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16. Abstract

Recent reviews of the relationship between aging, cognition, and performance in pilots have emphasized the importance of considering age effects in aviator skills, particularly perceptual-motor, and memory. One possible conclusion is that flight experience does not appear to modify this age performance relationship, except in aviator's ability to time-share. A recent study involving the administration of an aviation-relevant neuropsychological test battery over two days provided data to examine the extent to which experience moderates the effects of aging on performance. Sixty individuals ranging in age from 20 to 65 years completed the CogScreen© computerized neuropsychological test battery on five occasions on two consecutive days. Subjects were divided into three age groups of equal size and within-subject repeated measures analyses of variance (ANOVA) examined the relationship between chronological age and practice on performance. The performance of the subjects in the oldest group was consistently poorer and slower than that of the subjects in the youngest group for all of the measures. There were main effects of practice such that performance after five sessions was significantly better than that on the first practice session. On none of the measures was there a significant age by practice interaction. In the case of divided attention tasks, significant age by condition (single vs. concurrent) interactions revealed that concurrent task performance by the elderly was differentially affected, depending on the information processing demands. These data are consistent with previous reports of experience-based practice effects differentiating subjects based on age and, by extension, suggesting that age-related factors be considered during systems design and implementation (including task execution and training for new equipment).

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THE EFFECTS OF AGE AND PRACTICE ON AVIATION-RELEVANT CONCURRENT TASK PERFORMANCE

INTRODUCTION

As individuals age, there are clear alterations in their performance of cognitive tasks. Various models have been used to describe these changes, including a reduction in information processing resources (Salthouse, 1985; Salthouse, 1988), declines in "fluid" intelligence (Horn & Cattell, 1966; Salthouse, 1991), or significant slowing of information processing speed (Birren & Morrison, 1961; Salthouse, 1985). These age-related changes in cognition are relevant to aviation and are, in part, responsible for the retention of the Age-60 Rule which prevents pilots from flying airline transport aircraft after their 60th birthday. The relationships between aging, cognition, and performance in pilots (military, commercial, and general aviation) have been reviewed extensively by Tsang (1992) and by Hardy and Parasuraman (1997). These reviews emphasize the importance of considering age effects in aviator skills, particularly perceptual-motor and memory. Of special interest is Hardy & Parasuraman's (Hardy & Parasuraman, 1997) conclusion that flight experience does not appear to modify this age: performance relationship, except in aviators' ability to time-share.

This conclusion, regarding flight experience, is important because it is the ability to divide attention that appears to maximally differentiate old from young subjects in a variety of domains. For example, simple digit spans are relatively unaffected by aging, but *backwards* digit spans (i.e., repeating the list in reverse) show age-related decrements in performance from early adulthood onward presumably because subjects must simultaneously maintain information in a phonological store as well as resequence the list. Simple modifications of relatively straightforward memory span tasks can produce important changes in performance, and the greater the processing demands, the greater the age-related effects (see, for example, Becker, et al, 1983).

The effect of experience on performance in older individuals, and aviators in particular, is an important issue. To what extent does experience, defined as task-specific practice, alter the affects of age on performance? As part of a recent study (Schroeder, Harris, Collins, and Nesthus, 1995), subjects were tested on five separate occasions using an aviation-relevant neuropsychological test battery over two days. These data provided the opportunity to examine the relationships between aging and the performance of these cognitive tasks as a function of learning experience. To the extent that such experience moderates the effects of aging on performance, we would expect a significant interaction between age and time (i.e., practice). By contrast, failure to find such an interaction would mean that experience does not alter this important relationship.

METHODS

Subjects

Sixty subjects (50 men, 10 women), none of whom were licensed pilots, provided data; they were all participants in a study of the effects of low blood alcohol levels on test performance (Harris, Schroeder & Collins, 1995). The data described below represent the first five no alcohol test conditions. Subjects were divided into three study groups of 20 subjects, with mean ages of 29.25 (±1.86), 43.6 (±1.69) and 59.25 (±1.89) years.

Procedures

Each subject was tested four times on Day 1, and a fifth time at the beginning of Day 2. They were each administered CogScreen©, a computerized test battery developed by the Advance Resource Development Corporation and Georgetown University (Kay, 1995). CogScreen© was developed in response to a FAA request for an automated test battery to detect subtle clinical changes in the cognitive functioning of pilots. The tests were run on an IBM PC-type computer, and a light pen was used as the primary input device for all tests, with the exception of the tracking task, which involved using the right and left arrow keys on the computer keyboard. Auditory feedback occurred during several of the tasks. Nine of the CogScreen© tests were selected for study, and they were always presented in the same order during the sessions.

The test sessions were self-paced and usually lasted 30-45 minutes. Subject were allowed to ask questions during and following the first test session on Day 1, but after that proceeded on their own. Sessions 2-5 did not include detailed instructions, were self-paced, and took approximately 30 minutes. Between each of the four sessions on Day 1 there was a 15 minute break during which subjects could read magazines, watch television, or relax. On Day 2, subjects returned at approximately the same time after eating lunch approximately 30 minutes prior to their arrival. Testing was conducted as in sessions 2-4.

CogScreen Tasks

Backward Digit Span. Lists of digits were presented sequentially on the video screen, with the subject required to reproduce each sequence in reverse order. List length increased from three to six digit, with a total of eight lists presented. The total number of lists correctly reproduced in reverse order was recorded for each subject.

Visual Sequence Comparison. Pairs of strings of alphanumeric characters, four to eight items in length, were presented simultaneously on the right and left halves of the screen. The subject indicated "same" or "different" for each pair of strings, with "same" meaning, the same characters were in the same positions in both lists. For any pair, the strings could differ by one or two items; half of the trials were "SAME" trials and half were "DIFFERENT." The performance measures included accuracy, mean reaction time, and thruput (number correct per minute).

