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# **Air Traffic Control Specialist Age and Cognitive Test Performance**

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## N O T I C E

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16. Abstract <p>Researchers have explored the issue of air traffic control specialist (ATCS) age and performance many times over the past few decades (Cobb, 1968; Heil, 1999; Trites, 1961; Trites &amp; Cobb, 1962; Schroeder, Broach, &amp; Farmer, 1997; VanDeventer &amp; Baxter, 1984). These researchers have consistently found a negative relationship between the age of Air ATCSs and both training success and ratings of job performance. A recent study (Heil, 1999) found a curvilinear relationship between ATCS age and performance on a computerized simulation of air traffic situations, with performance decreasing for people in their mid 40s. Some researchers (Heil, 1999; Schroeder, Broach, &amp; Farmer, 1997) have speculated that these relationships may be due to a decline in cognitive ability with age. The purpose of the current study is to investigate the relationship between age and performance on tests of cognitive ability for incumbent ATCSs. As part of a concurrent validation study, 1083 incumbent ATCSs from 12 enroute centers took a newly developed air traffic control selection test. The tests included in the 6 hour battery were developed to measure the knowledge, skills, abilities, and other characteristics (KSAOs) relevant to the ATCS job. Some of the KSAOs measured by the battery include: ability to prioritize, situational awareness, planning, execution, thinking ahead, short-term memory, reasoning, decisiveness, concentration, perceptual speed and accuracy, mathematical reasoning, and ability to deal with dynamic visual movement. The relationship between current age and performance on these cognitive tests was compared using regression analysis and analysis of variance procedures. The results of these analyses suggest an age-related decline in those cognitive abilities that are most important to successful job performance.</p>					
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# AIR TRAFFIC CONTROL SPECIALIST AGE AND COGNITIVE TEST PERFORMANCE

## INTRODUCTION

Researchers have revisited the issue of Air Traffic Control Specialist (ATCS) age and performance many times over the past few decades (Cobb, 1968; Heil, 1999; Trites, 1961; Trites & Cobb, 1962; Schroeder, Broach, & Farmer, 1997; VanDeventer & Baxter, 1984). These researchers have consistently found a negative relationship between the age of Air Traffic Control Specialists (ATCSs) and both training success and ratings of job performance. A recent study found a curvilinear relationship between ATCS age and performance on a computerized simulation of air traffic situations, with performance decreasing for people in their mid 40s (Heil, 1999). To date, there has been no systematic study of factors associated with this decline in performance. However, some researchers (Heil, 1999; Schroeder, Broach, & Farmer, 1997) have speculated that it may be due to a decline in cognitive ability with age.

In the general population, the negative relationship between age and performance on tests of cognitive ability has been well-documented (Salthouse, 1994; Verhaeghen & Salthouse, 1997). Salthouse (1994) distinguished between two broad categories of age and performance relationships: 1) age and cognitive processes; and 2) age and work performance. In the first category, a negative relationship exists between age and measures of cognitive processing efficiency. However, this relationship does not generalize to all cognitive abilities. According to Salthouse (1991), there is little age-related decline in the amount of information or knowledge possessed by a person. In fact, there is evidence that knowledge increases well into the 60s. The lack of an age effect for knowledge, in conjunction with an age effect for cognitive processing, led to cognitive ability being categorized in one of two ways: *Fluid intelligence*, which refers to the efficiency of processing at the time of assessment; and *crystallized intelligence*, which refers to the cumulative products of processing from earlier periods in a person's life (Hardy & Parasuraman, 1997; Salthouse, 1994). Although fluid

intelligence tends to decline with age, there has been little evidence of such a relationship between crystallized intelligence and age (Salthouse, 1994).

The second relationship discussed by Salthouse (1994) is that between cognitive ability and performance in the work environment. Although the average magnitude of the relationship has varied across studies, the relationship between cognitive ability and job proficiency has been positive. According to Salthouse, results of research demonstrate that higher levels of cognitive ability, as measured by cognitive test performance, are related to higher levels of performance in work situations. He pointed out, however, that most researchers have found little convincing evidence that older workers are either less productive or less competent than younger workers. Salthouse postulated that this paradox might be due to selective attrition in the workplace or the use of job performance measures that are not sensitive to dimensions of the job requiring cognitive ability. Salthouse also suggested that age trends may be observed on cognitive measures but not in work performance due to relevant experience. Specifically, increased age is associated with greater levels of experience, which may be advantageous at work, but not necessarily on tests of specific abilities. Salthouse investigated whether or not experience moderates the relationship between age and work performance through either preservation of a high level of cognitive ability or a larger accumulation of relevant knowledge with age. The results of this research failed to demonstrate that experience moderates the relationship between age and basic cognitive processes (Salthouse, 1994).

According to Tsang and Shaner (1998), inconsistent reports of the interactive effects of age and experience may result from the domain-specificity of expertise effects. In their study of age, attention, expertise, and time sharing, Tsang and Shaner found age-related deficits in time-sharing efficiency and resource allocation for people over the age of 60. These deficits seemed to occur when subjects were

under intense attentional demands when precise control was required. The results of Tsang and Shaner's study suggest that both expertise and practice can reduce age-related declines in performance. However, the modulation of age-related declines in performance by expertise may be limited, with the exception of performance that is highly domain-specific, (Tsang and Shaner, 1998). In their study of pilots, Morrow, Menard, and Stine-Morrow (1999) found that expertise did not reduce age differences in readback accuracy. The issue of such age-related cognitive declines is relevant to the ATCS job because the Separation and Control Hiring Assessment (SACHA) job analysis identified prioritization, situational awareness, planning, execution, thinking ahead, reasoning, and timesharing as some of the cognitive functions most relevant to the ATCS job (Nickels, Bobko, Blair, Sanda, & Tartak, 1995).

Based on the findings of previous researchers (Becker & Milke, 1998; Hardy & Parasuraman, 1997; Salthouse, 1994; Tsang & Shaner, 1998), older ATCSs would be expected to demonstrate lower levels of performance on measures of cognitive ability. Although Salthouse (1994) stated that poor performance on cognitive ability measures does not necessarily mean that there is a corresponding decrease in job performance, Heil (1999) found that scores on experimental ATCS performance measures declined with age for ATCS in their mid 40s; however it is important to note that the lower levels of performance found among older ATCSs does not mean that they are unable to safely manage the flow of traffic within their areas of certification. The cognitive measures used to select people into the ATCS occupation are linked to the knowledge, skills, abilities, and other characteristics (KSAOs) critical to successful job performance. Consequently, an understanding of the relationship between age and performance on these tests may help provide insight into possible age-related declines in performance among incumbent ATCSs.

The purpose of the current study was to investigate the relationship between age and performance on tests of cognitive ability for incumbent ATCSs. The data used in the current study was collected during the Air Traffic-Selection and Training (AT-SAT) concurrent validation study. It was hypothesized that the age of the ATCS would be negatively correlated with performance on those cognitive measures and on tasks that require the greatest amount of fluid

intelligence, processing speed, and time-sharing. In addition, it was hypothesized that no significant relationship will be found between age and tests that require less time-sharing and are based primarily on existing knowledge.

