RELATIONSHIP OF INDIVIDUAL PILOT FACTORS

TO SIMULATED FLIGHT PERFORMANCE

by

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This thesis is dedicated to the memory of my father Jarnail Singh, PhD

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Abstract

Introduction: Requirements for greater cognitive skills have increased with expanding complexity of aircraft and the flying environment. The aim of this research was to investigate the relationship of age, cognition, education, experience, and income to simulated flight performance in general aviation pilots.

Method: Fifty-four pilots, aged 21 to 79 years, flew a Cessna 172 simulator in low and high workload conditions. Flight performance was determined by altitude, heading, and speed deviations on the downwind portion of the "perfect" circuit. CogScreen-AE, a computerized cognitive battery, was used to measure pilot working memory, processing speed, and visual tracking.

Results: In the low workload condition, older pilots did not perform as well as the younger pilots, r = -0.406, p = 0.002. In the high workload condition, there was a trend for older pilots not to perform as well as younger pilots but this was not significant, r = -0.253, p = 0.065. Significant contributions by working memory, visual tracking, and expertise determined flight performance in the low workload condition model, F = (8, 45) = 6.457, R^2 = 0.496, p < 0.001. In the high workload condition, experience was the only significant contributor with working memory and processing speed adding variance to the model, F = (9, 44) = 2.627, R^2 = 0.350, p = 0.016. Logistic Regression Probability Value (LRPV), a value obtained from the CogScreen-AE and often used to determine flight performance, correlated significantly in the high difficulty condition only but was not predictive of significant variance in the final linear regression model. Secondary analysis showed expertise had an enhancing effect in moderating between working memory and flight performance.

Conclusion: This study revealed working memory, processing speed, tracking abilities as well as expertise and age are some of the factors influencing general aviation flight performance in varied conditions. LRPV which is used as an indicator for flight performance was not a predictive factor for general aviation pilots.

Keywords: general aviation, pilots, CogScreen-AE, flight performance, working memory, processing speed, tracking, experience, age

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List of Abbreviations and Acronyms

ACE ....Advanced Cognition Engineering

AE.................. Aeromedical Edition

Air MIDAS.......Air Man-Machine Integration Design and Analysis System

AOPA............. Aircraft Owners and Pilots Association

ASI .... Air Safety Institute

ASF .... Air Safety Foundation

AsMA .... Aerospace Medical Association

ATC................ Air Traffic Control

BEA................ Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile – France

CAMA............ Civil Aviation Medical Association

CAMI .... Civil Aviation Medical Institute

CFA................Confirmatory Factor Analysis

CRA .... Canada Revenue Agency

DTIC............... Defense Technical Information Centre – U.S.

FAA................ Federal Aviation Administration

GA .... General Aviation

GPS................ Global Positioning System

IFR .... Instrument Flying Rules

FA...................Factor Analysis

fMRI .... functional Magnetic Resonance Imaging

KMO...............Kaiser-Meyer-Olkin

LRPV...............Logistic Regression Probability Value

MFD .... Multi-Function Display

MSA................Measure of Sampling Adequacy

NASA.............. National Aeronautics and Space Administration

NTSB............... National Transportation Safety Board

PFC................. Prefrontal Cortex

PIC..................Pilot-in-Command

PS .... Processing Speed

RMSE.............Root Mean Square Error

SFP .... Simulated Flight Performance

TC................... Transport Canada

TSB .... Transport Safety Board of Canada

U.S................. United States

VFR................. Visual Flying Rules

VHF .... Very High Frequency

VSIM............... Visualization and Simulation (Centre)

WCST.............. Wisconsin Card Sorting Test

WM .... Working Memory

WOMBAT.......Wonderful Original Method for Basic Airmanship Testing

Glossary

Aviator/Pilot. This is someone who "operates the flying controls of an aircraft" (Canadian Oxford, 2004, p. 1178).

Cognition. Cognition is the "mental faculties of perception, thought, reason, and memory" (Canadian Oxford, 2004; p. 297) and can be measured by the results obtained upon completion of the battery of tasks on CogScreen - AE (Aeromedical Edition) (Kay, 1995).

Experience. This is the composite of: (a) number of hours flown in the last year as pilot-in-command (PIC), (b) total hours flown, (c), rating, and (d) the total number of simulation hours.

General Aviation (GA). GA refers to "all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire" (TC, 2012).

Processing Speed. Speed of processing information can be measured by the reaction time and time taken to complete a task on the cognitive measures performed using the CogScreen-AE battery.

Root-Mean-Square-Error (RMSE). RMSE is calculated by obtaining the difference between the "perfect value" for altitude, heading, and speed and the actual value obtained and then squaring this difference to remove directionality. Then the square root is taken of this value. A higher RMSE value denotes larger error or greater deviation from the desired altitude, speed, and heading.

Simulated Flight Performance (SFP). SFP is the composite of the root mean square error on the downwind leg of the circuit for: (a) altitude, (b) speed, and/or heading. This will be expanded further in the methodology section.

Visual Tracking. Tracking is the ability to move eyes accurately, smoothly, and efficiently (C. Chant[1], personal communication June 30, 2014; DeHart & Davis, 2002) and tracking data can be obtained from the cognitive tasks related to tracking measures obtained from the CogScreen-AE battery.

Working Memory. Working memory is memory used to process information and can be measured by the accuracy cognitive tasks performed using the CogScreen-AE battery.

[1] Dr. C. Chant, optometrist.

1 Introduction

1.1 Background

The Wright brothers developed the first powered airplane, the Wright Flyer, which Orville Wright flew on December 17, 1903 (Wright, 1988). Since then, the complexity of the cockpit and the flying environment has increased significantly for general aviation (GA) pilots especially since the advent of the digital era (FAA, 2003; Schultz, 2011). Such complexities can have undesirable consequences on flight safety when task demands exceed capacity and thus requiring greater degree of cognitive ability on behalf of the pilot. However, cognitive abilities vary considerably between individuals regardless of chronological age (Reed et al., 2010) and this variability in cognitive function is most noticeable in older individuals (Salthouse, 2007). Alongside the age and cognition linkage, expertise has been noted to affect cognition (Zatorre et al., 2012) as well as buffering age effects (Ericsson et al., 1993). The age where expertise no longer has a moderating effect and cognition declines is not known but one can speculate that these declines may not be significant until decompensation begins (Diehr et al., 2002; Gerstorf et al., 2013).

1.2 Context for the Study

Research examining GA flying performances to various pilot factors was initiated approximately 10 years ago at the Advanced Cognition Engineering Laboratory (ACE Lab) at Carleton University. At that time, a local flying club's instructors were concerned about "something not being quite right" with some of the club's longstanding GA pilots and their handling of aircraft. Over the last decade, in pursuit of answers, this research theme developed from studies involving basic table top computer exercises to sophisticated research designs using a Cessna 172 non-motion simulator. This exemplifies the ideals of research where a question/concern is raised in the community and linkages developed with academic research institutions to answer the questions. Meeting with the flying club's manager was most helpful in understanding and linking the past, present, and ongoing research (S. Garrett, personal communication, November 23, 2011).

Examining similar and broader concerns in the aviation community reveals that over the last decade in the United States (U.S.), GA accidents account for approximately 90% of all civilian accidents and about 90% of the GA accidents occur during personal (74%) or instructional (16%) flying (AOPA ASF, 2003; AOPA ASI, 2013). Similar statistics regarding GA have been found in other countries: Australia (Lenne et al., 2008), Canada (TSB, 2008; TSB, 2012), France (BEA, 2000), and Germany (Dambier & Hinkelbein, 2006). Further analysis of accidents obtained through the National Transportation Safety Board (NTSB) showed pilot error was higher for GA accidents at 85% than the 38% for major airline accidents (Li et al., 2001). With the ultimate goal of increasing flight safety, researchers have tried to define the role and relative impact of factors that might contribute to a pilot's flying performance.

Research with respect to age in airline pilots has been limited in the past due to The Age 60 Rule, which prevented airline pilots from flying for airlines past their 60th birthday (AsMA, 2004; Cornell et al., 2007; Schroeder et al., 2000). As a consequence, historically commuter, air taxi, and general aviation pilots have been used as proxy subjects.

Issues affecting GA pilots merits attention in their own realm as the number of GA pilots exceeds those of professional pilots. In Canada, in 2011, approximately 37,000 medical certificate holders were private and recreational pilots as compared to approximately 24,000 professional pilots. As seen from Table 1, the largest increase of recreational and private pilots is in the greater than 65 year category of pilots (R. Schobesberger – Transport Canada, personal communication, July 3, 2013). Before and particularly after retirement, many professional/military pilots (Gillis et al., 2001) continue to fly in the GA group and thus further increasing the older class of pilots (Bruckart, 1992).

Table 1

Aeroplane Licence Holders in Canada

Pilots	Sept 2001		July 2, 2013	
	60–64year	> 65 years	60–64year	> 65 years
GA - Recreation & Private	2,015	2,861	2,437	3,994
Professional	575	437	1,106	1,134

Note: GA = general aviation

Experience and its constituents as well as age are continuing to be areas of research and interest to the aviation community (Adams & Ericsson, 1992; AOPA ASI, 2013). Another area of interest has been in neuropsychological/cognitive testing but the available testing specifically designed for pilots is focused on airline/commercial pilots and not GA pilots (Kay, 1995; CAMA, 2011). Such testing applied to GA pilots, especially in the U.S. by the FAA, has led to “push back” from pilots and medical examiners as being not appropriate for GA (CAMA, 2011).

