ability to remember to perform mental or physical acts in the future. The present research examined the prospective memory performance of older pilots (aged 51 to 76) and younger pilots (ages 26 to 50) in a naturalistic aviation-related setting. Existing literature on prospective memory and aging suggests that, in naturalistic settings, older and younger adults tend to perform similarly on measures of prospective memory (Einstein & McDaniel, 1990; Kvavilashvili & Fisher, 2007). In contrast, in laboratory settings, where prospective memory performance is tested using novel tasks, younger adults show better prospective memory performance than older adults (Craik & Bialystok, 2006). It has been suggested that in naturalistic settings older adults' prospective memory performance might benefit from (a) the time- and event-based cues afforded by the environment or strategically created by the older adult, (b) a reduced working memory load in the on-going or background tasks, and/or (c) an increase in the importance older adults might place on remembering in the naturalistic tasks (Dismukes, 2010; Einstein & McDaniel, 1990; Kvavilashvili & Fisher, 2007). In comparison with young adults, older adults are believed to have reduced working memory capacity (Craik, Anderson, Kerr, & Li, 1995; Salthouse, 1994; 1996). As such, some authors have investigated the influence of reduced working memory demands experienced by older adults in everyday naturalistic environments and explored how these reduced demands might improve performance in prospective memory tasks. For example, Einstein and McDaniel (1990) addressed the issue of this explanation for age effects based on the *ease of ongoing tasks* by attempting to equate the background working memory requirements during laboratory tasks for older and younger participants. The reduction in working memory resource allocation for older adults did result in better performance in prospective memory tasks for older adults (as compared to the younger adults).

Previous research pertaining to age and prospective memory can be classified according to the study variables of setting (laboratory vs. naturalistic), task (habitual vs. episodic), ongoing background working memory load (low or high), task cue (cued or non-cued) and task cue context (event-based vs. time-based). In a meta-analysis of prospective memory and aging, Uttl (2008) reported that younger adults tend to perform better on prospective memory tasks in most conditions, with the exception that older adults might demonstrate similar or better performance, as compared to younger adults, in naturalistic studies. It is important to note however, that when older adults performed as well as or better than younger participants the prospective memory tasks under investigation occurred in contexts of low working memory load, were habitual in nature and were associated with cues in the environment. The identification of features associated with naturalistic settings has lead other researchers to conclude that the similar prospective memory performance found for younger and older adults in naturalistic settings might not be as robust as originally thought (Craik & Bialystok, 2006).

Prospective memory has also been examined with respect to aviation-related tasks. Much of this work has come from the NASA Ames Research Center, Flight Cognition Laboratory (Dismukes, 2007; Dismukes & Berman, 2010; Dodhia & Dismukes, 2005, 2009; Holbrook & Dismukes, 2009). Generally speaking, when pilots failed to complete prospective memory tasks, in both habitual and episodic tasks the errors were caused by interruptions, missed cues, changes to routine procedures, and interleaving/timesharing of concurrent tasks. These sources of prospective memory failures were exacerbated by high working memory load (Dismukes, 2010). Dodhia and Dismukes (2005) found that prospective memory failures could be attributed to lack of or inefficient encoding of the intent to remember, changing goals and context at the end of the interruption and a mismatch between the original task cues and the cues available after the interruption.

The present research tested the hypothesis that older and younger pilots would perform similarly in a prospective memory task occurring in a naturalistic condition where the cued, habitual prospective memory task took place within an on-going context of a low working memory load.

Method

The present data are from a larger study of aging, cognitive health and general aviation. In this study, pilots operate a Cessna 172 simulator and carry out a variety of aviation-related tasks while flying standard practice circuit patterns (see Figure 1). One of the tasks required of all pilots is to remember to complete six radio calls (verbal transmission of pilot location) at specific times during each circuit flown.

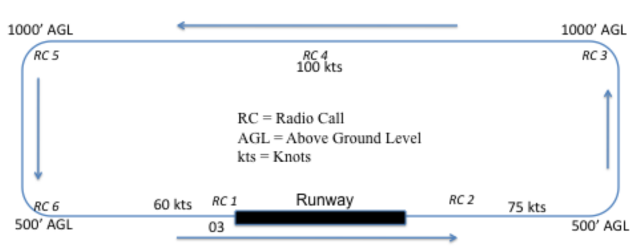

Figure 1: Standard Practice Circuit (Pattern)

We examined the prospective memory performance of pilots by comparing the radio communication task completion rates of older and younger pilot groups under both low and high working memory load conditions. Individual measures of working memory were also collected in order to determine if there was a relationship between pilot prospective memory performance and working memory ability.