## METHOD

### Participants

A total of 1083 Full-Performance Level (FPL) enroute ATCSs, supervisors, and staff voluntarily participated in the AT-SAT concurrent validation study, including a minimum of 75 ATCSs from each of 12 enroute air traffic control centers. Current staff and supervisors were excluded from the present study, leaving 828 FPL enroute ATCSs. All participants identified themselves as being FPL ATCS at the time of the concurrent validation, although 141 had previously held a staff position and 30 had previously been supervisors. Demographic information is presented in Table 1. Almost half of the controllers were between the ages of 32 and 37 ( $M=36.4$ ,  $SD=5.7$ ), and the majority of participants were Caucasian males, reflecting the current demographic makeup of the FAA's ATCS workforce. The average number of years in current position was 8.3, the average entry-on-duty age was 25.0, and the average number of years as an FPL ATCS was 7.2. As shown in Table 1, only 10.9% of the participants were above the age of 43. Although this number is not proportional to the other age groups, it is consistent with skewed age distributions of ATCSs reported by previous researchers (Cobb, 1967; Cobb et al., 1973; VanDeventer & Baxter, 1984).

### Procedure

Data collection teams were assembled and trained to conduct testing at each of the enroute air traffic control centers (ARTCCs) included in the study. Each team was comprised of a test site manager and two to four team members who were responsible for administration of the predictor battery and criterion measures. All participants were volunteers in the AT-SAT concurrent validation study who were recruited through on-site briefings and an informational memo. Volunteers were tested over a 2-day period in a room provided by their facility. One day of computer-based testing was devoted to the predictor tests and one day was devoted to administration of the criterion measure.

## Measures

The measures used in the current study are tests of cognitive ability that were included in the predictor test battery used during the AT-SAT concurrent validation study. There is a time limit for all tests; however, this limit is set so that applicants should be able to complete all items. The applied math and angles tests were used to assess knowledge-related abilities, or crystallized intelligence. The letter factory, air traffic scenarios, and scan tests were used to assess abilities requiring processing speed, time-sharing, and fluid intelligence. The dial reading and analogies tests both contain elements of fluid and crystallized intelligence: both require use of existing knowledge as well as reasoning and processing. However, the processing speed and timesharing requirements of these two tests are limited. A description of each test is provided below.

**Applied Math.** This test contains 30 multiple-choice questions. The test presents five practice questions before the test begins. Questions such as the following are contained on the test: *A plane has flown for 3 hours with a ground speed of 210 knots. How far did the plane travel?* These questions require the subject to be able to factor in such things as time and distance in order to identify the correct answer from among the four answer choices. (Total Time: 30 minutes.)

**Angles.** The Angles test measures the subject's ability to recognize angles. This test contains 30 multiple-choice questions. There are two types of questions on the test. The first presents a picture of an angle and the subject chooses the correct size of the angle (in degrees) from among four response options. The second presents a measure in degrees and the subject chooses the angle (among four response options) that represents that measure. (Total Time: 10 minutes.)

**Letter Factory Test (LF).** This test simulates a factory assembly line that manufactures only four letters of the alphabet (A, B, C, and D) in one of three colors. The test has 18 sections and requires that subjects use a mouse to perform multiple and often concurrent tasks. Each test section begins with letters appearing at the tops of the conveyor belts moving down toward the loading area. Based on those letters, subjects immediately begin selecting and moving boxes to the loading area to provide just the right number and color of boxes to correctly place all letters. Other tasks performed during the simulated

factory settings include: (1) picking up letters of various colors, (2) ordering new boxes when supplies become low, and (3) calling Quality Control when defective letters appear. Each section lasts between 30 seconds and 2 1/2 minutes. The LF test produces two scores: LF situational awareness and LF planning and thinking ahead. (Total Time: 91 minutes.)

**Air Traffic Scenarios Test (ATST).** This is a low-fidelity simulation of an air traffic control (ATC) radar screen that is updated every seven seconds. The goal is to maintain separation and control of a varying number of simulated aircraft (represented as data blocks) within the designated airspace as efficiently as possible. Aircraft in flight can pass through the airspace or land at one of two airports within the airspace. Each aircraft's data block indicates its present heading, speed, and altitude. There are eight different headings representing 45 degree increments, three different speeds (slow, moderate, fast), and four different altitude levels (1=lowest and 4=highest). Separation and control are achieved by communicating and coordinating with each aircraft by using the computer mouse to click on the data block representing each aircraft and providing instructions such as changes to current heading, speed, or altitude. The ATST produces three scores: ATST Efficiency, ATST Safety, and ATST Procedural Accuracy. (Total Time: 95 minutes.)

**Scan.** In the Scan test, subjects monitor a field that contains discrete objects (called data blocks) which are moving in different directions. Data blocks appear in the field at random, travel in a straight line for a short amount of time, then disappear. During the test, the subject sees a blue field that fills the screen, with the exception of a 1-inch white bar at the bottom. In this field, up to 12 green data blocks may be present. Each data block contains two lines of letters and numbers separated by a horizontal line. The upper line is the identifier and begins with a letter followed by a 2-digit number. The lower line contains a 3-digit number. Subjects are scored on the speed with which they notice and respond to the data blocks that have a number on the lower line outside a specified range. Throughout the test, this range is displayed at the bottom of the screen (e.g., 360-710). To "respond" to a data block, the subject types the 2-digit number from the upper line of the block (ignoring the letter that precedes it), and then presses "enter." (Total Time: 18 minutes.)

**Dial Reading Test.** The Dial test is designed to test the subject's ability to quickly identify and accurately read certain dials on an instrument panel. Subjects are asked to choose from one of five response alternatives for each question about a given display. The test consists of 20 questions. Individual items are self-paced against the display of time left in the test as a whole. Subjects are advised to skip difficult items and come back to them at the end of the test. Each panel consists of seven dials in two rows, a layout that remains constant throughout the test. Each of the seven dials contains unique flight information. (Total Time: 12 minutes.)

**Analogies.** The Analogies test measures the subject's ability to apply the correct rules to solve a given problem as well as their efficiency in using the available information to solve that problem. Analogies are based on words, pictures, or figures and appear in three "windows" on the same screen for a given item. Subjects use a mouse to move freely between the three windows, view the different parts of the analogy, and select their answer. However, they can view only one window at a time. Window A presents the first part of the analogy that requires subjects to infer the underlying rule. Window B contains that second part of the analogy that requires subjects to apply the inferred rule. Finally, Window C provides subjects the opportunity to confirm their choice by selecting their answer from the available response options. The test has 57 items: 30 word analogies and 27 visual (i.e., either pictorial or figural) analogies. (Total Time: 45 minutes.)