Age, cognition, and experience may predict flight performance but other factors may also be predictive, such as motivation or personality characteristics (Salthouse, 2004), health, and medication (Brady et al., 2005). Other factors such as reasoning (Causse et al., 2011), interference control (Taylor et al., 2005), and situation assessment (Wiegmann et al., 2002) have been found to be positive predictors of simulated flight performance in GA pilots.

Education and income have been linked to better health (WHO, 2013), higher cognitive abilities (Scarmeas & Stern, 2003), greater achievement but also stress (Evans & Schamberg, 2009). Although it may be ideal to study all these factors, it is not feasible to study all of these factors in one small study with limited time constraints and limited financial resources.

It can be difficult to fully evaluate the perimeters of flight performance of aviators in the real world under extreme conditions. Simulator evaluation allows performance to be tested at its limits by allowing additional tasks to be loaded on the pilot without affecting flight safety. Thus a simulator provides an effective research tool and environment to assess pilot performance (Valent Clairi et al., 2002).

Research examining age, cognition, experience as well as other factors affecting flight performance in GA pilots is garnering greater attention from the number of recent studies with GA pilots (Bazargan & Guzhva, 2011; Causse et al., 2011a; O'Hare et al., 2010; Taylor et al., 2005; Yesavage et al., 2011). The varied and demanding operating environment and the technically advanced GA aircraft continue to be a concern for GA safety both at a local and global aviation community level (FAA, 1999, 2003; S. Garret, personal communication, November 23, 2011). Thus, the purpose of this research was to explore the relationship of individual pilot factors to flying performance in a simulated task environment. The specific aim was to determine which of the following factors: age, cognitive abilities, education, experience, and income played any significant role in a GA pilot's flight performance.

1.3 Research Question

The research question for this study was: What is the relationship of age, cognition, education, experience, and income to simulated flight performance (SFP) in general aviation pilots in low and high workload conditions? See *Figure 1* for a schematic representation.

1.4 Hypotheses

1. Aviators with increasing age will tend to have lower levels of SFP.
2. Aviators with higher levels of cognition will tend to have higher levels of SFP.
3. Aviators with higher levels of experience will tend to have higher levels of SFP.
4. Aviators with higher levels of education and income will tend to have higher levels of SFP.

1.5 Model Formulation

"A picture paints a thousand words". Similarly it would be valuable if all individual pilot factors and their relationship to flight performance could be depicted in a *picture* or a model, summarizing the research. The research examined each factor and its unique association to flight performance prior to examining them collectively. Figure one is a visual representation of such a model of the relationships of the individual pilot factors to simulated flight performance being examined in this study.

This study examined these relationships to determine the eventual appearance of the final model.

1.6 Assumptions

Cognition is an entity that can be measured by neuropsychological testing. Aviation experience also can be measured by the summation of a pilot's recognized proficiencies and under study conditions simulator performance will reproduce a pilot's usual performance.

1.7 Independent Variables

1.7.1 Age and Cognition

Age itself only tells "the length of time a person or thing has existed" (Canadian Oxford, 2004; p. 24), but it is the basic knowledge of the *ageing* process, "the time-dependent functional decline that affects most living organisms" (Lopez-Otin, et al., 2013; p.1194) that can lead one to make assumptions about age. The ability to determine normal, accelerated or delayed ageing and the frequency of these changes during a lifetime is not known (Gerstorf et al., 2013; Lopez-Otin et al., 2013). Age-related performance deterioration (ageing) and cognition are two variables that are considerably difficult to quantify due to the great variability that exists in individuals and the interaction between the body and the mind (Mather, 2010). Thus, this research did not focus on wellness, primary/biological ageing – *healthy ageing* (Anstey et al., 1993; Hayflick, 2007) or secondary ageing, process related to disease affecting the ageing process and cognition (Hayflick, 2007; van Boxtel, 1998), but focused on age as a simple chronological variable.

Cognitive abilities were measured by the neuropsychological battery known as the CogScreen-AE (Aeromedical Edition). The results from the testing are provided as comparisons to normative data obtained from airline/commercial pilots. It was not the intention of this study to compare GA pilots to airline/commercial pilots. Thus the normative comparisons were not used but the raw data to analyse the relationship of cognition to flight performance for GA pilots. This will be discussed in greater detail in the Literature Review and Methodology section.

1.7.2 Education, Income, and Experience

Education and income are independent variables in this research that can be easily quantified. Experience also has concrete, measureable entities such as hours flown or years licensed but determining which of these quantifiable measures are consistent predictors is not always an easy task. Furthermore, there can be difficulties in trying to separate the passing of time in ageing versus the attainment of experience. Experience and its constituents will be elaborated further in the Methodology section.

1.8 Limitations

1. Greater arousal or stress can be created by a new environment or technology (Polit & Hungler, 1987). All possible efforts were made to obviate any confounding factors but some were unavoidable.

2. In any study, there will be more factors affecting the results than can be controlled (Wickstrom & Bendix, 2000). In this study documentation of personal health issues did not occur. Therefore, ill health or absence of good health may impact on cognition and other effects of ageing.

3. Many other factors can influence an individual pilot's performance. Health was excluded, even though it is well recognized that ill health adversely affects a range of human performance parameters. This study focused on flight performance with health status inquiry and testing of health related human issues not appropriate in the setting of this study.

4. The limitations mentioned above pertain mainly to the performance of the participants. A more extensive examination of the methodological limitations of this research will be undertaken in the Discussion section.

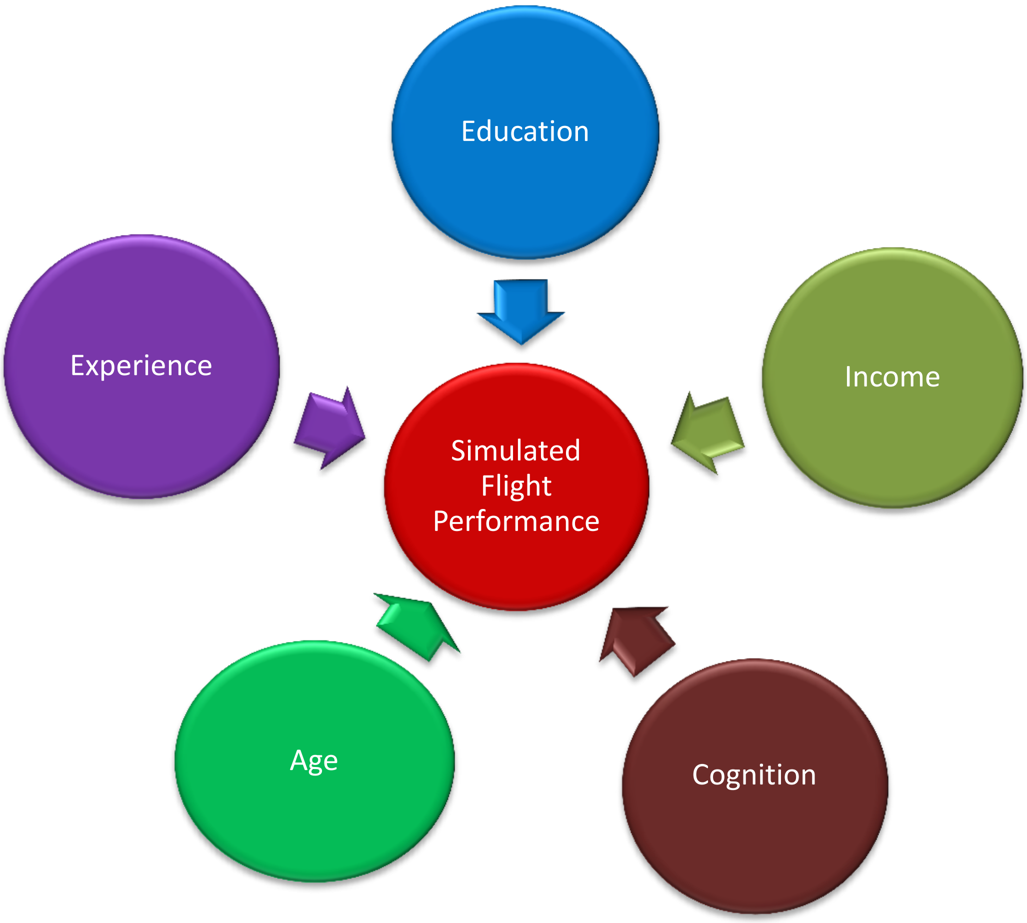

Figure 1. **Relationship of individual pilot factors to simulated flight performance.**

2 Literature Review

2.1 Narrative Review: Approach and Strategies

The purpose of this narrative review was to review studies pertaining to the hypothesis: relationships between age, cognition, education, experience, and income to flight performance in general aviation pilots as well as looking at selected key references pertaining to age and cognition. The research strategy utilized the databases from PubMed and Google Scholar with the key words from the hypothesis (e.g. age and flight performance, cognition and flight performance) with the filters "full text available" and "humans", and "English". Substituting general aviation pilots for flight performance enhanced the search. Other key words used were: CogScreen-AE, working memory, processing speed, tracking, biological ageing, primary ageing, secondary ageing, and the multiple-component model.