Symbol Digit Coding. Six pairs of symbols and digits were displayed near the top of the screen throughout the test. Farther down the screen a row of symbols was presented in random order, with blank spaces below. The task for the subject was to indicate which digit belonged in each empty cell making reference to the key at the top of the screen. This task is analogous to the WAIS-R Symbol-Digit Substitution Task (Wechsler, 1981) and the Symbol-Digit Modalities Test (Smith, 1968). Immediately after the Symbol Digit Coding Test, and again after approximately a 30-minute delay, the six symbols appeared in random order and the subject's task was to recall the digits that had been paired with each of the six symbols. For the substitution condition, the total number of correct responses and the mean reaction time for each trial, were recorded. For the recall condition, the total number of correct responses was recorded.

Matching To Sample. A 4x4 grid pattern with filled and empty cells (the "sample") was presented briefly on the video screen, followed after a short delay by that same pattern along with a slightly different "foil" pattern. A forced-choice response was required, with the subject indicating which grid pattern was the same as the one presented previously. The foils differed from the correct choice by a change in one of the sixteen pattern blocks. Twenty trials were presented and the performance measures included accuracy, reaction time, and thruput.

Divided Attention. This task had two parts. For the first, the Indicator Task, a horizontal bar moved continuously up or down within a circular display in the upper half of the screen, changing direction at unpredictable times. The subject was instructed to respond when the moving bar passed from the center region of the circle into the upper or lower regions, which were delimited by a different color. This response temporarily returned the bar to the center of the circle. This Indicator Task was performed alone and concurrently with the Visual Sequence Comparison task (see above), which was the second part of the Divided Attention test. These two conditions, i.e., Indicator and Visual Sequence, were both performed alone and concurrently. Thus, there were data for accuracy (Visual Sequence), Reaction Time (both tasks), and Premature Responses (Indicator Task) for both the single and dual administrations.

Shifting Attention. This task was analogous to several set formation and set shifting tasks, including the Category Test (Reitan & Wolfson, 1994), Wisconsin Card Sort (Grant & Berg, 1948), and Weigl's Sorting Task (Weigl, 1927). Four response boxes were displayed near the bottom of the screen, one with a colored border, one with an uncolored border, one with no border but containing a colored arrow pointing right, and one with no border but with an uncolored arrow pointing left. Stimuli were displayed in a similar box above this row of response boxes. There were five conditions, each requiring the subject to respond according to different rules. The task began by teaching the subject to respond based on a particular rule (e.g., Border Color). However, the rules changed, and the subject was required to learn to change the response strategy. In the Discovery condition, the task was for the subject to learn and apply the correct response rule using a trial-and-error approach. Data from the Discovery condition included accuracy, reaction time, and lost rules (i.e., failure to maintain the response set).

Dual Task. There were two tasks, each performed separately and then again concurrently. The first was a second-order compensatory tracking task in which the subject tapped the right and left arrow keys on the keyboard to center a vertical bar moving along a horizontal line. The second task involved the sequential presentation of single digits in random order; the subject responded with the light pen indicating which digit had been presented immediately previously. Thus, if the digits 2-3-1-3-3-2 were presented, the correct responses would be: NR-2-3-1-3-3. Data from the tracking task included tracking error and boundary hits. Data for the Previous-number task included accuracy, reaction time, and thruput for both single and concurrent conditions.

RESULTS

The mean results for each subject group on each measure at each of the five test points are presented in Tables 1 and 2. Also shown in the Tables are the F ratios for the main effects of group and test trial as well as the interaction between Age Group and Trial. The results for accuracy (Table 1) and reaction time (Table 2) may be summarized as follows. By and large, there were significant Main Effects of Age Group and Trial for almost every variable measured. That is, performance of the older subjects was poorer than the younger subjects, and became significantly better with increasing practice. However, there were no significant interactions between Group and Trial, indicating that the rate of change in performance, as a function of practice, was similar in all three age groups of subjects.

Because of the importance of the two time sharing tasks (i.e., Divided Attention and Dual Task), we further analyzed these data with regard to change in performance when the subjects had to perform under concurrent task conditions relative to single task conditions. We completed a series of Analysis of Variance (ANOVA) procedures with the additional within-subject factor of Condition (Single vs. Concurrent). These were performed for the Dual Task and Divided Attention Task measures of reaction time and accuracy. In terms of accuracy on the Dual Task Previous Number task, there was a significant effect of age ($F_{(2,57)}$=20.1, p<.001, $\mathbf{h}^2$ = .41), and test session ($F_{(4,228)}$=37.5, p<.001, $\mathbf{h}^2$ = .40). Furthermore, there was a significant difference in overall performance on the memory task in the concurrent condition relative to the single task condition ($F_{(1,57)}$=138.5, p<.001, $\mathbf{h}^2$ = .71). Of particular interest is the fact that there was a significant interaction between age group and concurrent condition ($F_{(2,57)}$=3.49, p<.04, $\mathbf{h}^2$ = .11) indicating that the effect of multi-tasking was greater in the older subjects.