## RESULTS

Pearson's product-moment correlations and hierarchical polynomial regression were used to test the hypotheses. Current ATCS age was positively correlated with many work-related variables, such as number of years as an FPL ATCS ( $r=.78$ ;  $p<.01$ ) and number of years in current position ( $r=.72$ ;  $p<.01$ ). As shown in Table 2, age was negatively correlated with scores on ATST Efficiency, ATST Safety, Analogies: Reasoning, LF Situational Awareness, LF Planning and Thinking ahead, and Scan.

Principal components analysis with varimax rotation was performed on all scores generated by the cognitive tests. Three factors were extracted, accounting for 60.1% of the variance. Loading of variables on factors, communalities, and percent of

variance are shown in Table 3. Loadings of .40 and above were used for interpretation of the factors. The tests that require the greatest amount of multi-tasking, perceptual speed, and fluid intelligence load together on the first factor. These tests are also presented in the form of dynamic computer situations or scenarios. The tests that predominately measure reasoning as well as use of existing knowledge load on the second factor. These tests do not require multi-tasking and may be classified as "page turner" computer tests. The ATST: Procedural Accuracy score loads alone on the third factor.

Hierarchical polynomial regression was used to assess the form of the relationship between age and cognitive test performance. For each cognitive test, age was entered into the regression equation first, followed by the age-squared (quadratic) term. If the relationship between age and cognitive test performance is primarily linear, then age alone should explain a significant proportion of the test score variance, and the quadratic term that is subsequently added should not account for a significant change in  $R^2$ . If the quadratic term explains a significant proportion of the variance beyond the age term, then there is evidence of a curvilinear relationship between age cognitive test performance.

Regression analyses were performed for each of the cognitive tests included in the study. Age did not significantly contribute to the prediction of the applied math score when entered into the regression equation. However, as shown in Table 4, the quadratic term, or age-squared, did contribute significantly when added ( $\Delta R^2=.016$ ,  $p<.01$ ; Adjusted  $R^2=.02$ ), providing evidence of a curvilinear relationship. This relationship is depicted in Figure 1. The regression of age on the angles score is depicted in Figure 2. This relationship is also curvilinear, as only the quadratic model produced a significant  $R^2$  change in predicting angles score ( $\Delta R^2=.011$ ,  $p<.01$ ; Adjusted  $R^2=.01$ ). The results of this analysis are summarized in Table 5. As demonstrated in Figures 3 and 4, the relationship between age and both the ATST efficiency and the ATST safety scores is linear. Only the linear model produced a significant change in  $R^2$  for ATST efficiency ( $\Delta R^2=.08$ ,  $p<.01$ ; Adjusted  $R^2=.07$ ), shown in Table 6, and ATST safety ( $\Delta R^2=.05$ ,  $p<.01$ ; Adjusted  $R^2=.05$ ), shown in Table 7. Both the linear and quadratic models failed to predict the ATST procedural accuracy score.

Both the linear and quadratic models contributed to the prediction of the analogies reasoning score. As shown in Table 8, when entered into the regression equation, age contributed significantly to the prediction of the analogies reasoning score ( $\Delta R^2=.01$ ,  $p<.01$ ; Adjusted  $R^2=.01$ ). The age-squared, or quadratic term, also contributed significantly when added ( $\Delta R^2=.02$ ,  $p<.01$ ; Adjusted  $R^2=.03$ ), suggesting that the relationship is best described as curvilinear. This relationship is depicted in Figure 5. Figure 6 shows that the relationship between age and the dial reading test score is best described as curvilinear, or quadratic. Only the quadratic term, age-squared, contributed significantly to the prediction of the dial reading score when entered into the regression equation ( $\Delta R^2=.01$ ,  $p<.01$ ; Adjusted  $R^2=.01$ ), as shown in Table 9.

Table 10 reveals that age contributed significantly to the prediction of LF situational awareness when entered into the regression equation ( $\Delta R^2=.07$ ,  $p<.01$ ; Adjusted  $R^2=.07$ ), although the quadratic term also produced a significant change in  $R^2$  when added to the equation ( $\Delta R^2=.01$ ,  $p<.01$ ; Adjusted  $R^2=.07$ ). The relationship between age and LF planning and thinking ahead is best explained by a linear model, as shown in Figure 8. As shown in Table 11, only the linear model produced a significant change in  $R^2$  when predicting the LF planning and thinking ahead score ( $\Delta R^2=.10$ ,  $p<.01$ ; Adjusted  $R^2=.10$ ). Table 12 shows that age contributed significantly to the prediction of the scan test score ( $\Delta R^2=.01$ ,  $p<.01$ ; Adjusted  $R^2=.01$ ), whereas the quadratic term did not. This indicates a linear relationship between these two variables, as shown in Figure 9.

## DISCUSSION

The results of the current study provide evidence of a negative relationship between ATCS age and performance on several measures of cognitive ability. Examination of the linear relationships between age and cognitive abilities suggests that older ATCSs have lower levels of performance on those tasks that require fluid intelligence and high levels of cognitive processing and multi-tasking. The ATST and letter factory test require high levels of awareness, time-sharing, prioritization, execution, scanning, planning, thinking ahead, tolerance for high intensity activities, perceptual speed and accuracy, decisiveness, and dynamic visual-spatial ability. These cognitive

abilities have been identified as the most relevant to the ATCS job (Nickels et al., 1995). The results suggest an age-related decline in those cognitive abilities that are most important to successful job performance.

It is interesting to note that no relationship was found between ATST: procedural accuracy and age. The ATST: procedural accuracy score also loads alone on its own factor. It may be that procedural accuracy is based less on fluid intelligence, since the procedures that must be followed remain the same regardless of the scenario. Both the safety and efficiency scores, however, depend upon quick assessment and response to new and increasingly complex situations and scenarios. The procedural accuracy score seems to reflect ability, or willingness, to follow procedures and does not necessarily tap into a specific knowledge or skill level. The negative correlations between scan and analogies reasoning, and age were low, despite being statistically significant. Although the Scan Test requires some of the same cognitive abilities as the ATST and Letter Factory Test, it is not as complex and does not require the same degree of multitasking.

Hierarchical polynomial regression revealed a curvilinear relationship between age and several of the cognitive tests, such as applied math, angles, analogies, letter factory situational awareness, and dial reading. Performance on these tests increased with age until ATCSs entered their mid- to late- 40s. This pattern is consistent with that found when investigating the relationship between ATCS age and indicators of job performance (Heil, 1999). Consequently, it seems that a decline in ATCS performance coincides with a decline in cognitive abilities relevant to the ATCS occupation. This decline occurs despite continued experience with time-sharing activities on the job, which is consistent with the findings of Tsang and Shaner (1998), who studied pilots. This does not mean that the older ATCSs are performing at an unacceptable level but, rather, that they are performing at a level that is lower than that of their younger colleagues.