Other strategies were to examine the reference lists of the selected papers for any previously non-identified articles. Also explored were the websites for the Federal Aviation Administration (FAA), Transport Canada (TC), National Transport Safety Board (NTSB-U.S.), Transport Safety Board (TSB-Canada), American Owners and Pilots Association (AOPA), Canadian Owners and Pilots Association (COPA), and Defense Technical Information Centre (DTIC) – technical reports. Research colleagues and supervisors also provided valuable leads to relevant information.

This literature search highlighted: (1) historical significance of some of the events and research and (2) the limited number of research articles on the topic. The following narrative literature review briefly examined the historical perspective and events in aviation with emphasis of their outcomes on general aviation. A brief examination of ageing and cognition is presented to assist in understanding the pilot studies. Each pilot factor is then examined followed with a look at the neuropsychological tool and concluding with the conceptual framework and models.

2.2 Historical Background

The evolution of aircraft technology and aviation systems has changed the demands on aviators from being mainly oriented to physical and perceptual-motor skills to being largely dependent on greater cognitive skills and higher executive functions (Hardy & Parasuraman, 1997; Van der Velde, 2005).

Even those who fly aircraft with conventional instrumentation have through the years had to learn to deal with added technologies in the cockpit, such as: Automatic Direction Finder, Very High Frequency (VHF) Omni-Directional Range, Instrument Landing System, autopilot, the increasingly popular Global Positioning System, and most recently the iPad.

New technologies are continuously evolving in production, materials, electronics, and propulsion which are considered “the foundation stones of the future development of aviation” (Tsach et al., 2004; p.5). Today, in general aviation (GA), the modern Cessna

172, a much utilized GA trainer, has the Garmin G1000® avionics (Cessna, 2014), *Figure 2*. This technology known as the "glass cockpit" has replaced most conventional flight instruments and avionics in many of the newly manufactured GA aircraft, *Figure 3*. Even air traffic controller-to-pilot data link communications system (CPDLS) for Small Aircraft Transportation System (SATS) has been envisioned by FAA and NASA (National Aeronautics and Space Administration) – replacing voice communications with text messages (Lancaster & Casali, 2008).

***Figure 2*. Garmin G1000®** (Boyer, 2006).

The increasing sophistication, especially since the digital age, of both the environment and instruments places greater flying task demands on the GA aviator. The benefits and drawbacks of new technologies have been recognized by the FAA (2003); “This emerging category of GA aircraft present new safety opportunities that could enhance GA safety, but it also offers new safety challenges.” (p. 9). Some of the aircraft used by GA have been labelled *Technically Advanced Aircraft* and have many of the features that were once only found on commercial aircraft such as: “IFR-certified GPS navigation equipment (navigator) with moving map; a multi-function display (MFD) with weather, traffic or terrain graphics; or an integrated autopilot.” (FAA, 2003; p.9). The GA aviator now not only needs to know how to monitor and supervise the instruments and controls but also know how to skillfully detect, diagnose, determine future automation behaviour while dealing with malfunction problems (Bainbridge, 1983; Olsen & Sarter, 2001) without being affected by *automation bias* (Merlin et al., 2011). Thus for the GA aviator, new technologies can make flying safer but the use of these technologies requires additional “competence in flying …the ‘Mental Airplane’…” (FAA, 2003; p. 20).

Figure 3. **New and Old** (Boyer, 2006).

2.3 Biological Ageing – Healthy Ageing

While "chronological age is only an index of the passing of time" (Birren & Fisher, 1995; 347-8); ageing leads to functional decline over time (Lopez-Otin et al., 2013). Some of the normal physical declines noted over time are: visual acuity, hearing, grip strength (Gerstorf et al., 2013), and sleep disturbances (Cooke & Ancoli-Israel, 2011). (Cognition will be discussed in the next section.)

Nine hallmarks of the ageing process have been identified by Lopez-Otin et al. (2013): (I) Primary hallmarks: genomic instability, telomere attrition, epigenetic alterations, loss of proteostasis, (II) Antagonistic hallmarks: deregulated nutrient-sensing mitochondrial dysfunction, cellular senescence, and (III) Integrative hallmarks: stem cell exhaustion and altered intercellular communication. It is the relatedness of these hallmarks that likely determines the process of ageing, leading to structural brain changes throughout one's life (Fjell & Walhovd, 2010). In another words the "molecular fidelity ultimately exceeds repair and turnover capacity and increases vulnerability to pathology of age-associated diseases" (Hayflick, 2007; p. 4). It is at this time period where biological ageing would be distinguished from secondary ageing occurring from the effects of disease(s) and/or environment (Anstey et al., 1993).

2.4 Cognition

Cognition has been defined as the "mental faculties of perception, thought, reason, and memory" (Canadian Oxford, 2004; p.297). These executive functions along with focus of attention occur in the prefrontal cortex (PFC). The integrity of the PFC can be jeopardized as noted in immediate recall by diseases such as hypertension leading to accelerated white matter shrinkage especially if hypertension is uncontrolled (Brady et al., 2005; Raz et al., 2005) as well as diabetes and chronic bronchitis (van Boxtel et al., 1998).

2.5 Age and Aviation

There is limited and contradictory evidence of age affecting pilot performance. As life expectancy increases more people are obtaining pilot licences at a later age and thus more pilots are retaining the private pilot licences to a later age (Table 1). This is of interest to aviation organizations and regulatory bodies alike that now have interactions with a larger and older group of pilots than in the past.

2.5.1 Age and Flight Performance

This section looks at studies examining the relationship of age to flight performance in GA pilots. Some studies have used aircraft accidents as a proxy for pilot flight performance. Pilot error was noted to be the likely cause in 38% of major airline crashes and 74% of commuter/air taxi crashes. However, in general aviation, 85% of the crashes were due to pilot error (Li et al., 2001). This suggests that pilot performance would be a major determinant of aircraft accident characteristics and trends.

Bazargan & Guzhva (2011) examined GA accidents between 1983 - 1992 and 1993 - 2002. The researchers examined 23,184 accidents in the first decade and 16,616 accidents in the second decade. To examine the impact of pilot age on pilot error, they divided the pilots into six age groups: under 20, 20 -29, 30 -39, 40 - 49, 50 - 59 and greater than 60 years of age. For the two decades, there was no difference in pilot errors to total accidents across all the age groups. The ratio of fatal to total accidents was also examined in the different age groups. Pilots older than 60 years of age had the highest fatality rate. Older pilots being more experienced and thus flying the more difficult routes was suggested as an explanation for these results by the authors.

Causse et al. (2011) studied the flight path deviation of 24 GA pilots in the horizontal axis from the ideal flight path which consisted of taking off, reaching a waypoint and landing at a given airport. A relationship of age affecting flight performance was not found.

Kennedy et al. (2010) studied 72 IFR or higher rated pilots, 19 to 79 years of age. Half of the pilots were less than 41 years of age (younger group) and the other half of the pilots were 41 years and above (older group). Age was not a predictor of holding pattern execution. However, pilot decision-making may be less reliable; the older pilots were more likely to land when visibility was inadequate than the younger pilots, possibly due to poorer vision and strategy error.

Other studies have found somewhat different results. Yesavage et al. (1999) looked at the flight performance of 100 pilots aged 50 to 69 years in a flight simulator. They found increased age was significantly associated with decrease in performance but it accounted for only 22% or less of the variance of performance on different flight tasks. Taylor et al. (2005) had 97 general aviation pilots, aged 45 to 69 years, follow Air Traffic Control (ATC) instructions from memory, and found on average older pilots were less accurate than younger pilots .

Taylor et al. (2007) report results on 118 general aviation pilots aged 40 to 69 at one year of a 3 year longitudinal study. Older pilots initially performed worse than younger pilots but older pilots showed less longitudinal decline in overall flight performance than younger pilots. The older pilots improved in their traffic avoidance performance over time better than the younger pilots and thus offsetting the decline. Three possible reasons for the improvement were suggested: (1) older pilots (poor performers) decline less than younger pilots (high performers) due to floor effects[2], (2) lower performers improve over time while higher performers decline (regression to the mean), and (3) older pilots benefit from practice more than younger pilots. Other areas where older pilots did not perform as well as younger pilots were in the area of evading air-traffic conflicts and approaches to landings.

[2] Floor effects – a measure has a lower limit of potential responses and participants score at or near this limit – opposite of ceiling effects (Lewis-Beck et al., 2004)

In 1990, Hilton Systems, Inc. had a two year Age 60 Rule Study contract, which was overseen by the Civil Aeromedical Institute (CAMI), to explore “the relationships among pilot age, experience, and accident rates” (Kay et al., 1994; p.1-2). This was a very comprehensive study utilising a consolidated database consisting of the FAA Airmen Certification file, the FAA Medical History file, and the National Transportation Safety Board Accident database. The main conclusion was that accident rates decrease with increasing age for younger pilots and level off for older pilots. Since there were not any pilots over the age of 60 working for major airlines due to the Age 60 Rule, the Age 60 Study, (Kay et al., 1994) examined Class III (general aviation pilots). These GA pilots ranged from 50 to 70 years with more than 500 total flight hours and with more than 50 hours flown in the last 12 months for the years 1976-1985 and 1987-1988 as a function of age, and year by year. They found no effect for age on accident rate. It has been argued that research with GA pilots is not applicable to airline pilots (Wilkining, 2000; Woosley, 2001) but as mentioned in the Introduction, non-airline pilots have been used as proxy for research as a result of the Age 60 Rule.