Participants

Participants represented a wide range of pilot certification levels and expertise: including student (*n*=10), private (*n*=27) and military, commercial or airline transport pilots (*n*=8). Pilots were recruited from local flying clubs with posters and notices in club newsletters. Selection criteria for this analysis included pilots (aged 26 or older) having a minimum of a valid student's certification. Pilots were grouped by age as *younger* (aged 26 to 50, *M*=40 years, *n*=29) and *older* (aged 51 to 76, *M*= 59 years, *n*=16). The length of time pilots had been certified to fly was the only pilot characteristic that differed significantly between older and younger pilot groups, $F(1,43)= 18.44$, $p<.001$.

Table 1: Pilot Characteristics

Pilot Characteristics (*n*=45, 4 Female)	Younger Pilots Mean Value (Range)	Older Pilots Mean Value (Range)
Years Certified	9 (1-29)	23 (1-43)
Total Hours Flown	817 (22-8000)	789 (34-4460)
Pilot-in-command Hours (Previous 12 months)	40 (0-308)	29 (0-150)

Procedure

Participants provided informed consent after a thorough description of the study purpose and activities. Each participant completed a flight experience questionnaire regarding their overall flying experience/expertise and experience with simulated aircraft. Participants then completed a full cognitive health assessment battery (the DCAT™). Only Subtest 6, an index of working memory is discussed in this analysis. Participants were provided with a visual and verbal presentation outlining the requirements for flying a "perfect circuit" followed by a practice session (four full circuits with experimenter feedback) to familiarize themselves with the flight simulator and the controls. After the practice session, participants flew six left hand circuits at two uncontrolled airfields (one representing a low and the other a high workload condition). Detailed instructions regarding the radio communication tasks were provided in both writing and verbal presentation. Participant feedback indicated that the circuit flying procedures to be followed in this study were either similar or very similar to their own circuit procedures. Thus, despite being simulated flight, the situation was considered familiar and many of the tasks habitual for these pilots.

DCAT™ Subtest 6: The Identification of Driving Situations The DCAT™ consists of a computerized touch-screen system comprised of six individually scored sub-tests each designed to capture some element of cognitive function implicit in the cognitive abilities required for safe driving. Participants respond by touching the correct target on the screen. The DCAT™ produces aged-normed *z*-scores for each of the six subtests. The *z*-scores reflect both accuracy and timing of the responses. All the subtests were completed for each participant; however, because of Subtest 6's comprehensive use of working memory functions it is the only subtest selected for this analysis. For further information on the other five subtests and their utility in predicting high risk older drivers see DriveABLE (1997). DCAT™ Subtest 6 requires participant to watch ten short (approximately 5 to 15 seconds) narrated video clips of actual driving footage and then answer a question relating to some aspect of spatial judgment or driving safety related to the just-seen video clip. Participants must quickly integrate the auditory and visual stimuli in each of ten video clips and hold the stimuli in working memory in order to answer each trial correctly. After the presentation of each scenario stimulus and a one second inter-stimulus interval, a multiple-choice method of target selection is provided on the next screen presentation. Four answer options are provided via text and narration and include targets such as "how should you respond?" or "what is the most dangerous thing in this situation?" Participants select a response by touching the desired target (either 1, 2, 3 or 4) on the screen.

Cessna 172 Simulator The aircraft simulator was a Cessna 172 aircraft cockpit and fuselage (see Figure 2) running Microsoft FSX software. The simulator was equipped with actual Cessna 172 controls and physical instruments. Large screens provided 45 degrees of vertical field of view and 120 degrees of horizontal field of view. Pilots wore a headset in order to hear communication from other simulated aircraft at their aerodrome and beyond.

Figure 2: Cessna 172 Simulator

Working Memory Workload Manipulation Pilots flew in two experimental protocols. In the first protocol, the low workload condition, pilots flew at an aerodrome with simple flat terrain and no other aircraft during circuit one; one other aircraft during circuit two; and two other aircraft during circuit three. In the second protocol, the high workload condition, the pilots flew in unfamiliar mountainous terrain with two other aircraft during circuit one; three other aircraft during circuit two; and four other aircraft during circuit three. In both workload conditions pilots were informed that they would be required to maintain situation awareness of their aircraft and all other aircraft. In each condition the simulated weather was clear and no critical events with respect to instrumentation or aircraft controls were introduced.

Prospective Memory Task: Radio Communication Completion Rate Participants were provided with detailed instructions regarding the number and the timing of the radio calls they were to perform during each circuit they completed. As per standard procedures, the pilots' radio calls were to convey information pertaining to their current location. Each circuit required six radio calls to be completed. One radio call was required during each of the following six circuit events: initial rolling on runway (or subsequent runway *touch and go* or runway overshoot events), airborne, turning downwind, mid-downwind, turning base, and turning final. Participants were not penalized for extra calls, but only received a point for each required call made during the prescribed circuit event. Six calls per circuit ***X*** three circuits ***X*** two workload conditions allowed for a total of 36 radio communication calls to be recorded. Implicit cues used by the pilots to remember to perform the radio communication tasks might be considered as both time- and event-based as each radio communication was to be completed at a specified location (e.g. turning downwind), or point in time (immediately after take-off), during each circuit. Explicit cues were not provided by the experimental except during the practice session when the experimenter would remind pilots if a radio call was forgotten.