With regard to the accuracy during the tracking condition of the Dual Task, the results were very similar. Age ($F_{(2,57)}$=11.2, p<.001, $\mathbf{h}^2$ = .28), test session ($F_{(4,228)}$=17.6, p<.001, $\mathbf{h}^2$ = .24), and dual tasking condition ($F_{(1,57)}$=331.0, p<.01, $\mathbf{h}^2$ = .85), were all significantly associated with performance. The age by condition interaction was significant ($F_{(2,57)}$=6.40, p<.003, $\mathbf{h}^2$ = .18), as was the time by condition ($F_{(4,228)}$=3.97, p=.004, $\mathbf{h}^2$ = .07) interaction, and the three-way interaction of age, session, and condition ($F_{(8,228)}$=2.69, p=.008, $\mathbf{h}^2$ = .09) (See Figure 1.) Performance by the young subjects improved in the concurrent task condition ($F_{(4,76)}$ = 7.36, p < .001, $\mathbf{h}^2$ = .28) but that of the middle age ($F_{(4,76)}$ = 1.45, p = .23, $\mathbf{h}^2$ = .07), and older subjects ($F(4,76)$ = 1.09, p = .37, $\mathbf{h}^2$ = .05) did not.

Finally, the accuracy data from the Visual Sequence Comparison of the Divided Attention Task did not reveal a significant effect of age overall ($F_{(2,57)}$= 0.42, p=.65, $\mathbf{h}^2$ = .02). However, test session ($F(4,228)$=6.65, p<.001, $\mathbf{h}^2$ = .10) and condition ($F_{(1,57)}$= 83.9, p<.001, $\mathbf{h}^2$ = .60) did significantly affect performance. There were no significant interactions between age and the divided attention condition ($F_{(2,57)}$=1.35, p = 74, $\mathbf{h}^2$ = .03) or between age, session, and condition ($F_{(8,225)}$=1.08, p=.38, $\mathbf{h}^2$ = .04).

The reaction time data for the two divided attention tasks were transformed prior to analysis in $\log_{10}$ units. A four-way repeated measures ANOVA (task x dual x session x age) revealed a significant effect of age group ($F_{(2,57)}$ = 16.7, p < .001, $\mathbf{h}^2$ = .37), and concurrent condition ($F_{(1,57)}$ = 365.2, p < .001, $\mathbf{h}^2$ = .87).

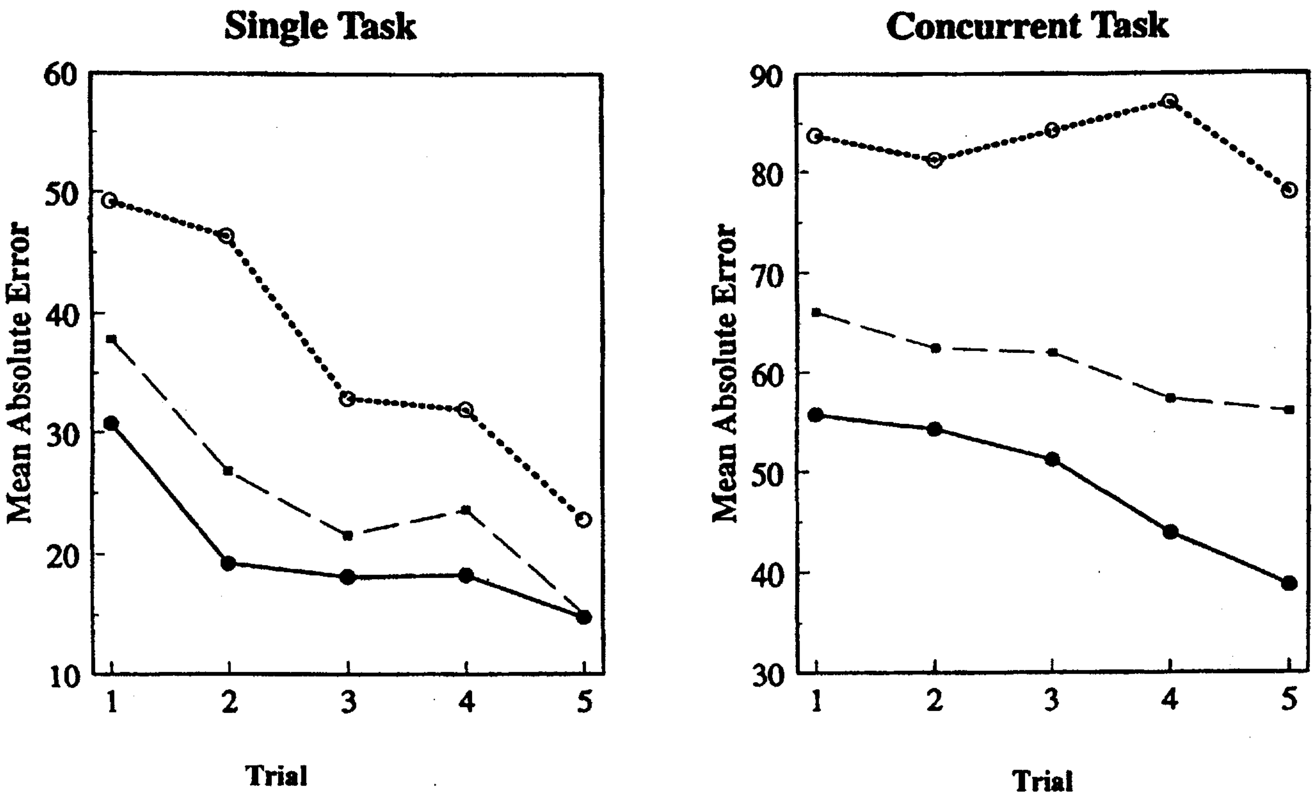

Figure 1. Performance on the Tracking component of Dual task. The left graph shows the mean absolute error by age group over the five learning trials when the task was performed alone. The right panel presents the same information, but was obtained when the task was performed concurrently with the Previous Number task.

There was no significant interaction between age group and concurrent task overall ($\underline{F}_{(2,57)} = 1.31$, p = 28, h^2 = .04). However, the effect of concurrent condition was significantly greater in Divided Attention, relative to the Dual Task ($\underline{F}_{(1,57)} = 559$, $p < .001$, h^2 = .92). Further, older participants were more affected in the concurrent condition of Divided Attention, relative to the Dual Task ($\underline{F}_{(2,57)} = 4.41$, p = .02, h^2 = .13) (See Figures 2 and 3.)