2.5.2 Summary: Age and Flight Performance Studies

The number of older GA pilots is increasing worldwide (Bea, 2000; Hardy & Parasuraman, 1997). GA accidents as a substitute measure for flight performance did not show any age effects over a twenty year period nor did the Hilton Study over a 12 year period. Other studies have revealed a decrease in flight performance with age, especially in tasks associated with memory, communication as well as situations with high workloads such as emergencies and landings. In one study age contributed only 22% of the variance to flight performance. Therefore, age is likely one of many factors that influences cognition and flight performance.

2.6 Cognition and Flight Performance

2.6.1 Cognition Testing

Various types of test batteries have been used to study cognition, usually by determining accuracy, reaction speeds, or errors on the various tests in the battery. A higher accuracy, faster reaction speed, and fewer errors are usually correlated with better test scores and participants with better test scores are thus considered as having *better* cognitive skills.

CogScreen-AE is one such computerized battery being used by researchers, airlines, and some regulatory bodies (Kay, 1995; CAMA 2011). It was developed in the late 1980s and early 1990s to meet “the Federal Aviation Administration’s need for an instrument that could detect subtle changes in cognitive functioning…” (Kay, 1995; p.1). It was “standardized and validated for use with commercial airline pilots, ages 25 to 67, with 12 or more years of education” (Kay, 1995; p.17). This cognitive tool compares a pilot’s performance on the test relative to the normative data in his/her age range and/or the entire normative data of 585 U.S. commercial pilots. Researchers use the raw data obtained on the actual tasks. There are not any cognitive batteries that the author is aware of that are designed for specific use with GA pilots but further testing is being conducted of the CogScreen-AE with GA pilots (G. Kay, personal communication, March 31, May 12, 2014).

2.6.2 Cognition and Flight Performance Studies

Hyland et al. (1994), as part of the Age 60 Study, had 40 male, active and non-active, Boeing 727 (B727)-rated volunteers aged 41 to 71 years participate in their simulator study. These pilots completed CogScreen-AE, WOMBAT[3] (domain-independent), and Flitescript[4] (domain-dependent) tests. The researchers only used 22 of the many CogScreen-AE variables. "Older pilots completed fewer Flitescript problems correctly; performed more poorly on WOMBAT (particularly on the tracking task); and, performed more poorly on COGSCREEN (with lower levels of accuracy and longer reaction times)" (p.26). However, performance on Flitescript and WOMBAT was not significantly correlated with simulator performance. The CogScreen-AE total composite variable (reflection of speed, accuracy, memory subsets) was only correlated "with the raters'

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[3] WOMBAT (Wonderful Original Method for Basic Airmanship Testing) was developed to predict the success of pilot training. It measures an individual's ability to multitask, determine priorities and provide information on vigilance (Hyland et al., 1994). It employs a left- and a right-hand joystick and a keyboard (Roscoe & Carl, 1987).

[4] Flitescript recognition version was used to assess situational awareness and pilot knowledge. Individuals listen to air traffic control (ATC) calls and select the appropriate graphic version of the situation from a set of answers (Hyland et al., 1994).

subjective evaluation of pilots' performance of emergency/abnormal maneuvers" (p.28). Thus CogScreen-AE seems to show some potential whereas the other two tests did not correlate at all.

Causse et al (2011a) examined cognitive ageing and flight performance in general aviation pilots. Their study participants were 32 private pilots with a mean age of 47.28 years (SD = 15.87), range 22 to 78 years. The participants completed the following cognitive tests: Target Hitting Test, The 2-back Test, The Reasoning Test, The Wisconsin Card Sorting Test (WCST), and the Spatial Stroop Test. Flight performance was based on flight path deviation. Workload was manipulated by mental calculation of the ground speed and failure of the compass. They found updating of working memory (WM) was sensitive to age effects, especially after the age of 55; reasoning did not seem to decline until after age 65; and processing speed (PS) declined with age. WM and PS were predictive of flight performance. They also looked at weather-related decision making in regards to landing with cross winds not compatible with aircraft crosswind limits. Fifty percent of the pilots landed when they should have gone around. Those pilots who did not land had better updating in WM and set shifting determined from the WCST.

Taylor et al. (2000) examined the relationship between CogScreen-AE to simulated flight performance in 100 GA pilots aged 50 to 69 years who had not been or were not employed by major air lines. The researchers reduced CogScreen-AE's nine factors into five, named by Kay (1995) as the Taylor Aviation Factor Scores. In this study all factors except for Attribute Identification contributed a total variance of 45% to flight performance. The largest contributor was Speed/WM at 33%. This factor encompasses Visual Scanning/Sequencing, Visual Perceptual/Spatial Processing, Visual Reaction Time, Working Memory, and Numerical Operations. The contribution to the total variance of the three remaining factors was: Visual Associate Memory- 6%, Motor Coordination – 3%, and Tracking – 3%. The tracking factor was a predictor of approach scores. These researchers also found age dependent CogScreen-AE factors relating to cognitive speed, associative memory, and concept formation. The age-performance correlation coefficient was 0.35. Motor coordination and tracking were the least age dependent.

In the ATC instruction study (Taylor et al., 2005), besides WM span, older pilots on average performed worse on speed and interference control. However, with greater message difficulty, age-related differences in accuracy did not increase.

In the study of 72 IFR rated pilots, aged 19 to 79, by Kennedy et al. (2010), older pilots performed worse on four of the six CogScreen-AE measures: Dual task - Tracking error, Dual task – Boundary hits, Shifting Attention Instruction thruput[5], and Symbol Digit Coding thruput. However, the dual task measures did not predict flight performance. A possible explanation suggested for these results was that these expert pilots were better at performing the actual domain relevant tasks rather than computerized testing tasks.

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[5] thruput measures "are derived scores that express response efficiency and reflect the number of correct responses per minute… The formula used in CogScreen-AE for calculations of thruput measures is:

Thruput = ([Accuracy/100] X 60 seconds /
Median Response Time for Correct Trials" (Kay, 1995; p.8)

Yesavage et al. (2011) examined whether initial cognitive performance would predict longitudinal aviator performance. The participants were 276 pilots aged 40 to 69 years with an average participation of 3.8 years. The exploratory analysis was based on 184 pilots. The following composite scores of seven factors derived from CogScreen-AE were used to determine potential predictors of age related change: (1) processing speed, (2) executive function, (3) symbol-digit recall (% accuracy), (4) working memory updating (% accuracy), (5) working memory manipulation, (6) motor coordination, and (7) tracking (error score). Processing speed and executive function predicted longitudinal flight performance.

Kennedy et al. (2013) examined the intraindividual variability (IIV) relationship to flight performance in 236 pilots aged 40 to 69 years over a three year period. The following subsets of CogScreen-AE were used to test cognitive function: Pathfinder (Number, Letter, and Combined), Shifting Attention, Divided Attention Test Indicator Alone Task, and Symbol Digit Coding. From these measures, processing speed and executive function measures were obtained. Through Principal Factor Analysis two factors were determined: basic IIV (Pathfinder) and complex IIV (rest of the measures). Complex IIV was not correlated with any results but was correlated with basic IIV; researchers only used basic IIV in their analysis. Pilots with the greatest IIV did not do as well as pilots with the lowest IIV on initial simulator flight performance scores except for approach. In this analysis, processing speed and executive function were not predictive of longitudinal flight performance. The researchers suggest that the loss of reaction time results for 41 pilots due to software malfunction may have affected the latter results.

2.6.3 Summary: Cognition and Flight Performance

The desire to find some form of testing that could easily assist in predicting an association between cognition and flight performance has led to a number of studies using neuropsychological tests with simulator testing of flight performance. Cross-sectional and longitudinal studies have shown processing speed, working memory, and executive function to be predictors of flight performance. However, a study with expert pilots did not find any correlation with dual tasks, executive function, or derived processing speed.

2.7 Experience and Flight Performance

In the Hilton Age 60 simulator study of active and non-active B727 pilots aged 41 to 71 years, the pilots had a minimum of 5000 flying hours regardless of aircraft type (Hyland et al., 1994). For the 40 pilots in the study, novice and experienced, it was only the B727 simulator hours in the last 30 days which correlated with flight performance and not the actual flying hours in the B727 over the last six months.

In a small study of 24 general aviation pilots rated for visual flight conditions with a mean age of 43.3 years, experience was predictive of flight path deviations (Causse et al., 2011). Morrow et al. (1994, 1996) showed that more experienced pilots were more accurate than less experienced pilots in executing ATC instructions. Experience, did not reduce age differences for less relevant tasks as it did for domain relevant tasks in 48 retired or active pilots with experience flying multi-engine aircrafts. In 97 non-airline pilots aged 45 to 69 years, experience was associated with higher accuracy in executing ATC instructions (Taylor et al., 2005).

In Kennedy et al.'s (2010) study of 72 instrument rated pilots from 19 to 79 years, age X experience (expertise assisting older pilots) did not predict flight performance. Older pilots made less accurate control of the ailerons during approach but when cognition and expertise were included in the assessment, processing speed and expertise were associated with better performance.