### Limitations

There are limitations to this study that must be considered when reviewing the results and conclusions that are presented. All of the ATCSs who participated in this study were volunteers. It is likely that controllers uncomfortable with their level of

performance would choose not to participate. This is particularly likely for older controllers, since their average level of performance was generally found to be lower than that of other controllers (Heil, 1999). Consequently, the older ATCSs included in this study may represent the better performers from that particular age group, resulting in an under-estimation of the age-related decline in cognitive ability. It should also be noted that the R-squares generated during the regression analyses indicate that age does not explain a large percentage of the variance in cognitive test performance. Although the effect sizes are not large, the results of the regression analyses reveal a consistent trend in the relationship between age and cognitive test performance.

The cross-sectional approach of this study also creates limitations. Conclusions regarding changes in cognitive ability are based on the assumption that ATCSs possess ability levels that are relatively equal following training. Consequently, lower cognitive test scores among older ATCSs would be attributed to a decline in ability rather than to a lower level of ability throughout their career. One mitigating factor that must be considered is that the best performers are often promoted into supervisory positions. This means that the average cognitive test scores of older controllers may be lower because the “best” ATCSs of this age group are no longer actively controlling traffic. A longitudinal study of age, so that individuals are tracked throughout the course of their career, is the only way to determine the extent to which cognitive ability changes over time for an individual, the manner in which this change occurs, and its potential influence on job performance.

### Conclusion

Over the years, researchers have speculated about the possible causes of the decline in job performance with age (Cobb, 1968; Trites, 1961; Trites & Cobb, 1962). As the ATCS workforce ages and reaches retirement age, the actual job performance of older controllers becomes a more important issue. The results of the current study support the suggestion that declines in performance on simulations of air traffic control situations and experimental ratings may be associated with the age-related declines in cognitive ability and processing speed. One important question is whether or not there are ways to mitigate this age-related decline. Some researchers have speculated that age-related decline in actual job

performance might be delayed with experience (Becker & Milke, 1998; Heil, 1999; Salthouse, 1994; Schroeder et al., 1997; Tsang & Shaner, 1998). The extent to which this may be the case with the ATCS job should be further investigated.

### REFERENCES

- Becker, J.T., & Milke, R.M. (1998). Cognition and aging in a complex work environment: Relationships with performance among air traffic control specialists. *Aviation, Space, and Environmental Medicine, 69*, 944-51.
- Cobb, B.B. (1968). Relationships among chronological age, length of experience, and job performance ratings of air route traffic control specialists. *Aerospace Medicine, 39*, 119-24.
- Hardy, D.J., & Parasuraman, R. (1997). Cognition and flight performance in older pilots. *Journal of Experimental Psychology: Applied, 3*, 313-48.
- Heil, M.C. (1999). An investigation of the relationship between chronological age and job performance for incumbent air traffic control specialists. (DOT/FAA/AM-99/18). Oklahoma City, OK: FAA Civil Aeromedical Research Institute. Available from: National Technical Information Service, Springfield, VA 22161.
- Morrow, D. G., Menard, W.E., & Stine-Morrow, E.A.L. (1999). *The influence of aging and expertise on pilot communication*. Paper presented at the Tenth International Symposium on Aviation Psychology, Columbus Ohio.
- Nickels, B.J., Bobko, P., Blair, M.D., Sands, W.A., & Tartak, E.L. (1995). Separation and Control Hiring Assessment (SACHA): Final job analysis report. Washington, D.C. Federal Aviation Administration Office of Personnel.
- Salthouse, T.A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.
- Salthouse, T.A. (1994). Age-related differences in basic cognitive processes: Implications for work. *Experimental Aging Research, 20*, 249-255.

- Schroeder, D.J., Broach, D., & Farmer, W.L. (1997). Current FAA controller workforce demographics, future requirements, and research questions. *Proceedings of the Ninth Annual International Aviation Psychology Symposium, 1*, 135-41.
- Trites, D.K. (1961). *Problems in air traffic management: I. Longitudinal prediction of effectiveness of air traffic controllers*. (DOT/FAA/AM-61/1). Oklahoma City, OK: FAA Civil Aeromedical Research Institute. Available from: National Technical Information Service, Springfield, VA 22161; order # AD268954.
- Trites, D.K. & Cobb, B.B. (1962). *Problems in air traffic management: III. Implications of age for training and job performance of air traffic controllers*. (DOT/FAA/AM-62/3). Oklahoma City, OK: FAA Civil Aeromedical Research Institute. Available from: National Technical Information Service, Springfield, VA 22161; order # N62-10353.
- Tsang, P.S., & Shaner, T.L. (1998). Age, attention, expertise, and time-sharing performance. *Psychology and Aging, 13*, 323-47.
- VanDeventer, A.D., & Baxter, N.E. (1984). Age and performance in air traffic control specialist training. In VanDeventer, A.D., Collins, W.E., Manning, C.A., Taylor, D.K., & Baxter, N.E. Studies of poststrike air traffic control specialist trainees: I. Age, biographical factors, and selection test performance related to academy training success. (DOT/FAA/AM-84/6). Washington, D.C. Federal Aviation Administration Office of Aviation Medicine. Available from: National Technical Information Service, Springfield, VA 22161; order # ADA147892.
- Verhaeghen, P. & Salthouse, T.A. (1997). Meta-analyses of age-cognitions relations in adulthood: Estimates of linear and nonlinear age effects and structural models. *Psychological Bulletin, 122*, 231-249.