DISCUSSION

These data address several issues of relevance to aviation and cognitive neuropsychology in the context of aging and human factors. As would be predicted, we found consistent differences across virtually all measures as a function of age group. That is, the older subjects (mean age 60 years) performed consistently poorer when compared with the younger subjects (mean age 30 years). This finding is not surprising given the long history of data that demonstrate the decreasing efficiency of cognitive operations, especially when measured with attention and resource demanding tasks (e.g., Birren & Morrison, 1961; Hasher & Zacks, 1988; Morrow & Leirer, 1997; Salthouse, 1991b; Taylor, Yesavage, Morrow, Dolhert & Poon, 1994).

We also found consistent improvements in performance across virtually all tasks as a function of practice. Over the five test sessions, there were marked increases in accuracy and reductions in reaction time in all three groups of subjects. However, what is perhaps more important, is that generally, there were no significant interactions between age group and practice. That is, the relative difference between age groups did not change (i.e., did not get bigger *or*

TABLE 1. Performance on CogScreen Measures:Accuracy

	Age Group 1					Age Group 2					Age Group 3					Statistics		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Age	Trial	T x A
Digits	6.00	7.40	7.60	8.15	8.40	6.55	6.90	7.55	7.40	8.10	4.25	4.95	5.35	5.75	6.60	8.05	9.69	0.42
Backwards	*2.08*	*2.23*	*2.98*	*2.56*	*2.76*	*1.79*	*2.34*	*2.52*	*2.76*	*3.01*	*2.51*	*2.91*	*2.39*	*1.83*	*3.05*			
Matching to	19.21	17.60	18.90	18.74	19.15	18.65	18.40	18.20	17.95	18.90	17.25	17.53	17.05	17.65	17.71	4.6	.71	.50
Sample	*.92*	*5.10*	*1.25*	*2.16*	*1.09*	*1.35*	*2.44*	*2.71*	*3.24*	*1.07*	*2.90*	*3.31*	*2.16*	*2.21*	*1.43*			
SYMBOL-DIGIT CODING																		
Total	55.10	67.10	69.75	67.89	73.91	50.35	53.95	57.35	53.65	62.25	34.10	44.80	46.65	41.85	46.10	19.09	22.63	1.37
Correct	*15.02*	*13.17*	*12.84*	*15.07*	*16.01*	*19.74*	*13.69*	*13.89*	*13.97*	*14.62*	*15.49*	*15.38*	*14.85*	*11.51*	*13.33*			
Immediate	5.45	5.60	5.90	5.20	5.94	5.15	5.20	5.55	4.90	5.45	4.6	5.15	5.30	4.75	5.20	6.67	4.08	.21
Recall	*1.28*	*.99*	*.31*	*1.15*	*.23*	*1.60*	*1.11*	*.83*	*1.37*	*.89*	*1.43*	*1.09*	*.98*	*1.21*	*1.06*			
Delayed	5.00	5.60	5.75	4.75	5.84	5.30	4.90	5.35	4.75	5.67	4.20	4.75	5.20	4.10	4.85	4.35	8.05	1.01
Recall	*1.56*	*.82*	*.79*	*1.59*	*.51*	*1.49*	*1.41*	*.93*	*1.41*	*.65*	*1.54*	*1.52*	*1.20*	*1.80*	*1.27*			
DIVIDED ATTENTION																		
Visual Seq.	16.20	17.75	18.10	18.40	18.80	16.00	17.45	17.30	17.90	18.40	16.75	17.55	17.20	16.65	17.85			
Comp. Alone	*2.56*	*1.48*	*1.20*	*.88*	*.69*	*3.85*	*2.72*	*2.10*	*1.68*	*1.27*	*2.07*	*1.73*	*2.83*	*2.77*	*1.04*	*1.59*	*8.41*	*1.18*
Visual Seq.	16.90	16.70	16.05	18.17	16.35	17.97	15.77	16.75	19.27	18.71	18.39	17.32	16.90	18.40	18.22			
Concurrent	*4.07*	*4.14*	*4.32*	*3.61*	*3.99*	*4.61*	*4.58*	*4.02*	*3.89*	*3.26*	*3.13*	*2.79*	*3.40*	*4.48*	*3.26*	.64	6.37	1.26
Indicator	18.95	18.90	18.85	19.10	19.15	18.64	17.97	18.80	18.90	18.64	19.29	18.51	18.45	19.10	18.40	2.41	3.65	1.93
Alone	*.75*	*.91*	*.93*	*.64*	*.93*	*.98*	*1.36*	*.89*	*.78*	*1.03*	*.86*	*.80*	*1.23*	*1.29*	*1.31*			
Indicator	17.60	17.60	17.90	18.06	17.80	17.65	16.72	18.05	18.11	17.81	17.71	17.20	17.60	18.50	18.22	.10	4.00	.71
Concurrent	*1.72*	*1.69*	*1.51*	*1.60*	*2.11*	*2.39*	*2.24*	*1.66*	*2.37*	*1.66*	*2.37*	*1.66*	*2.23*	*1.82*	*1.33*			

Note: Upper row represents the mean; lower row (in italics) represents the standard deviation.