Results

Impact of Workload

Overall, pilots completed more radio communication tasks in the low than in the high workload condition, $F(1, 42) = 23.12$, $p<.001$, $\eta_p^2 = .35$. Pilots demonstrated a 92% radio communication task completion rate in the low workload condition and an 86 % radio communication task completion rate in the high workload. As shown in Figure 3, the workload effect was found for both pilot age groups: $F(1, 28) = 13.05$, $p<.01$, $\eta_p^2 = .32$ (younger group) and $F(1, 15) = 9.41$, $p<.001$, $\eta_p^2 = .39$ (older group).

Comparison of Younger and Older Pilot Prospective Memory Task Performance

In both the low and high workload conditions there was a main effect of Age, $F(1,43) = 8.00$, $p < .01$, $\eta p2 = .16$ (low workload) and $F(1,43) = 5.45$, $p < .05$, $\eta p2 = .11$ (high workload).

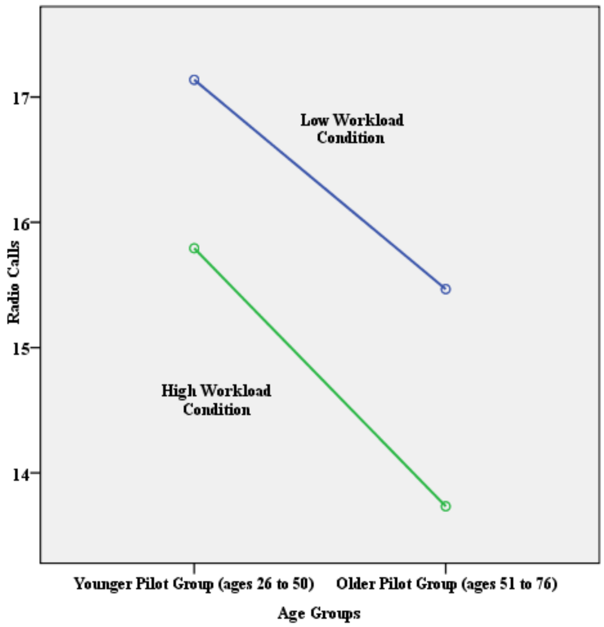

Figure 3: Mean Number of Radio Calls for the Younger and Older Pilots across Workload Conditions

As shown in Figure 3, there was no interaction between age and workload condition, ($F < 1$): older pilots completed fewer radio calls than the younger pilots in both the low and the high workload conditions.

Variance in Prospective Memory Performance

Multiple regression analyses provide an indication of pilot characteristics, which might predict some of the variance in prospective memory task scores. Individual radio communication completion rates were examined with respect to the pilot characteristics of age, recent pilot-in-command hours and the working memory index (i.e., DCAT™ Subtest 6 scores). Years certified to fly and total hours flown were not included in the model due to their high correlation with age and recent pilot-in-command hours, respectively.

The low workload condition produced a model with age and DCAT™ Subtest 6 as the strongest predictors of prospective memory performance (ANOVA, $F(2, 42) = 5.05$, $p<.05$. The *R-square* value indicated that age and working memory index together account for 19.4% of the variance in radio communication task completion rates in the low workload condition. This pattern of results suggests that age and working memory are relevant predictors of prospective memory performance in our low workload condition.

Multiple regression results for the high workload condition produced a model with marginal significance (ANOVA, $F(2, 42) = 3.15$, $p = .053$). The *R-square* value indicated a 13.0% shared contribution of working memory index and recent flight hours to high workload radio communication task completion rates.

Discussion

The present research examined the hypothesis that older pilots would perform as well as younger pilots for prospective memory tasks in naturalistic study conditions where an implicitly cued, habitual prospective memory task occurred across a low workload background. Despite our efforts to create the aforementioned condition, we found that younger pilots tended to outperform older pilots in both the low and high workload conditions. The finding that older pilots did not perform as well as younger pilots on a naturalistic prospective memory task is contrary to findings from other researchers such as Einstein & McDaniel (1990) and Uttl (2008), who found that older participants typically performed as well as or better than younger participants for prospective memory in naturalistic settings.

Pilots were not explicitly cued to perform radio calls, but relied upon implicit event and time-based cues. This provided the participants with a realistic scenario of radio call completion during a circuit as well as provided the experimenters with a prospective memory task with cues incorporated into the underlying or foundational task. This was meant to overcome the issue with laboratory setting research where the underlying task itself does not necessarily provide clues as to when a task should take place.