FIGURES

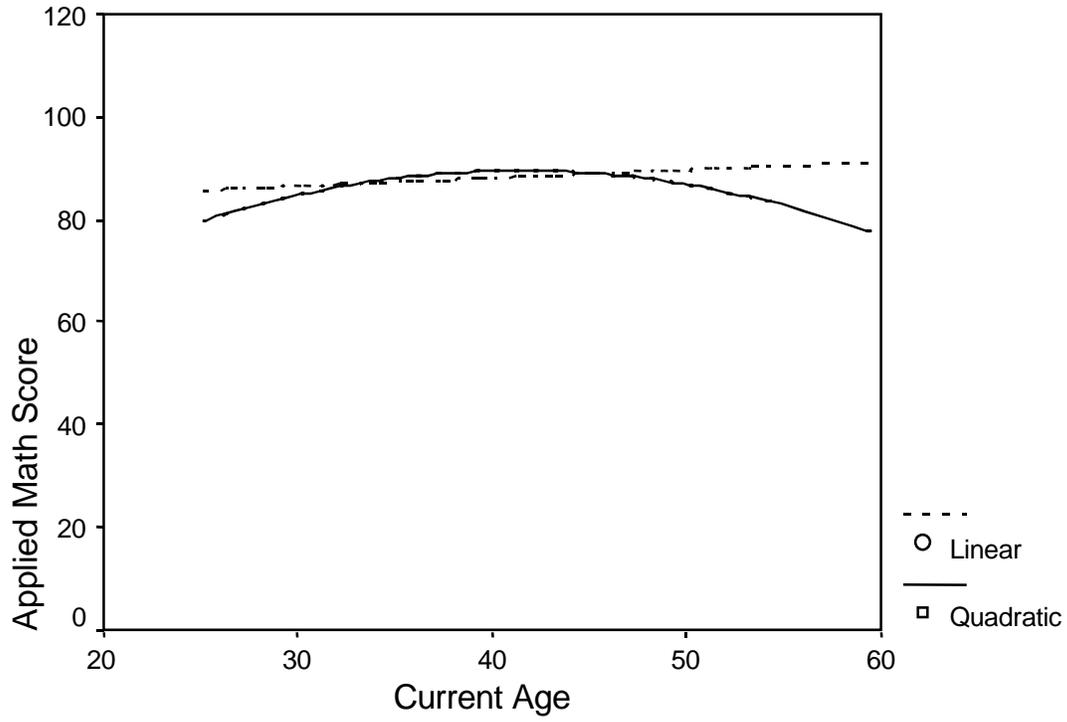


Figure 1. Regression of Current Age on Applied Math Score

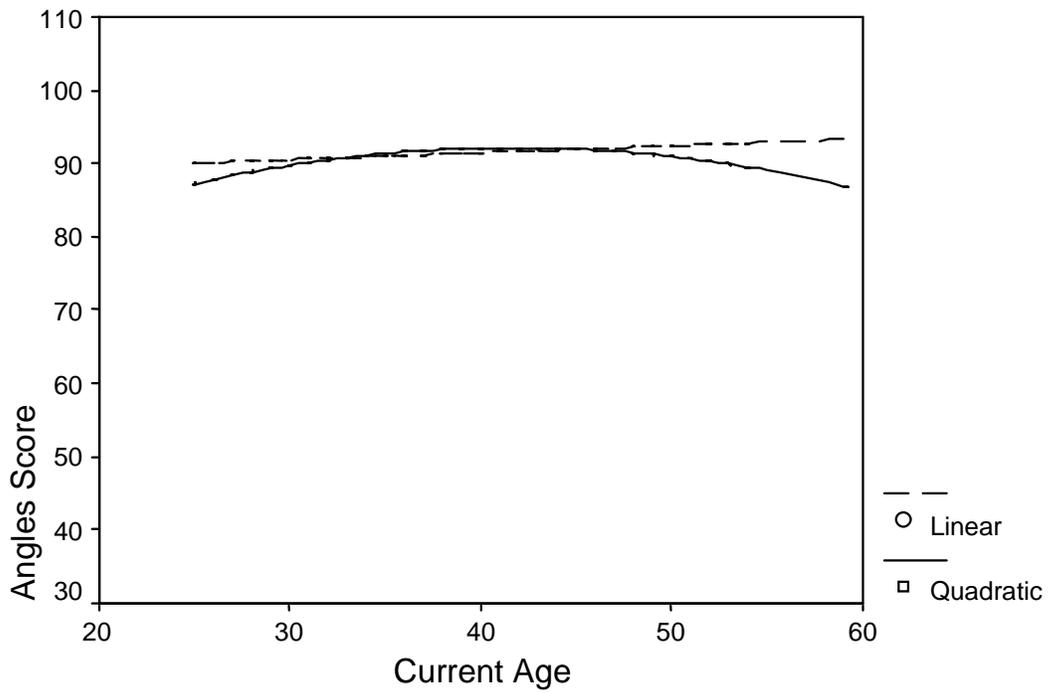
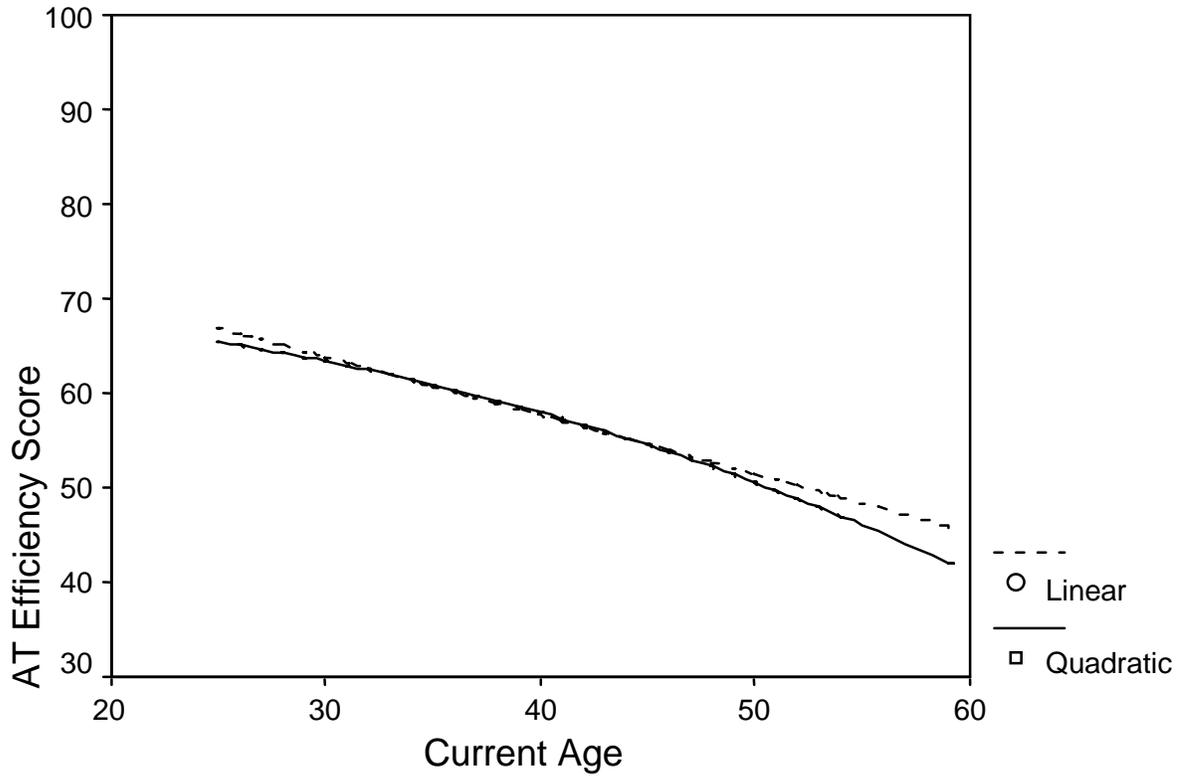
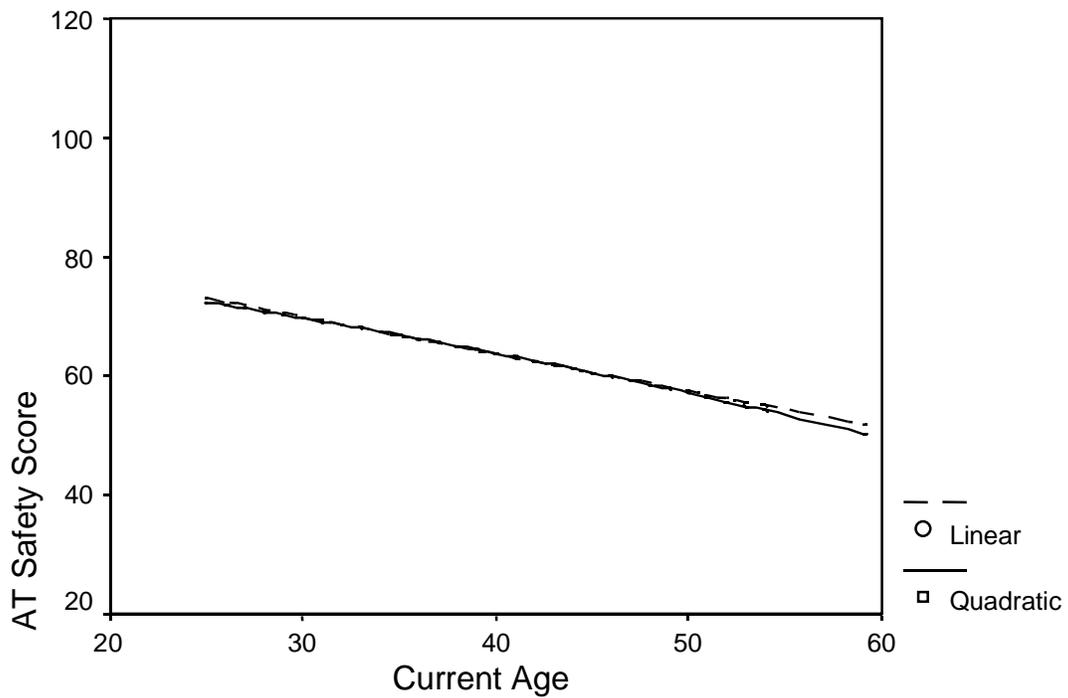