Yesavage et al. (2011) used FAA pilot proficiency ratings to determine pilot experience: low experience – visual flight rules (VFR) only, moderate experience – instrument flight rules (IFR), and high experience – certified flight instructor of IFR students and/or air-transport ratings. These researchers did not find experience was helpful in slowing the rate of age-related change in aviation performance. However, experience was associated with higher baseline performance on aviation tasks. Thus in the longitudinal study more experienced pilots maintained a higher level of function longer than less experienced pilots, even though both groups' performance declined at the same rate.

Morrow et al. (2009) compared older and younger active expert and novice pilots in their decision making. The testing scenario was paper and pencil based and did not involve a simulator. Airline and corporate pilots were considered the experts and the novices were defined as general aviation pilots holding only a private pilot's licence. An example of a scenario presented involved medium-size, wing-mounted, twin-engine jet with leading edge devices where the aircraft in the simple version strikes a tug towing an engine crane without causing major problems. In the complex version, the strike leads to an engine falling off and causing some problems (p.55). The older expert pilots "better understood and made more appropriate decisions about flight-relevant problems" (p.48) and age had little impact on the experts' decision making. GA pilots however did as well as the experts in general aviation knowledge. Also, young (18-42 years) GA pilots did as well as the young (23-42 years) experts on the decision making task.

Schriver et al. (2008) looked at expertise and decision making in 28 pilots, 19 to 44 years old. Experience was measured by: total flight hours, combined actual and simulated instrument flight hours, type of pilot certificate and rating, and a 20 question aviation knowledge test adapted from FAA written exam for instrument rating. The less expert group were private pilots without an instrument rating while the expert group pilots were commercial instrument rated pilots. Attentional inferences were made from tracking eye movements. Cognitive abilities in PS, verbal ability, and flexibility to switch attention between tasks were also measured. There was no difference in cognitive abilities between the two groups. Expert pilots did better on the knowledge test. They also made more appropriate decisions more quickly than less expert pilots. Expert pilots devoted more attention to cues in failure scenarios which corresponded with better decision accuracy.

In a study of 35 pilots aged 18 to 62 years with 25 pilots being instrument rated, Wiegmann et al. (2002) examined novice and expert pilot decisions to continue to fly by visual flight rules into adverse weather in simulated short and long cross-country flights. Pilots flew a Frasca 142 flight simulator which was configured as a Cessna 172. In the short cross-country adverse weather conditions were encountered early in the flight and further into the flight in the long cross-country. There was a tendency for the experienced pilots to divert sooner than the less experienced pilots especially in the long cross-country but this was not statistically significant. Pilots with more cross-country hours and pilots having flown in the last 30 or 90 days diverting sooner was statistically significant in the longer cross-country flight.

2.7.1 Summary: Experience and Flight Performance

Overall, experience was a positive predictor of flight performance, especially with domain dependent tasks. Recent flying experience irrespective of whether it was actual or simulator hours, leads to better flight performance than total flying hours or years of flying. In some studies, increasing experience and age was beneficial; in other studies, age and experience combined were not predictive of flight performance. In a similar analogy to cognition, decline in performance tends to be at the same rate for experienced or inexperienced pilots but experienced pilots tend to have higher baseline flight performance and thus maintain adequate levels of function longer than inexperienced pilots. Experience tends to be advantageous in emergency/novel situations regardless of age.

2.8 Education, Income, and Flight Performance

Lyketsos et al. (1999) observed that having 8 years or more of education was associated with less cognitive decline. More years of education was associated with better short-term memory recall in 763 adults ranging from 18-65 years of age from Rotorua, New Zealand (Woods et al., 2011). The prospective Canadian Study of Health and Aging examined risk factors for Alzheimer's disease from 1991 to 1996 of adults 65 years and older; for the 4615 subjects alive in 1996, aged 69 to 105 years, low educational level was associated with increased risk of Alzheimer's disease (Lindsay et al., 2002).

Zahodne et al. (2011) in the Victoria Longitudinal Study followed 1014 subjects, aged 54 to 95 years for 12 years living in the area of Victoria, British Columbia, Canada. They examined processing speed, working memory, verbal fluency and verbal episodic memory. Subjects with higher education had better performances in all of the above four mentioned domains. Education seemed to benefit the most in the verbal fluency domain and the smallest effect was for processing speed. However, there was no relationship between education and the rate of decline in any domain.

Cagney and Lauderdale (2002) looked at the association of education, wealth, and income to cognition in adults 70 years of age or over along with their spouses or partners.

Wealth more than income, had a stronger association with cognitive function. Wealth and income effects were attenuated after adjusting for education. However, association of education to cognitive function remained significant even when controlling for wealth and income. Lee et al. (2006) in the Women's Health Study investigated the relationship of education and individual income to cognitive decline in 5,573 women, 66 years of age or older. These researchers found higher annual income and higher education related to better cognitive function and less cognitive decline. There was no interaction between education and income.

2.8.1 Education and Flight Performance

There are only a few studies that have examined the association of education to flight performance. The preliminary report by Adamson et al. (2010) examined the relationship of brain size[6] to pilot performance. The number of years of education was truncated at 20 years. In this study of 51 GA pilots, aged 45 to 65 years, a significant positive correlation was found between education and aviation expertise ($r = 0.38$, $p < .001$). They found education had a moderating effect on brain size and thus indirectly affecting simulated flight performance. In the expanded version of this study and the study by Taylor et al. (2007) no significant correlation was found between education and aviation expertise.

[6] Brain size was determined by Magnetic Resonance Imaging (MRI) by measuring total intracranial volume (TIV) (Adamson et al, 2010).

2.8.2 Summary: Education, Income, and Flight Performance

Education and income have been shown to be important factors in health as well as in cognitive function, especially during ageing. Rate of cognitive decline however does not seem to be related to either education or income. Education and income appear to act independently rather than interacting together to effect an individual's cognitive outcome.

There were no studies that the author could find regarding income and flight performance. There is a trend that better education leads to aviation expertise through the process of obtaining advanced proficiency ratings and thus greater aviation education. However, considering the high cost of obtaining and maintaining higher aviation ratings, financial accessibility would tend to be related to aviation experience.

2.9 Conceptual Framework

It follows from the above studies that the ageing process can have some decrement effect on certain flying skills which can be mediated by experience. Various cognitive abilities such as working memory, attention, processing speed, reasoning, prioritizing, decision making, and interference control also improve flight performance. In trying to understand how all these concepts fit together, executive control function and the ageing process will be examined in greater detail.

Barrett et al. (2004) suggest that attention as an executive function is a major contributor to the individual differences in the capacity of working memory especially in competing demand situations. Thus, the ability to control attention is essential but exactly how this is accomplished by the prefrontal cortex (PFC) is not known and considered "the homunculus question" (Barret et al, 2004, p. 7). However, the PFC in some manner directs interactions within the PFC and other parts of the brain through network of circuits to control this attention (Barrett et al, 2004; Tisserand & Jolles, 2003).

Besides attention, other contributors to working memory capacity under the control of the central executive which affect individual differences are:

(1) Activation effects - goal directed stimuli
(2) Interference effects - resist distraction
(3) Suppression effects – subdue unwanted, irrelevant, goal incongruent information
(4) Processing strategies – automatic vs controlled (goal) directed and
(5) Processes related to learning and memory – encoding new information, construction of mental representations to support new learning, domain knowledge (Barrett et al., 2004).

As briefly discussed under cognition, executive function resides in the PFC. The ageing process leads to shrinkage of the brain with the largest effects being on the PFC. It then follows that a decline in the PFC would affect executive function in the normal ageing process even in the absence of disease. However, even in the normal ageing process there is great variability, likely due to the variability in the interactions of the nine hallmarks of ageing.

As noted in the studies, cognitively demanding portions of a flight are often experienced when dealing with approaches at landings as well as in-flight emergencies. These stressful situations can impair the executive functions by releasing excessive amounts of dopamine neurotransmitters (Arnsten, 2009). Stress also affects working memory capacity by changing strategies that can be used, for example - using habit memory and rigid rather than flexible, goal-directed strategies (Sandi, 2011).

Age related variance can also be explained by the speed of processing information (Salthouse, 1996). PS is affected by the amount of myelin set down which proceeds from the back to the front decision-making areas (Fields, 2008; Zatorre et al., 2012). During normal ageing there can be up to 50% reduction in the length of myelinated axons (Fjell & Walhovd, 2010). However, skill/knowledge/expertise produce structural changes seen in imaging studies which enhance PS in those with *cognitive specialization* (taxi drivers – spatial navigation, musicians) (Zatorre et al., 2012).

Flying involves monitoring and performing many tasks *simultaneously*. To study these abilities, dual/time sharing tasks have been used by researchers. Some dual tasks in the CogScreen-AE and in the studies above involve tracking and another task such as the N back task. In dual tasks there can be switching of attention from one task to another task which requires successful co-ordination from the central executive of the two/multiple tasks as seen in neuroimaging studies (Fletcher & Henson, 2001). Dual tasks have also been referred to having interference effect or in older adults a reduced ability “to update task goals in a rapidly sequential manner” (Braver & Best, 2008; p. 50). Dual task responses are also subjected to an individual's prioritizing strategies (Tsang, 2006, 2013).

In a recent study by Tsang (2013), no age effect was found on equal priority tasks. High-priority goals were attained by young participants (18-30 years) by sacrificing low-priority goals. Older participants (60 to 70 years) did not always complete the priority (difficult) task first; realizing they were slower, completed the second faster task first. Older participants were slower in their reaction times on single and dual tasks than the younger and the middle aged (50-59 years) groups. Practice effects were noted for all age groups except for the most demanding conditions. In summary "time sharing requires more than the sum of performing multiple single tasks and involves additional coordination and resource management" (Tsang, 2013; p. 1539).