The habitual nature of the radio communication task can also be examined. Because other prospective memory studies in naturalistic environments have utilized habitual tasks such as remembering to take medication, or brushing your teeth, it could be argued that the prospective memory task used in the present research might not have been as habitual in nature as is typically seen in a habitual prospective memory task. Indeed, while participants indicated that, in reality, some aerodromes and situations might require only four or five calls per circuit, without exception, completing radio communication calls habitually during circuit events was considered standard and even required practice. Additionally, pilots in the present study had flown an average of 40 hours (younger pilots) and 29 hours (older pilots) in the previous 12 months: thus assuring that both groups had recently been engaged in similar radio call tasks. While the amount of recent flight time varied across participants, performing radio calls is ingrained within circuit flight behaviour and once circuit activity begins, pilots are all aware of and well versed in knowing when to complete radio tasks during the circuit flight. To minimize experience effects of low recent flight hours and differences in radio call routines between subjects a minimum of four practice circuits was provided with feedback and reminders about when to perform the radio calls.

Subject matter experts for this present research reported that the low workload condition, with its simple terrain and low levels of circuit traffic (maximum of two other aircraft), constituted a reasonable facsimile of a low workload circuit. The findings that the low workload condition produced an

86% (older pilots) and 95% (younger pilots) task completion rate appear to represent a reasonable compromise between a workload that no longer offers face validity (because the condition would be too simplistic and no longer reflect a naturalistic circuit setting) and a workload that was overly demanding, and beyond the threshold of "low". Additionally, the near perfect performance of some pilots in the low workload condition demonstrated that the first scenario was indeed "low".

Main Effect of Age

The present research has implications for a wide range of systems designed to promote prospective memory for older adults. Specifically, it should not be assumed that because a task in a naturalistic setting is performed against the backdrop of a low workload that older adults will perform to the same level as younger adults. Attention should be paid to the features of the task context, including the cues afforded by the environment or cues embedded within the task itself. In this study, time- and event-based cues were not sufficient enough reminders to promote the required behaviour by the older participants suggesting that features of the cues might play an important role in prospective memory performance for older adults.

With respect to age effects in both workload conditions: pilot age contributed significantly to the regression model predicting radio call performance in the low workload condition; however, age was not a significant contributor to the regression model in the high workload condition, but was replaced instead by recent pilot-in-command hours. It should be noted, however, that older pilots had fewer recent pilot-in-command hours than younger pilots, thus indirectly associating age with performance in the high background working memory load condition. Older pilots flew approximately one hour less per month in the previous 12 months than younger pilots. This difference in recent flight hours between age groups was not statistically significant; however, it might be the case that in high working memory load contexts the reduced flight time by older pilots represented a functionally significant difference.

Working Memory and Task Cues

Working memory performance and cue features can also illuminate the paradox that exists in the prospective memory literature pertaining to age effects reliably found in the laboratory but not in naturalistic settings. The radio communication task required not only prospective memory, but also retrospective memory with respect to the instructions regarding timing of the required radio calls. Embedded within each circuit were implicit event-based cues as to when to complete a radio call, e.g. at the start of each downwind leg of the circuit. If this instruction was not maintained in working memory throughout the task (even though radio calls are a habitual event within circuit activity) then prospective memory would also appear to be reduced. This tension between retrospective and prospective memory highlights the importance of working memory, even with habitual and implicitly cued tasks. Recall that the results of the multiple regression analysis revealed that only the working memory index predicted prospective memory task performance in both workload conditions. The present study demonstrates that for a broad range of pilot age, experience and expertise, working memory might play a leading role in supporting prospective memory performance of radio communication tasks. While one might be tempted to rely on the strength of "habit" to undergird prospective memory performance in naturalistic settings, working memory resources appear to overshadow advantages afforded by habit or the total experience with a task. In summary, despite the naturalistic setting, older pilots may not have performed as well as younger pilots in the low workload condition due to task reliance on working memory and the implicit nature of the cues.

Future Research

Aviation studies pertaining to prospective memory have revealed that, in the cockpit, pilots forget to complete both habitual and episodic tasks because of interruptions, missed cues, changes to routine and timesharing of concurrent tasks (Dismukes, 2010). In light of the present findings it would be beneficial to examine each of these sources of distraction with respect to their working memory demands, in addition to the possible effects of age and working memory performance of pilots on habitual and episodic cockpit tasks. It would also be useful to compare older and younger adult performance on prospective memory tasks by further examining the effect of recent flight hours for older pilots, in particular, in high workload conditions. Additionally, manipulating the cues afforded by the environment would further explicate how elements within naturalistic settings might promote prospective memory performance for older adults. Finally, replication of the present findings in other complex tasks, either within aviation or beyond, would add to the theory pertaining to the effects of age and working memory load on prospective memory in naturalistic settings.

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