TABLE 1 (continued)

	Age Group1					Age Group2					Age Group3					Statistics		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Age	Trial	T x A
SHIFTING ATTENTION																		
Correct	44.10	47.10	48.37	48.95	49.15	38.32	39.30	41.60	41.25	39.85	30.26	33.79	38.30	37.80	36.45	10.17	5.11	.28
Response	*6.01*	*2.85*	*1.46*	*2.37*	*2.52*	*12.52*	*13.75*	*8.92*	*10.61*	*12.6*	*73.14*	*11.39*	*11.49*	*12.07*	*13.06*			
Lost	2.15	1.30	1.47	1.65	1.45	2.42	2.20	2.90	3.00	3.15	3.63	3.74	2.60	3.60	2.85	7.54	1.33	1.93
Rule	*1.81*	*.92*	*.90*	*1.18*	*1.15*	*1.64*	*2.12*	*2.31*	*1.78*	*2.39*	*2.29*	*2.47*	*2.09*	*2.41*	*2.08*			
DUAL TASK																		
Prev. Num.	32.35	35.05	36.90	37.65	39.85	27.43	29.88	30.90	33.45	33.65	24.25	25.15	28.38	29.28	29.85	13.33	23.44	.41
Alone	*7.82*	*6.73*	*7.03*	*7.73*	*6.02*	*5.85*	*4.92*	*5.80*	*7.35*	*5.43*	*7.70*	*8.27*	*6.18*	*6.67*	*6.75*			
Prev. Num.	26.15	30.45	30.55	32.80	32.30	22.48	25.03	25.60	27.10	25.95	14.65	16.95	18.15	20.39	20.80	21.22	23.03	.78
Concurrent	*8.15*	*8.61*	*7.49*	*8.15*	*8.27*	*4.32*	*5.81*	*5.04*	*5.75*	*6.37*	*5.66*	*7.33*	*6.74*	*6.12*	*6.49*			
Tracking	30.78	19.23	18.10	18.24	14.81	37.86	26.84	21.50	23.63	15.09	49.27	46.42	32.84	31.94	22.80	4.75	17.58	1.19
	26.30	*20.15*	*17.44*	*19.33*	*12.70*	*25.01*	*19.58*	*21.01*	*24.60*	*12.87*	*26.19*	*27.80*	*24.02*	*25.99*	*19.89*			
Tracking	55.78	54.29	50.15	43.81	38.63	66.16	62.50	62.01	57.28	56.00	83.72	81.20	84.19	87.04	77.91	14.44	5.40	1.43
Concurrent	*30.89*	*28.40*	*28.85*	*27.68*	*23.79*	*20.22*	*21.00*	*24.24*	*27.07*	*28.08*	*15.06*	*20.17*	*20.57*	*16.82*	*19.16*			

TABLE 2. Performance on CogScreen Measures: Reaction Time

	Age Group 1					Age Group 2					Age Group 3					Statistics		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Age	Trial	T x A
Matching to Sample	1612.05	1479.31	1640.69	1509.30	1444.05	1921.69	1947.08	1929.04	1828.61	1727.02	2176.33	1951.72	2135.05	2094.84	2053.04	20.63	5.56	1.65
	321.79	*274.37*	*282.59*	*352.73*	*245.01*	*359.98*	*322.68*	*329.34*	*356.50*	*333.95*	*341.58*	*320.10*	*380.08*	*379.45*	*366.56*			
SYMBOL-DIGIT CODING																		
Total Correct	1667.14	1322.30	1237.68	1321.24	1206.85	1905.51	1643.07	1536.42	1685.64	1444.35	2839.74	2138.13	1972.50	2132.73	2011.01	16.46	36.57	3.06
	435.48	*255.74*	*207.78*	*271.98*	*233.03*	*566.91*	*343.14*	*332.60*	*454.48*	*352.72*	*1076.70*	*887.16*	*618.17*	*562.00*	*706.65*			
Immediate Recall	5303.21	2508.79	2602.78	2827.94	1770.81	4766.72	3527.73	4047.71	3277.14	2634.91	6913.48	4752.08	4187.75	3758.25	3659.00	6.90	18.96	1.14
	2926.55	*1486.28*	*1453.08*	*1862.83*	*694.22*	*3072.75*	*2066.0*	*4067.54*	*1565.14*	*1396.89*	*3223.79*	*2104.31*	*2094.57*	*1241.21*	*1645.27*			
Delayed Recall	4514.25	2443.29	2372.98	2654.12	1801.07	4871.92	4338.21	3719.56	2873.82	2552.19	6172.90	5359.92	4477.12	4783.40	4813.60	14.99	18.90	1.87
	2171.47	*1487.16*	*1233.91*	*1460.16*	*681.79*	*1663.09*	*2735.14*	*2288.33*	*1069.56*	*1196.92*	*1871.52*	*2795.74*	*1804.32*	*2559.54*	*2061.48*			
DIVIDED ATTENTION																		
Visual Seq. Comparison	2178.52	2041.82	1812.23	2005.86	1788.68	2805.12	2752.27	2406.0	2573.61	2373.16	3227.63	2866.44	2516.08	2846.25	2913.14	18.79	17.53	2.07
	670.18	*601.03*	*485.13*	*559.86*	*500.76*	*593.85*	*618.87*	*509.64*	*657.74*	*799.08*	*638.08*	*504.76*	*431.79*	*581.86*	*624.28*			
VSC-Dual	645.15	604.35	592.56	575.86	509.17	853.02	634.97	623.39	700.84	594.76	1146.51	889.95	830.40	914.94	832.78	13.74	11.97	1.35
	194.77	*152.50*	*147.25*	*140.63*	*129.65*	*397.43*	*140.57*	*103.63*	*238.99*	*189.12*	*387.53*	*277.19*	*253.21*	*240.49*	*264.74*			
Divided Attention	2371.42	2143.75	2092.46	2045.29	1912.04	2643.26	2484.54	2319.01	2416.90	2447.93	2777.10	2540.11	2397.13	2439.44	2518.89	2.51	11.57	.99
	1034.43	*822.92*	*758.95*	*672.20*	*615.65*	*597.34*	*760.11*	*656.74*	*781.81*	*621.57*	*614.76*	*548.19*	*557.52*	*600.78*	*577.07*			
Shifting Attention	890.68	729.95	726.70	669.06	640.67	1110.77	999.39	940.93	919.68	894.59	1321.28	1132.31	1136.88	1153.02	1065.50	11.90	19.34	.78
	262.40	*160.78*	*189.45*	*119.51*	*133.39*	*327.75*	*335.87*	*329.47*	*370.21*	*296.07*	*508.42*	*343.29*	*371.22*	*394.15*	*475.89*			
Prev. Num. Concurrent	602.19	524.30	474.34	406.33	384.56	808.71	710.08	655.29	516.06	583.63	926.78	826.62	729.46	685.30	629.34	11.73	32.98	.87
	269.68	*233.69*	*256.28*	*201.51*	*218.15*	*215.14*	*227.26*	*193.26*	*209.34*	*190.76*	*262.25*	*263.61*	*201.87*	*201.38*	*171.12*			
Prev. Num Dual	859.15	730.74	647.75	565.48	561.35	960.03	820.52	844.88	732.94	757.22	1080.22	967.13	883.12	841.53	876.68	7.66	27.40	1.02
	329.09	*359.38*	*259.97*	*241.0*	*278.04*	*198.24*	*203.54*	*208.19*	*204.04*	*208.88*	*163.44*	*217.44*	*214.65*	*280.78*	*212.58*			