2.9.1 Cognitive Performance Models

A number of models exist in facilitating the understanding of cognitive ability. Cowan (1988, 2007) developed the Embedded-Process Model which focuses on information processing, with emphasis on attention and memory storage. The controlled-Attention Framework by Engle, Kane, and Tuhoiski is a "system consisting of those long-term memory traces above threshold, the procedures and skills necessary to achieve and maintain that activation, and limited capacity, controlled attention" (Engle et al., 2007; p.102). Other models such as the Executive-Process/Interactive-Control (EPIC) use computational architecture examining human-computer interfaces (Kieras et al., 2007). A well-known model is The Multiple-Component Model initially developed by Baddeley & Hitch (Miyake & Shah, 2007) and later updated to the schematic representation seen in *Figure 4* (Baddeley, 2000).

The Multiple-Component Model is composed of a central executive that decides where to focus attention, co-ordinates, and monitors the information of the "slave systems", the phonological loop and the visuospatial sketch pad (Baddeley, 1992). The phonological loop stores acoustic or speech-based information for 1-2 seconds and has the ability to recite information to prevent decay. The Visuospatial Sketchpad deals with visual and spatial information and deals with dynamic and static visuospatial recall. The episodic buffer, the newest component, transfers information about experiences between long-term memory and the central executive (Baddeley, 2000; Baddeley et al., 2011). Some of the architecture suggested by this model has been used in developing Air Man-Machine Integration Design and Analysis System (AIR MIDAS) as part of The NASA Human Performance Modeling Project (Corker et al., 2008).

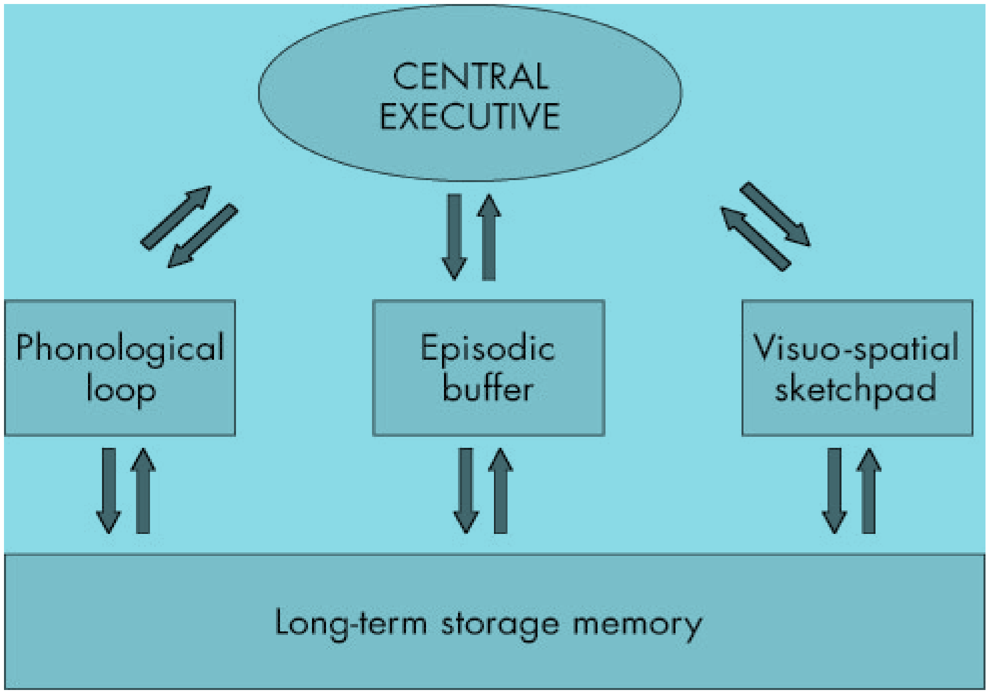

Figure 4. **The Multiple - Component Model**

2.9.2 Summary: Conceptual Framework

Executive function resides in the prefrontal cortex which undergoes the steepest declines with biological ageing. These decrements can affect working memory, processing speed, along with decision making, reasoning, and ability to divide and focus attention which can hinder effective prioritizing especially in demanding and stressful conditions. Experience can have a beneficial effect on anatomy and thus enhancing information processing. The Multiple-Component Model may not be flawless but it incorporates besides executive function, other aspects such as acoustic, visual, and long term memory information that a pilot utilises in successfully flying an aeroplane.

2.10 Conclusion

The preceding narrative review highlights the relevant literature regarding general aviation pilots in the areas of age, cognition, education, experience, and income in relationship to flight performance. Key literature references are presented from the social sciences to assist in understanding pilot performance. An existing well-known schematic model is offered to facilitate visualizing a complex topic.

The study described in the following chapters examines possible predictors of flight performance in general aviation pilots with the goal of contributing to the literature in support of understanding and increasing pilot safety.

3 Methodology

3.1 Research Design

This was an experimental study examining the relationship between individual pilot factors to simulated flight performance during low and high workload conditions in general aviation (GA) pilots. This research was part of a larger study underway at the Advanced Cognition Engineering (ACE) Laboratory, Visualization and Simulation (VSIM) Centre at Carleton University in Ottawa, Ontario Canada.

3.2 Ethics Approval

Ethics approval was obtained from the Carleton University Psychology Research Ethics Board. A Certificate of Ethics Clearance (Appendix A) was issued approving the research procedures as being acceptable on ethical grounds involving human participants.

3.3 Sample Recruitment

Participants were recruited from flying clubs and flying schools in the Eastern Ontario region of Ontario, Canada from August, 2011 to December, 2012. Permission was obtained from these organizations to put posters at their locations as well as through their electronic communication methods (Appendix B & C). To participate in the study, pilots had to be at least 18 years of age, have a current medical certificate, be able to fly a Cessna 172 aircraft, and have flown in the past year. All pilots who responded to the recruitment had further communication by e-mail and/or by telephone. During these interactions, the pilots were made aware of the information on the recruitment poster as well as information such as: purpose of the study, length of the study, pre-requisites for participation in the study, location of the study, and the volunteer nature of participating in the study. They were advised that parking was free for participants of the study. Fifty-six pilots agreed to volunteer to participate in the study.

3.4 Procedure for Data Collection

3.4.1 Personnel Involved in Data Collection

The author and the researcher conducting the larger study were the only ones involved in interacting with the participants and the data collection.

3.4.2 Informed Consent Form

All the participants signed an informed consent form (Appendix D) which outlined the purpose of the study, research personnel involvement, brief description of the tasks they would be required to complete, location/ duration/compensation of the study, and potential risks/discomforts from participating in the study. There were no known risks to participating in the study. The consent form also outlined the anonymity/confidentiality of the data collected as well as the right to withdraw anytime during the study.

3.4.3 Demographic Information

The author or the researcher conducting the larger study completed the demographic information (Appendix E) with the participants.

3.4.4 Simulated Flight Performance and Cognitive Testing

The order of completing the simulated flight performance and cognitive testing was randomly generated by computer for each participant. The order was adhered to as much as possible. However, unforeseeable events such as power outages, and electronic malfunctions occasionally necessitated the reversal of the randomization process. A short break took place between the two activities.

3.4.5 Tasks to be Performed for Simulated Flight Performance

The simulated environment consisted of a Cessna 172 medium fidelity simulator on a non-motion platform running Microsoft FSX software, *Figure 5*. Each of the simulated flying activities took approximately 30 to 40 minutes to complete. The participants were given two pages to read titled “Circuit Instructions” (Appendix F). These instructions familiarized the pilots with the flying speeds, altitudes, and headings that needed to be maintained in the circuit. Participants were not aware when additional traffic would be introduced into the scenarios. These instructions were repeated with each scenario. Other activities performed by the pilots were not part of this study.

Figure 5. **Cessna 172 simulator used in the study.**

3.4.5.1 Warm- up Exercises

To familiarize themselves with the simulator, the participants were asked to fly four left-handed circuits at an aerodrome of their choosing. Information regarding runway and altitude was provided for the aerodrome.

3.4.5.2 Low Workload

The first scenario had the participants flying a left-hand circuit in a prairie setting aerodrome, *Figure 6*. Information regarding runway direction and altitude was provided for this aerodrome. The participants were to make two touch and go landings with the third circuit landing being a full stop. During the second circuit, after turning downwind, another aircraft was introduced into the circuit. A second aircraft was introduced during the third circuit. The participants were not aware when additional traffic would be introduced into the scenario.

***Figure 6*. Low workload aerodrome** (Google Maps)**.**

3.4.5.3 High Workload

The second scenario had the participants flying a left hand circuit in a mountainous region in Western Canada, *Figure 7*, *8*. Information regarding runway and altitude above sea level of the aerodrome was provided to the pilots. Again, they were to make two touch and go landings, coming to a full stop after the third circuit. The first additional traffic was introduced when the participant had turned downwind of the first circuit; second aircraft announced itself at the aerodrome when the participant was mid downwind of the first circuit; and the third aircraft took off from the aerodrome when the participant had turned downwind of the second circuit.