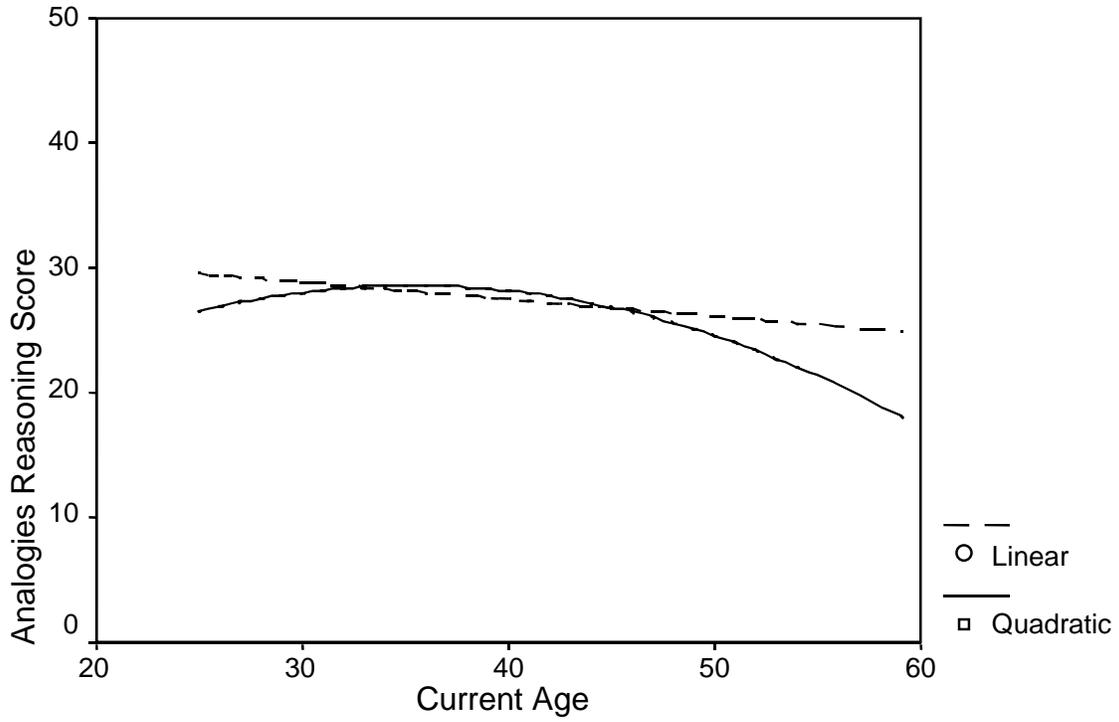
Figure 2. Regression of Current Age on Angles Score



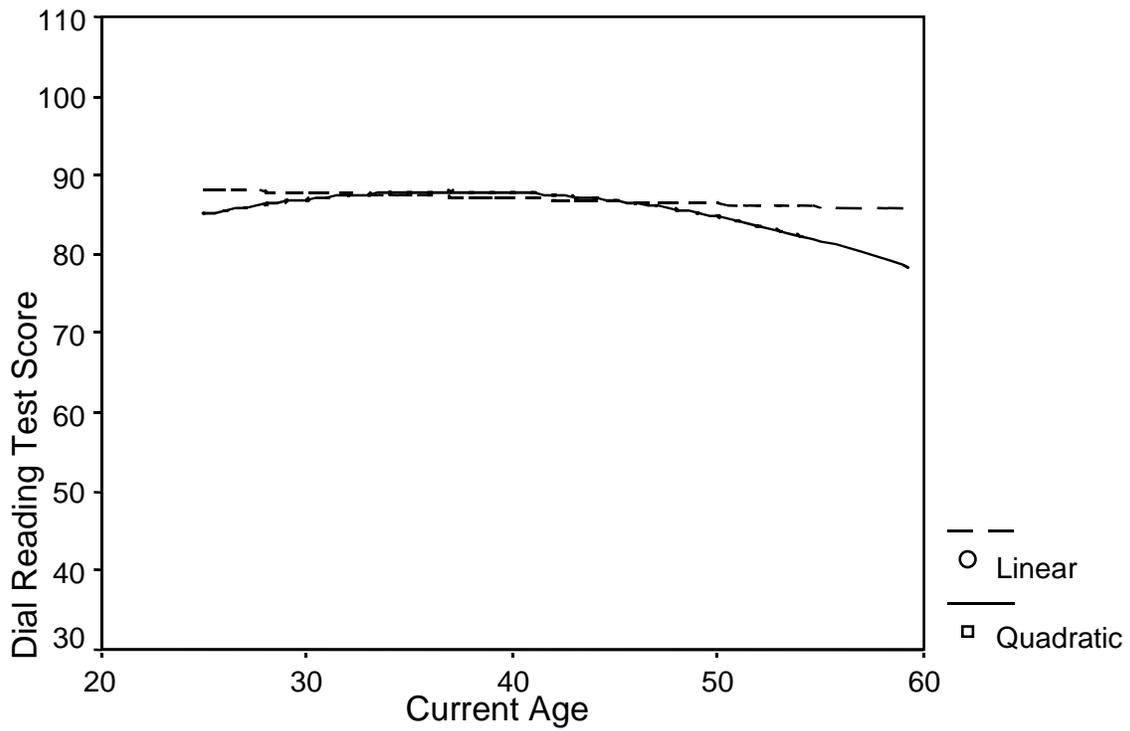
**Figure 3.** Regression of Current age on AT Efficiency Score