Note: Upper row represents the mean; lower row (in italics) represents the standard deviation.

TABLE 2. Performance on CogScreen Measures: Reaction Time (Continued)

	Age Group 1					Age Group 2					Age Group 3					Statistics		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Age	Trial	T x A
Matching to	3.19	3.16	3.20	3.16	3.15	3.27	3.28	3.27	3.25	3.22	3.33	3.28	3.32	3.31	3.30	20.98	6.29	1.74
Sample	*.08*	*.08*	*.07*	*.10*	*.07*	*.07*	*.07*	*.07*	*.08*	*.08*	*.06*	*.07*	*.07*	*.08*	*.07*			
SYMBOL-DIGIT CODING																		
Total	3.20	3.11	3.08	3.11	3.07	3.25	3.20	3.17	3.21	3.14	3.42	3.30	3.27	3.31	3.28	19.27	34.80	1.07
Correct	*.11*	*.08*	*.07*	*.08*	*.08*	*.14*	*.09*	*.09*	*.11*	*.09*	*.17*	*.15*	*.13*	*.10*	*.13*			
Immediate	3.65	3.31	3.35	3.37	3.22	3.59	3.45	3.48	3.47	3.36	3.79	3.63	3.57	3.55	3.52	11.90	16.61	1.12
Recall	*.27*	*.32*	*.23*	*.24*	*.15*	*.28*	*.32*	*.29*	*.19*	*.22*	*.20*	*.20*	*.21*	*.15*	*.20*			
Delayed	3.60	3.32	3.32	3.35	3.22	3.66	3.56	3.52	3.42	3.36	3.77	3.67	3.61	3.63	3.64	19.55	27.75	3.32
Recall	*.20*	*.23*	*.22*	*.25*	*.16*	*.16*	*.24*	*.19*	*.16*	*.20*	*.14*	*.21*	*.17*	*.20*	*.19*			
DIVIDED ATTENTION																		
Visual Seq.	3.34	3.30	3.29	3.29	3.26	3.41	3.38	3.34	3.26	3.37	3.43	3.39	3.36	3.37	3.38	3.94	13.80	1.31
Comp. Alone	*.15*	*.14*	*.13*	*.12*	*.12*	*.09*	*.11*	*.11*	*.12*	*.10*	*.09*	*.09*	*.10*	*.10*	*.10*			
Visual Seq.	2.78	2.76	2.75	2.74	2.69	2.89	2.79	2.78	2.82	2.74	3.03	2.92	2.89	2.94	2.90	13.13	10.95	1.03
Concurrent	*.14*	*.11*	*.10*	*.11*	*.12*	*.16*	*.09*	*.07*	*.13*	*.16*	*.15*	*.13*	*.14*	*.11*	*.12*			
SHIFTING ATTENTION																		
Correct	2.92	2.85	2.84	2.81	2.79	3.02	2.97	2.93	2.92	2.92	3.12	3.03	3.03	3.03	2.87	5.76	5.17	.90
Response	*.14*	*.09*	*.10*	*.07*	*.08*	*.14*	*.17*	*.21*	*.22*	*.15*	*.11.*	*13*	*.14*	*.15*	*.69*			
DUAL TASK																		
Prev. Num.	2.73	2.67	2.62	2.55	2.50	2.89	2.83	2.79	2.67	2.74	2.94	2.89	2.84	2.81	2.78	11.75	31.55	1.15
Alone	*.21*	*.20*	*.21*	*.23*	*.29*	*.11*	*.13*	*.15*	*.20*	*.15*	*.14*	*.16*	*.13*	*.14*	*.11*			
Prev. Num.	2.89	2.80	2.76	2.68	2.68	2.97	2.89	2.91	2.84	2.85	3.02	2.97	2.93	2.83	2.93	5.72	13.58	.84
Concurrent	*.19*	*.25*	*.23*	*.29*	*.29*	*.09*	*.12*	*.10*	*.15*	*.14*	*.06*	*.10*	*.10*	*.44*	*.10*			