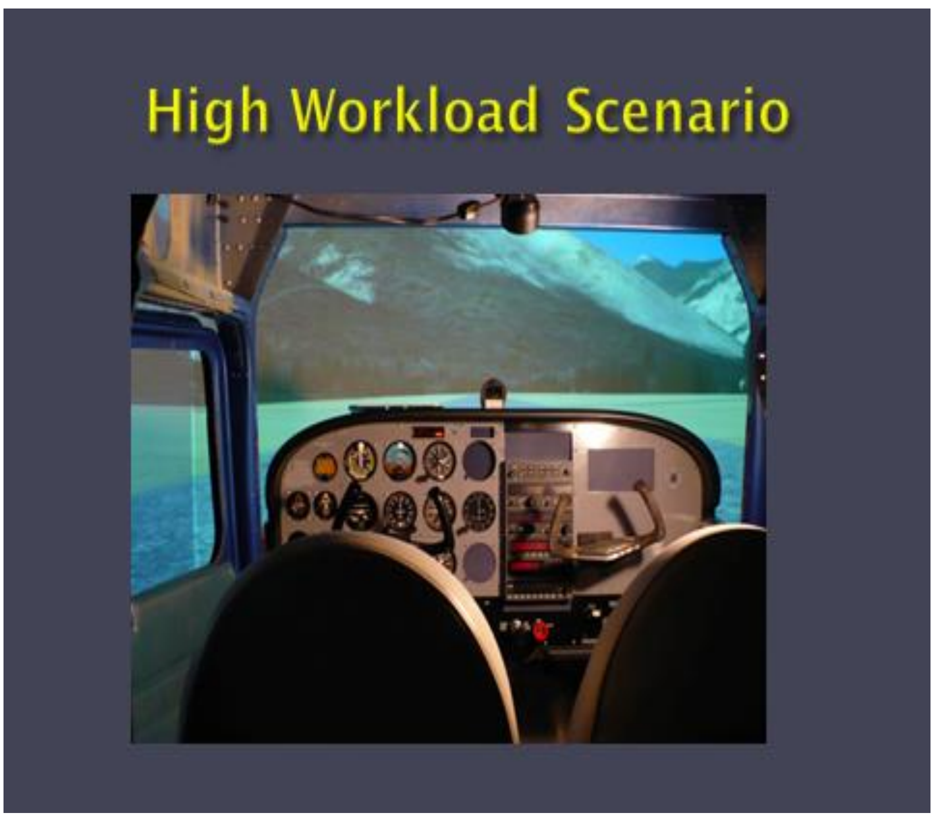

Figure 7. **Cessna 172 on runway.**

***Figure 8*. High workload aerodrome** (Google Maps)**.**

3.4.5.4 Cognitive Testing

Participants completed the cognitive assessment battery, CogScreen-AE (Aeromedical Edition) (Appendix G, H). The time required to complete this battery ranged from approximately 45 to 75 minutes. This test was administered on a touch screen computer. It consists of a series of tasks which are presented with instructions and a practice segment. There are 13 subsets with two subsets having tasks being performed alone and in combination with another task. CogScreen-AE measures attention, immediate and short-term memory, working memory, visual-perceptual functions, sequencing functions, logical problem solving, calculation skill, reaction time, simultaneous information processing abilities, and executive function (Kay, 1995).

3.4.6 Debriefing

Upon completion of the experiment, participants were given the opportunity to ask questions about the study. A page titled "Debriefing" (Appendix I) was given to all participants to take with them. This again stated the purpose of the study, provided a reference if they so wished to delve further in this area of research, as well as listing personnel involved in the research with their contact information.

3.5 Data Analysis of Present Study

There is a considerable amount of methodology involved in the analysis of the data in this study. Therefore most of the headings and subheadings in this section mirror those in the Results section to assist the reader in cross-referencing methodology and results from one section to another. This division also assists in de-cluttering the results section.

3.5.1 Data Management

Unless otherwise specified IBM SPSS Statistics 21 was used to analyze the results. Prior to any computations or analyses being conducted, raw data from cognition and simulated flight performance testing was truncated to plus and minus 2.5 standard deviations to control for outliers. Upon completion of the study power analysis was carried out using IBM SPSS SamplePower 3.0.

3.5.2 Demographic Data

Descriptive statistics were carried out on the demographic information and the flying characteristics of the participants. Age was calculated from date of birth to date of participation in the study and the participants were divided into three relatively even age groups. Highest degree achieved represented education. Income bracket divisions were rounded to the nearest ten thousand dollars of the amounts shown for *indexation adjustment for personal income tax* by the Canada Revenue Agency (CRA, 2012).

3.5.3 Flight Performance Difficulty and Scores

Flight performance data was collected for the variables of altitude, speed, and heading as root mean square error (rmse[7]). Data obtained from the downwind portions of the circuits was used to measure flight performance as this part of the circuit generally provides the least variability as opposed to take-offs and landings. Paired t-tests were conducted to determine if there was a difference in the task difficulty between the low and high flying conditions on the downwind legs of the circuits.

To further delineate the role of the latent indicators (altitude, speed, heading) upon the latent variable (flight performance) for each flying condition, factor scores for flight performance were computed with partial least squares regression using Warp PLS

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[7] rmse - calculated by obtaining the difference between the "perfect value" for altitude, heading, and speed and the actual value obtained and then squaring this difference to remove directionality. Then the square root is taken of this value. A higher rmse value denotes larger error or greater deviation from the desired altitude, speed, and heading.

3.0 (Kock, 2013). For the low workload condition, two factor reflective latent indicators were created using the rmse scores for speed and altitude deviations. For the high workload condition, three reflective latent indicators were created using the rmse scores for altitude, speed, and heading deviations. Factor scores were saved to create a new performance variable for each workload condition.

3.5.4 Cognition and Simulated Flight Performance

The normative population data for CogScreen-AE was obtained from commercial airline pilots, Appendix J (Kay, 1995). Therefore, in this study of general aviation pilots, cognitive data analysis focused on the actual scores for all the measures of the CogScreen-AE. (Appendix K).

CogScreen-AE has 13 subsets and produces 99 tested and derived measures. All 99 measures were individually examined to fully understand what each measure represented and to look for data irregularities. All irregularities were further examined by exploring the computer *raw data* information (Appendix L). This examination led to the extraction of fifty-four measures (53 tested and one derived – Logistic Regression Provability Value (LRPV)). Theory application resulted in further extraction of measures related to the constructs of processing speed, working memory, and visual tracking.

Concerns for ceiling effects in the subset Pathfinder Accuracy, related to working memory, led to combining results in this subset. Three similar measures of working memory required participants to sequence numbers (PFNACC), letters (PFLACC), and combinations of number and letters (PFCACC) were combined to make one measure PFNLCACC. Similarly, six measures related to processing speed: three measures (PFNRTC, PFLRTC, PFCRTC) for the reaction times and three measures (PFNTOT, PFLTOT, PFCTOT) for the total time required to take a test, were combined to make two measures (PFNLCRTC, PFNLCTOT). This resulted in a total of 48 CogScreen-AE measures: 18 measures for working memory, 17 measures for processing speed, 4 measures for tracking, 8 non-related measures, and LRPV. See Appendix M for the breakdown of these measures.

Power analysis was then carried out using Monte Carlo simulations (10,000 repetitions) with MPLUS version 7.11 (Muthen & Muthen, 2013) to determine if adequate power existed to detect significant loadings for Confirmatory Factor Analysis (CFA). The simulation was of one factor for 54 participants using twelve indicators with 0.20 to 0.80 loadings. The Monte Carlo simulations showed power ranging from 0.84 to 0.99 to detect significant indicators with loadings of 0.4 to 0.8. When the loadings were less than 0.4, power fell below the convention of 0.80. Confirmatory factor analysis for each construct led to the measures utilized for further analysis, Appendix M.

Guidelines suggested by Cohen for determining the effect size, *r*, from Pearson correlation coefficients were used: r = 0.10 (small effect), r = 0.30 (medium effect), and r = 0.50 (large effect) (Field, 2009; McGrath, 2006). It should be kept in mind that "…there is a certain risk inherent in offering conventional operational definitions for these terms for use…in a diverse a field of inquiry as behavioral science" (Cohen, 1988, p.25).

3.5.4.1 Working Memory

Initial factor analysis (FA) of eighteen measures resulted in the removal of four measures which did not meet the measure of sampling adequacy (MSA) of less than 0.5. Two more measures were removed which likely would not affect analysis of working memory. FA of these 12 measures showed the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.651. Bartlett's Test of Sphericity significance was less than 0.001. The KMO measure value above 0.5 and Bartlettt's Test less than 0.05 of significance suggests the variables are related and suitable for factor analysis, Appendix M.

Working memory scores are given either as percentages of correct trials or as the number of correct responses. Concern from some researchers (Callister et al., 1995) is that many of the tasks performed are at ceiling levels. This leads to the independent variables having very little variance. Thus the results obtained are unable to distinguish participants from each other. Callister et al. (1995) did not discuss measures which had a standard deviation of 0.10 or less. In this study, the twelve measures used for factor analysis had standard deviations ranging from 0.88 for Backward Digit Span (BDSMSPAN) to 29.12 for Symbol Digit Coding Delayed Recall (SDCDRACC).