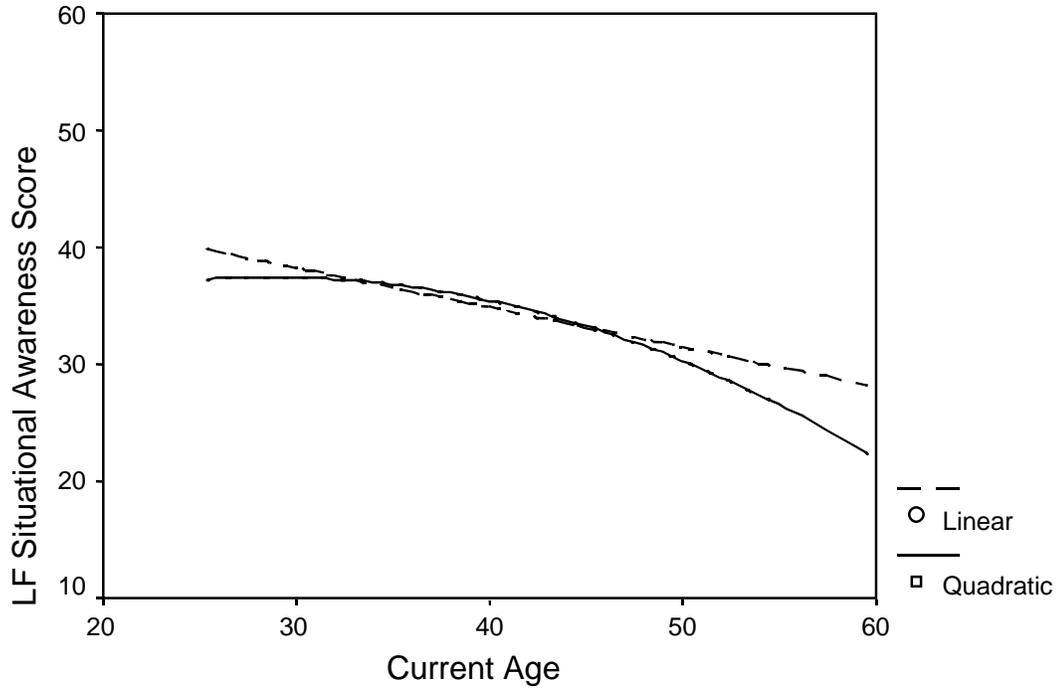
**Figure 4.** Regression of Current Age on AT Safety Score



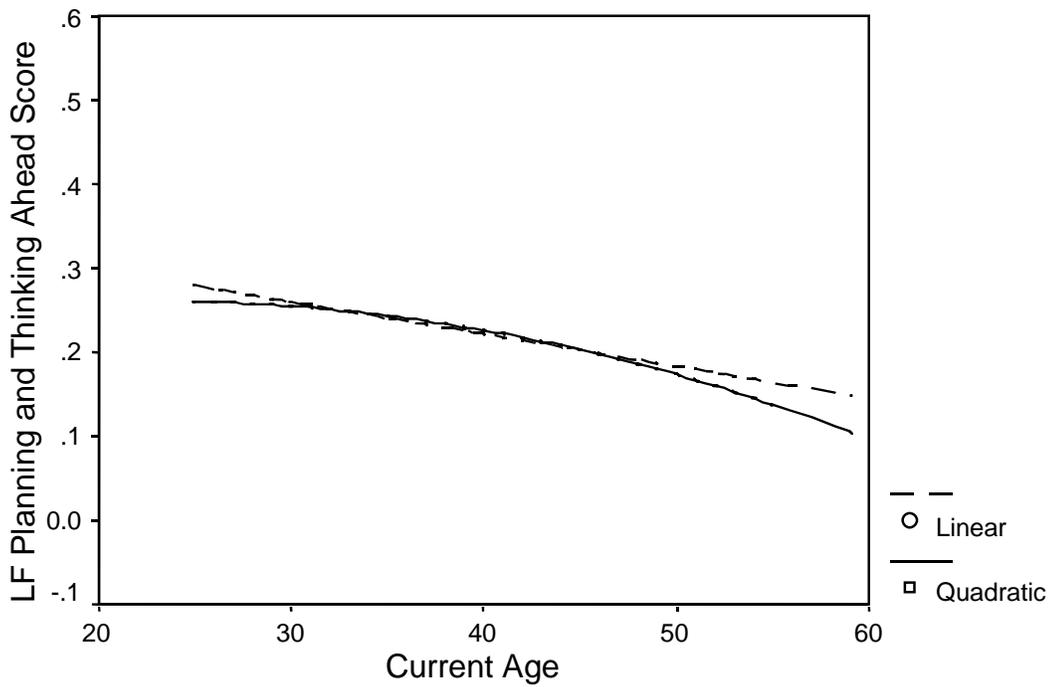
**Figure 5.** Regression of Current Age on Analogies Reasoning Score



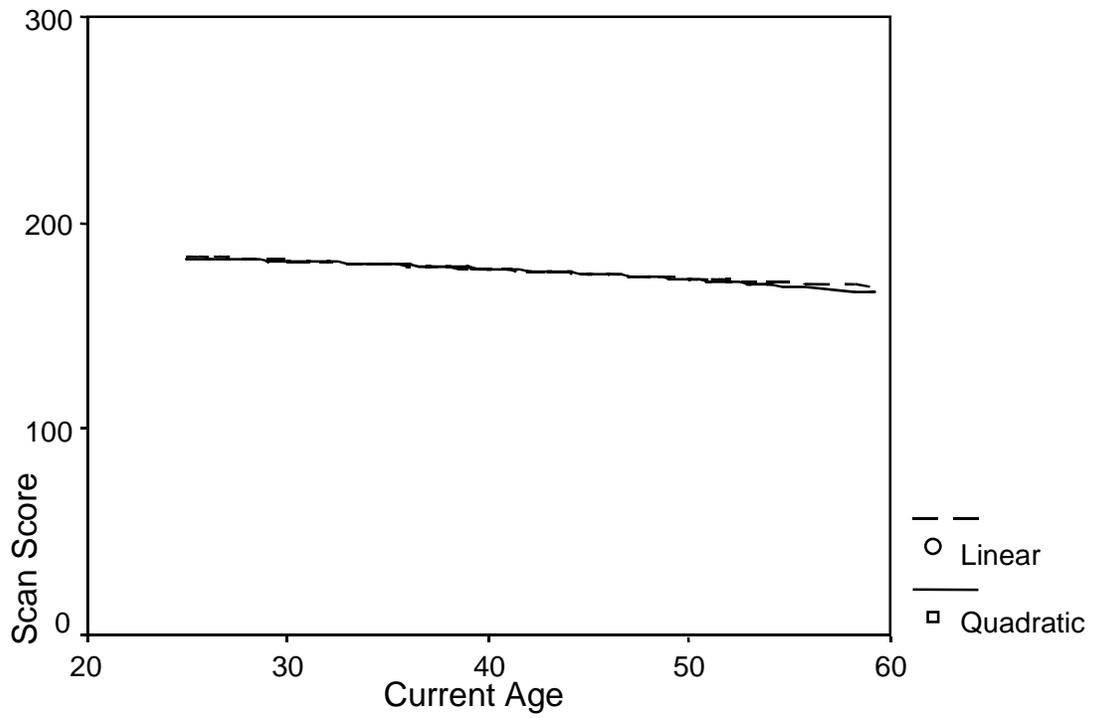
**Figure 6.** Regression of Current Age on Dial Reading Test Score