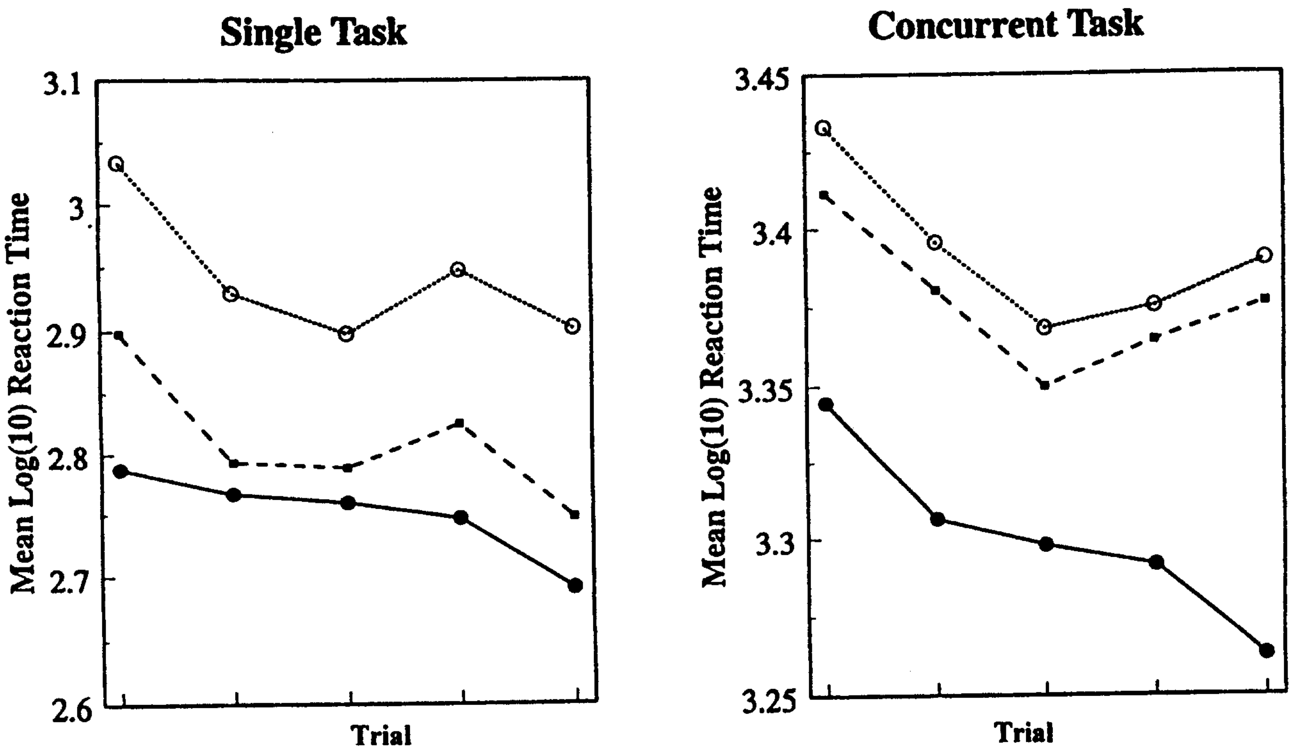

Figure 2. Reaction time (log_{10} milliseconds) on the Visual Sequence Comparison Task. The left hand panel shows the data when the task was performed alone. The right panel shows performance in the concurrent task condition (i.e., with the Indication Task).

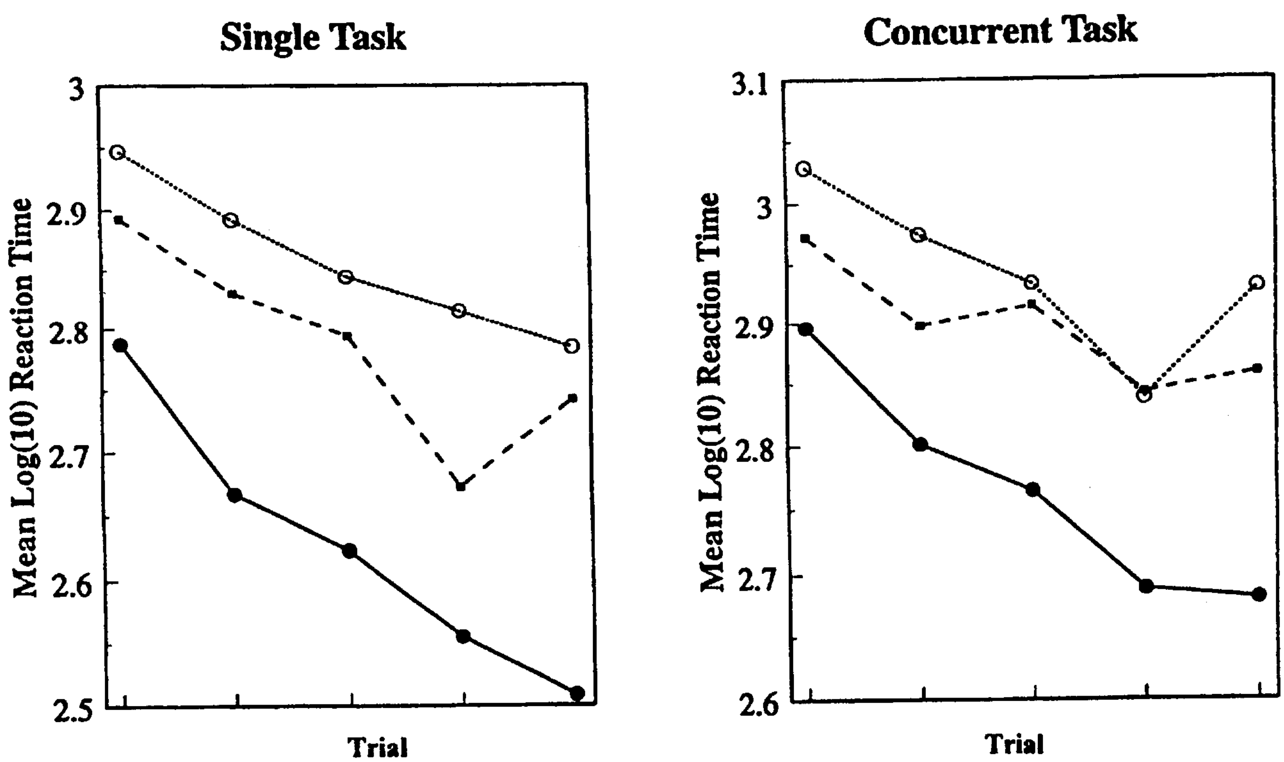

Figure 3. Reaction time on the Dual Task— Previous Number Task presented alone (left panel) and with the tracking task (right panel).

