DESIGNING EXTERNAL AIDS THAT SUPPORT OLDER PILOT PERFORMANCE

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Communication taxes pilots' cognitive resources. External aids such as note-taking help pilots manage these demands. Morrow et al. (2003) found that note-taking eliminated age differences among pilots on a readback task compared to a no-aid condition. However, we investigated communication-only rather than multi-task environments typical of piloting. The present study compared note-taking (*kneepad*) with an electronic notepad positioned next to the instrument panel in a flight simulator *(epad)*. The epad may be easier to coordinate with concurrent tasks because it is more integrated with flight instruments. Six older and six younger pilots used these aids to respond to ATC messages in a flight simulator. Readback accuracy was higher when pilots used either aid compared to a no-aid condition. The pattern of results suggested a smaller age difference in the aid than in the no-aid conditions. The results replicate the earlier finding of note-taking benefits and extend them to the novel epad.

INTRODUCTION

Communication in complex, dynamic environments such as piloting or driving places heavy demands on operators' cognitive resources such as working memory and attention, contributing to problems that reduce safety and efficiency (Morrow & Rodvold, 1998). It may especially challenge older adults because of age-related differences in these cognitive resources (Craik & Jennings, 1992). External aids such as note-taking may help older pilots manage these demands, especially if these aids are part of the pilots' skill repertoire. We investigated these pervasive but little studied aids, examining the cognitive demands of using the aids as well as their benefits for aviation communication.

Routine flight in controlled air space requires pilots to listen to, read back (repeat), and execute instructions from Air Traffic Control (ATC) messages, and these communication tasks impose demands on working memory and other cognitive resources. Note-taking provides environmental support (Craik & Jennings, 1992) that can reduce these cognitive constraints on pilots' response to ATC messages, for example by providing an external form of working memory (Zhang & Norman, 1994). Morrow et al. (2003) found that note-taking eliminated age differences among expert pilots on a readback task compared to a no-aid condition. However, note-taking in that study was investigated in communication-only rather than multi-task environments typical of piloting. Note-taking involves visual-manual components and thus, according to multiple resource theory, may compete with concurrent visual tasks such as flight control for modality-specific attentional resources (Helleberg & Wickens, 2003). For example, writing on a kneepad draws attention from the instrument panel, which supports flight control. This may especially challenge older pilots because of declining ability to allocate resources to multiple tasks. Thus, the attentional pre-requisites for using the aid may reduce the impact of this environmental support on age differences in performance. We compared conventional note-taking (*kneepad*) with an electronic notepad positioned adjacent to the instrument panel *(epad)*. The epad, similar to the Mode Control Panel in many commercial aircraft, may be easier to coordinate with concurrent tasks because it is more integrated with flight instruments, reducing heads-down and visual scanning time. Both aids should reduce age differences in communication compared to a no-aid condition, and the epad may be more likely to reduce age differences as concurrent task demands increase.

On the other hand, older pilots may be more adept at using the kneepad because of experience with this aid compared to the novel epad. Because of this difference in novelty, we first tested in a

preliminary study whether the epad supported communication as effectively as the kneepad in a communication-only condition. We also investigated the cognitive requirements of using the two aids by exploring correlations between readback accuracy in each aid condition and a speed of processing measure frequently used to index fluid mental ability, which declines with age (Letter and Pattern Comparison tasks, Salthouse & Babcock, 1991). To the extent that an aid reduces the cognitive demands of communication (as measured by readback accuracy), these correlations should be reduced.

METHODS

Participants

Twelve instrument-rated pilots participated (minimum 500 total flight hours). Six were older (50-64 years) and six younger (20-40 years). Table 1 shows that the age groups did not differ significantly in education, self-rated health, or flight experience. Reflecting general cognitive aging, older pilots had lower mean scores on the processing speed measures, although only the Letter Comparison task produced a significant difference.

Procedure

Participants performed all ATC communication tasks in a Frasca 142 flight simulator, configured as a single-engine, fixed wing light aircraft, including a full set of flight displays on the instrument panel and radio. They listened to recorded Air Traffic Control (ATC) messages describing four scenarios. Each message directed the pilot to make heading, altitude, speed, and radio frequency or squawk changes. Such instructions often load working memory, producing age differences in readback accuracy (e.g., Morrow et al., 2003). In three scenarios, participants either used the kneepad, epad, or no aid while listening to the ATC messages (communication-only tasks) In the other scenario, participants flew the described route as well as using the e-pad, so that we could assess ease of using the epad in multi- as well as single-task conditions. In the kneepad condition, participants wrote notes on a kneepad typical of General Aviation operations while listening to the messages. In the epad condition, they entered heading, altitude, and speed changes into a touch screen display located next to the instrument panel (Figure 1). In all conditions, participants used the radio, located to the right of the instrument panel, to enter frequencies. Participants could also request ATC message repeats, as they would if flying. Pilot readbacks and requests were tape recorded for later analysis. After the scenarios, participants completed a questionnaire about the usability of the epad, as well as the demographic questionnaire and the Comparison tasks.