**Figure 7.** Regression of Current Age on LF Situational Awareness Score



**Figure 8.** Regression of Current Age on LF Planning and Thinking Ahead



**Figure 9.** Regression of Current Age on Scan Score

TABLES

**Table 1. Demographics**

Variable	Number	Percent
<b>Current Age</b>		
31 or Younger	144	17.5
32-37	391	47.6
38-43	197	24.0
44-49	59	7.2
50 or greater	30	3.7
<b>Gender</b>		
Male	690	83.3
Female	138	16.6
<b>Race</b>		
American Indian	17	2.1
Asian/ Pacific Islander	5	0.6
African American	36	4.3
Hispanic	33	4.0
White	731	88.1
Other	6	0.7
<b>Education</b>		
H.S. or GED	68	9.1
Attended Trade School	3	0.4
Completed Trade School	15	2.0
Attended College less than 2	165	22.1
Attended College 2 or more	179	23.9
Completed College, 2 yr.	55	7.4
Completed College, 4 yr.	225	30.1
Attended Graduate School	38	5.1

**Table 2. Correlation of Age and Cognitive Test Scores**

Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
1. Current Age	36.4	5.7	1.0										
2. Applied Math	88.2	13.7	.07	1.0									
3. Angles	91.1	8.14	.06	.47*	1.0								
4. ATST: Efficiency	60.0	12.1	-	.24*	.17*	1.0							
5. ATST: Procedural Accuracy	70.1	14.7	-.04	.07	.07	.12*	1.0						
6. ATST: Safety	66.0	14.6	-	.15*	.08	.72*	.06	1.0					
7. Analogies: Reasoning	28.0	6.5	-.01	.46*	.37*	.19*	.00	.19*	1.0				
8. Dial Reading	87.4	9.0	-.05	.35*	.30*	.10*	.05	.04	.29*	1.0			
9. LF: Situational Awareness	36.5	7.3	-	.30*	.19*	.34*	.05	.29*	.40*	.17*	1.0		
10. LF: Planning & Thinking Ahead	.24	.07	-.01	.25*	.19*	.51*	.03	.43*	.32*	.13*	.54*	1.0	
11. Scan	179.1	23.2	-	.09	.11*	.21*	.06	.16*	.22*	.07	.20*	.27*	1.0

\* p<.01

**Table 3.** Factor Loadings, Communalities, and Percent of Variance for Principle Components Analysis of AT-SAT Cognitive Tests.

Test	Factor			$r^2$
	1	2	3	
ATST: Efficiency	<b>.83</b>	.04	.24	.75
ATST: Safety	<b>.81</b>	.07	.19	.70
LF: Planning and Thinking Ahead	<b>.77</b>	.20	-.10	.64
LF: Situational Awareness	<b>.59</b>	.34	-.16	.50
Scan	<b>.40</b>	.13	-.11	.19
Applied Math	.19	<b>.76</b>	.05	.61
Angles	.07	<b>.73</b>	.09	.55
Dial Reading	.05	<b>.66</b>	.07	.44
Analogies: Reasoning	.31	<b>.67</b>	-.21	.59
ATST: Procedural Accuracy	.03	.11	<b>.91</b>	.84
Percent of Variance	32.1	17.8	10.2	

**Table 4.** Regression of Current Age on Applied Math Score

Variable	B	$\beta$	$\Delta R^2$
Current Age	3.03	1.22	.004
Current Age <sup>2</sup>	-.04	-1.16	.016**
			$R^2=.02$
			Adj. $R^2=.02$
			$R=.14^{**}$

\*\* $p<.01$

**Table 5.** Regression of Current Age on Angles Score

Variable	B	$\beta$	$\Delta R^2$
Current Age	1.46	.99	.004
Current Age <sup>2</sup>	-.02	-.94	.011**
			R <sup>2</sup> =.02
			Adj. R <sup>2</sup> =.01
			R=.12**

\*\*p&lt;.01

**Table 6.** Regression of Current Age on AT Efficiency

Variable	B	$\beta$	$\Delta R^2$
Current Age	.13	.06	.08**
Current Age <sup>2</sup>	-.01	-.34	.00
			R <sup>2</sup> =.08
			Adj. R <sup>2</sup> =.07
			R=.27**

\*\*p&lt;.01

**Table 7.** Regression of Current Age on AT Safety

Variable	B	$\beta$	$\Delta R^2$
Current Age	-.30	-.11	.05**
Current Age <sup>2</sup>	.00	-.12	.00
			R <sup>2</sup> =.05
			Adj. R <sup>2</sup> =.05
			R=.23**

\*\*p&lt;.01

**Table 8.** Regression of Current Age on Analogies Reasoning

Variable	B	$\beta$	$\Delta R^2$
Current Age	1.33	1.14	.01**
Current Age <sup>2</sup>	-.02	-1.26	.02**
			R <sup>2</sup> =.03
			Adj. R <sup>2</sup> =.03
			R=.18**

\*\*p&lt;.01

**Table 9.** Regression of Current Age on Dial Reading Test

Variable	B	$\beta$	$\Delta R^2$
Current Age	1.46	.90	.00
Current Age <sup>2</sup>	-.02	-.95	.01**
			R <sup>2</sup> =.01
			Adj. R <sup>2</sup> =.01
			R=.11

\*\*p&lt;.01

**Table 10.** Regression of Current Age on LF Situational Awareness

Variable	B	$\beta$	$\Delta R^2$
Current Age	.90	.69	.07**
Current Age <sup>2</sup>	-.01	-.95	.01**
			R <sup>2</sup> =.08
			Adj. R <sup>2</sup> =.07
			R=.28**

\*\*p&lt;.01

**Table 11.** Regression of Current Age on LF Planning and Thinking Ahead

Variable	B	$\beta$	$\Delta R^2$
Current Age	.00	.45	.10**
Current Age <sup>2</sup>	.00	-.76	.00
			R <sup>2</sup> =.10
			Adj. R <sup>2</sup> =.10
			R=.32

\*\*p&lt;.01

**Table 12.** Regression of Current Age on Scan

Variable	B	$\beta$	$\Delta R^2$
Current Age	.19	.04	.01**
Current Age <sup>2</sup>	.00	-.15	.00
			R <sup>2</sup> =.01
			Adj. R <sup>2</sup> =.01
			R=.10**

\*\*p&lt;.01