smaller) as the subjects had more practice on the tasks. In some cases, the change in performance by the older subjects only brought them to the same level as that of the younger subjects *at the first test session.*

With regard to the tasks that required concurrent performance, the data overall provided the same message: Performance was poorer by the older subjects and was poorer in the concurrent performance conditions relative to when the tasks were performed alone. Performance of the older subjects suffered more from the concurrent task requirements and was consistent with a variety of other data. In general, the difference between the single and dual conditions in the three sets of tasks was not attenuated over the course of the five test sessions. However, in terms of the tracking performance accuracy of the Dual Task, we also found that this was not true among the middle age and older subjects. As shown in Figure 1, these subjects failed to improve tracking performance during the concurrent condition making the age-related divided attention effect actually larger. Because tracking skill improved overall (left panel of Figure) and the Previous Number task showed improved performance with practice under concurrent conditions, this suggests that the older subjects had focused their attention on the memory task and made the tracking task secondary. Thus, while the basic competence skills necessary to perform the tasks are relatively unaffected by age, resource allocation *is* affected, and only one task can be performed effectively at any given time. This finding could be interpreted in the context of working memory (Baddeley, 1986) with an age-related deficit in Central Executive System function at the root of this problem.

Analysis of the reaction time data also revealed differential sensitivity of the two divided attention tasks to the effects of age. This finding is consistent with the literature on executive functioning (See Baddeley, 1986, for discussion). In the case of the Dual Task, subjects had to perform a *visual* tracking task and a *visual* memory task. By contrast, the Divided Attention task involved a visual attention task and a visual-verbal memory task. By placing demands separately on visual and verbal modalities, Divided Attention has less of an executive component (e.g., resource allocation) and, thus, is less affected by age. By contrast, as Dual Task heavily loads visual processing, executive demands are greater, and age has a significantly greater impact.

These data raise interesting questions about the effects of general aviation-related experience on performance. It is clear that pilots are better able to manage the effects of age on domain-relevant tasks (Morrow & Leirer, 1997) than non-pilots, examination of this issue within the aviation community (e.g., pilots, controllers) is more problematic. Because age is highly correlated with experience (esp. flight time), it is often difficult to disentangle the qualitative and quantitative effects that these factors have on performance. One approach that might be more useful within the Air Traffic Control (ATC) environment would be to sample controllers within a specific age range (e.g., 35-45 years old) stratified by their age at entry into the ATC system. Alternatively, one could recruit controllers who enrolled at the same age and stratify them on their current age. While neither of these solutions is ideal, together they could aid significantly in addressing this important issue.

Generally, these findings are important for several reasons. First, although the performance of older subjects improves with experience, it may never reach the same level as that of younger subjects. Thus, when job task demands and requirements are detailed for specific operations, they must be created for the target group as a whole, and not "normed" only on younger operators. Second, when designing new systems, it would perhaps be imprudent to assume that, with sufficient experience, older operators would utilize the systems in the same way, and with the same efficiency as younger operators; age-related differences in performance, performance style, and cognitive functions, should be considered in designing new operating systems (Morrow, 1996). Third, the contrast between the findings from the Divided Attention and Dual Task procedures suggests that system designers should attend to the types of tasks that must be performed concurrently. Thus, while younger subjects may be relatively unaffected by task similarities, older subjects are at a disadvantage if they must concurrently perform two or more operations that involve common information processing demands.

Finally, the introduction of new systems to the aviation work environment needs to account for the age-related differences in task acquisition. It seems clear from these data that simple repeated exposure to a novel task (and novel test environment) does not maximize performance, although it may optimize operation. Ease of acquisition of a new system needs to account for these factors. Thus, the fact that new job candidates (or recent hires) in the aviation field can learn to operate the new system effectively does not mean that the same would be true of individuals already in the work force, especially if they are over 40 years old. To the extent that the difference between the old system and the one to be phased in can be minimized with regard to "look and feel," the effects of age on performance may be attenuated.

This is one of the first demonstrations of the negative effect of older age on the acquisition of an aviation relevant task. The measures of CogScreen© have been shown to have significant validity relative to measures of in-flight performance (Yakimovitch et al, 1994). Thus, the failure of the older subjects to reduce the "cost" of the dual tasking requirement with practice suggests that this may represent a limit on their performance ability. However, while age affects the acquisition of these aviation-relevant tasks, the precise contribution of age itself is not clear. For example, the absence of a ***qualitative*** measure of performance, such as cognitive style, precludes an understanding of whether the older subjects approached the tasks in the same way as the younger subjects. Nevertheless, these data do emphasize how age can not only affect performance, but also learning. In keeping with the conclusion of Hardy and Parasuraman (1997), we did find important age-related differences in performance on pilot-related tasks. Future studies must also use aviation-relevant tasks "that go beyond the typical measure of cognitive skill and flight performance" (Hardy & Parasuraman, 1997, pg. 340) to best understand the age-performance relationship in aviation.

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