Table 1
Mean Demographic and Cognitive Ability Scores

	Older	Younger	*Age t(10)*
Age	53.8	25.5	
Educ	17.4	15.8	*1.0*
Letter Comp[1]	10.4	12.8	*2.1**
Pattern_pattern[1]	18.7	19.8	*<1.0*
Total Flight hours	2975.6	1342.7	*1.2*
Hours last 12 months	49.9	245.6	*1.7*
Total IFR hours	488.25	139.4	*2.1*
Self-rated Health	5.5	6.3	*1.0*

* $p < .05$

1. Letter and Pattern Comparison tasks (Salthouse & Babcock, 1991).).

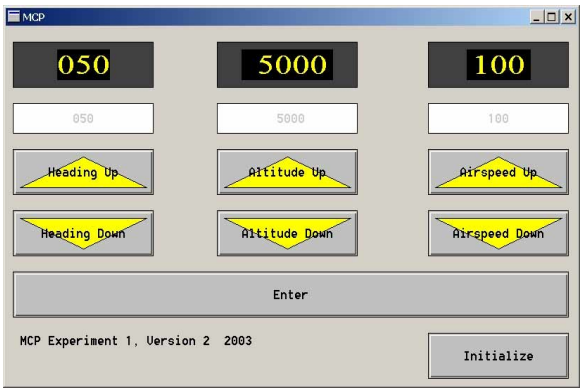

Figure 1. E-pad touch screen display.

RESULTS AND DISCUSSION

Communication Accuracy

Mean readback accuracy (excluding radio frequency readbacks) was analyzed by an Age x Aid (no aid, kneepad, e-pad) ANOVA with Aid as a repeated measure. Accuracy was higher when pilots used either aid (KP=99%, EP=99%, NA=84% correct), $F(2,20)=31.8$, $p < .001$, and for younger pilots (96% versus 93%), $F(1,10)=5.6$, $p < .05$. While the Age x Aid interaction was not significant, $F(2,20)=1.1$, the pattern of results suggested a greater aid benefit for older pilots, with a smaller age difference in the two aid conditions (Y=100%, O=98%) than in the no-aid condition (Y=88%, O=81%). We also analyzed age and aid effects on readback accuracy for each type of instruction. There were aid benefits for all three instructions, but only a significant age decline for the altitudes. Most important, the Aid x Age interaction was significant for altitudes, $F(2,20)=4.1$, $p < .05$. Finally, we analyzed mean number of request for repeats, and found a similar effect of aid (KP=0.0, EP=0.48, NA=2.0 mean requests), $F(2,18)=5.9$, $p < .05$, but no age difference.

Despite our small sample, the results replicate the earlier finding of note-taking benefits for older as well as younger pilots' communication (Morrow et al., 2003), and extend these findings to the novel epad aid. There was also some evidence that both aids reduce age differences in communication accuracy, consistent with environmental support theory (Craik & Jennings, 1992).

Analyses of Cognitive Demands of External Aids

We conducted an Age x Aid ANCOVA on readback accuracy with the Comparison task score (mean of letter and pattern comparison tasks) as covariate as a preliminary exploration of two issues: 1) Do differences in speed of processing help explain age differences in readback accuracy? 2) Do the external aids differ in the cognitive demands they impose on pilots? The age effect was not reduced in this analysis, $F(1,9)=8.2$, $p < .05$, suggesting that the age difference in accuracy did not reflect differences in mental speed. Age-related variance in readback accuracy in earlier studies were more often associated with age differences in working memory than with speed (e.g., Morrow et al., 2003), so it is possible that individual differences in working memory, and more generally executive function, are more likely to constrain pilot communication accuracy.

The analysis also revealed an Aid x Speed interaction, $F(2,18)=5.4$, $p < .05$, suggesting that the relationship between mental speed and readback accuracy depended on the type of aid. Correlations between the speed and readback accuracy scores in each aid condition showed a positive relationship in the epad condition ($r=.55$, $p<.07$), while the correlations did not approach significance in the other conditions (KP: $r=.27$; NA $r=-.43$, both p's $> .15$).

While these individual difference analyses are limited by the small sample, they suggest that the epad required cognitive resources to be used effectively, such that more able participants used the aid more successfully. This may reflect the fact that the novel epad imposed demands on fluid mental abilities. Findings from the usability questionnaire are consistent with this conclusion. For example, pilots noted that the lateral scan required to switch attention between instruments and the epad was less familiar than the vertical scan required by the kneepad (even though the distance of the scan was reduced in the former). Pilots also noted several features of the epad interface that required excessive control inputs. We modified the epad interface based on the usability findings in order to reduce the "cognitive overhead" of using this form of environmental support by older pilots. We are now investigating whether the epad is as effective as the

kneepad in supporting performance when communication is the primary task, as well as whether it is more likely to reduce age differences in communication under demanding multi-task (flight control as well as communicating) conditions. Our broader goal is to develop aids that support older pilots' overall task management as well as communication accuracy in General Aviation and commercial environments.

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