3.5.4.2 Processing Speed

Initial FA resulted in the removal of Auditory Sequence Comparison Reaction Speed (ASCRTC) which did not meet the measure of sampling adequacy (MSA). Further three measures were removed which likely would not affect processing speed analysis. Factor analysis of the remaining 12 measures showed the KMO value was 0.705 and Bartlett's Test of Sphericity significance was less than 0.001, Appendix M.

3.5.4.3 Tracking

Four measures fit into this construct and all had MSA above 0.5. The KMO was 0.628 and the Bartlett's Test of Sphericity significance was less than 0.001, Appendix M.

3.5.4.4 Remaining Working Memory and Processing Speed Measures

Correlation coefficients were calculated between the eleven discarded measures (six working memory and five processing speed) and the two flight performance conditions to determine if the removal of these measures was appropriate.

3.5.4.5 Relationship of Cognition to Simulated Low and High Workload Flight Performance

Pearson correlation coefficients were calculated between the measures identified through FA and the two flight performance conditions. In order not to be too restrictive, all measures with a correlation coefficient with a value of $p < 0.1$ were initially considered for analysis, Appendix N.

3.5.4.6 Taylor Aviation Factor Scores and Simulated Low and High Workload Flight Performance

Correlation coefficients were calculated between the five Taylor Aviation Factor Scores and the two flight performance conditions.

3.5.5 Experience and Simulated Flight Performance

For each participant, experience was represented by a composite score of four flying experience attributes: hours flown as pilot-in-command (PIC) in the last year, total hours flown, total simulator time, and rating level. Pearson correlation coefficients were used for analyses in the low and high workload conditions.

3.5.6 Age and Simulated Flight Performance

Pearson correlation and ANOVA analyses were conducted to examine the relationship of age to simulated low and high workload flight performances. Post-hoc analyses at Bonferoni significance were undertaken to determine if differences existed in the three pilot age groups.

3.5.7 Education and Income and Simulated flight Performance

Pearson correlation coefficients were calculated between education, income, and the two flight performance workload conditions as well as between education and income.

3.5.8 Model Development for Simulated Flight Performance

Multiple linear regression modelling was utilized to determine how all the examined variables with significant relationship to flight performance contributed to variance in the low and high workload conditions. Description of the significant variables can be found in Appendix O. Taylor factors were not included as they have already been derived from the CogScreen-AE measures. Examples of some of the tests are shown in *Figure 9*, *10, 11*.

Figure 9. **Matching-to-Sample.** In MTS, a four-by-four grid is presented with empty and filled cells. Then two grids are presented with one having the original pattern just seen and the other pattern differs by one cell. The participant selects the grid that corresponds to the original pattern. (Drawn by Tolton, R.)

4e56hp 4e56pl

SAME DIFFERENT

Figure 10. **Visual Sequence Comparison (VSC).** The participants are presented with two alphanumeric strings side by side. The participants select "SAME" or "DIFFERENT" for the presented strings. For the strings to be "SAME", the sequence has to be in the same order for both sequences (Created by Tolton, R.)

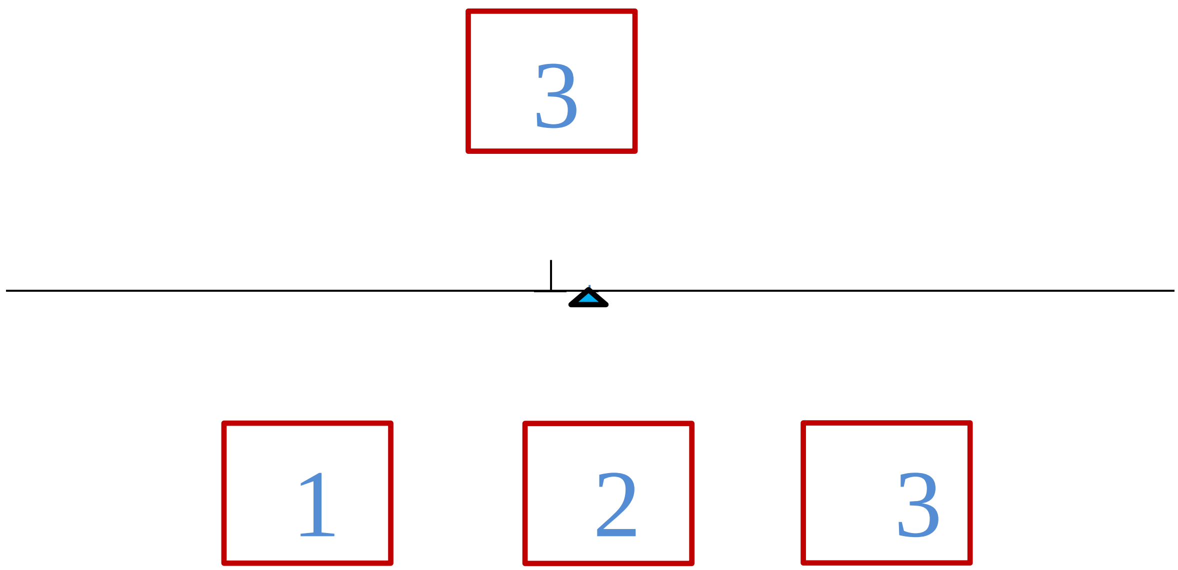

***Figure 11.* Dual Task Tracking Dual Error.** The participant maintains a cursor in the centre of the screen by pressing left and right keys. The absolute tracking error (in pixels) is measured based on displacement of cursor from the centre. The participant simultaneously performs the previous number task. In the previous number task, a 1, 2, or 3 is shown at the top of the tracking line which is then replaced by a 1, 2, or 3. The participant is to recall the previous number shown and select that number (Drawn by Tolton, R.).

3.5.8.1 Model Development for Simulated Low Workload Flight Performance

All significant independent variables (age, cognition measures, and experience) had a $p < 0.05$ except for the tracking measure DTTAHIT which had $p = 0.08$. Since three of the four tracking measures were significant at $p < 0.05$; DTTAHIT was removed from further analysis (see Table 7 of the Results section). It was noted that the three Dual Task Tracking (DTT) measures (DTTDHIT, DTTDABS, DTTPDACC) had high collinearity. Also, DTTDABS and DTTPDACC were unstable and thus were removed from further analysis.

3.5.8.2 Model Development for Simulated High Workload Flight Performance

All significant independent variables (age, cognition measures, experience) had a $p < 0.05$ except for the tracking measure, DTTDABS, which had $p = 0.062$ and age which had $p = 0.065$. Both of these variables were retained for further analysis.

3.5.8.3 LRPV and Flight Performance

LRPV is a derived value and provides the probability of a pilot having brain dysfunction (Kay, 1995). LRPV was added in the sixth block of the regression model to determine if it would significantly contribute to the final model.

3.5.9 Secondary Analysis

Further analyses were assessed to determine if experience was having a moderating effect between working memory (MTSACC) and flight performance. Thus the interaction effect between MTSACC and experience was examined to determine whether or not such an effect was significant in predicting flight performance.

To avoid multicollinearity with the interaction term, the variables experience and MTSACC were centred and an interaction term was created between experience and working memory (MTSACC). The interaction term was then added to the regression model and examined for significance.

4 Results

4.1 Participants

Pilots from local flying clubs and schools in the Eastern Ontario region of Ontario, Canada were invited to participate in the study from August 2011 to December, 2012. Fifty-six pilots meeting the criteria as outlined in the Methodology section participated in the study. One participant on day of testing had problems with his vision and did not complete the simulated flight performance or the cognitive testing. A second participant did not complete the entire cognitive testing part of the study. Thus, the results reflect the participation of 54 pilots.

4.2 Data Management and Analyses

Prior to any computations or analyses being conducted, raw data from cognition and simulated flight performance testing was truncated to plus and minus 2.5 standard deviations to control for outliers. Truncation of data occurred in 6 of 324 data points of flight performance testing and 56 of 2160 data points in the cognition test. Six cognition measures had one data point missing. Two participants did not give their income information. Missing and the above truncation of data represented 2.45% of the entire data used for analyses.

4.3 Demographic Data

The participants are described according to the following demographic data: age, education, gender, and income. There was only one female participant. The participants were divided into three relatively even age groups. Education of the pilots ranged from grade school to university, but the majority of the pilots had a university degree. Income of the pilots varied with 53.8% of the pilots earning less than $80K per year, Table 2.

4.3.1 Flying Experience

Flying experience is described according to the following data: years licensed, total flying hours, hours as pilot-in-command (PIC) in the last 12 months, and total simulator time, Table 3. The rating level of the participants varied from student pilots to experienced pilots with numerous ratings, Table 4.

Table 2

Personal Characteristics of the Participants

Characteristic		*n*	%
Gender			
Female		1	1.9
Male		53	98.1
Age in Years			
21 to 42		19	35.2
43 to 58		17	31.5
59 to 79		18	33.3
Mean	48.1		
Range	21 to 79		
Standard Deviation	18.8		
Education			
Grade School		1	1.9
High School		11	20.4
College		14	25.9
University		28	51.9
Income in thousands of dollars			
Less than 40		6	11.1
40 to 80		22	40.7
80 to 130		14	25.9
Greater than 130		10	18.5
Missing		2	3.7

Table 3

Flying Characteristics of the Participants

***N* = 54**

Characteristic	*M* (Range)	*SD*
Years licensed	14 (0 -63)	16
Total flying hours	557 (5 – 5440)	927
PIC hours in the last year	22 (0 – 122)	29
Total simulator time	84 (0 – 1000)	185

Note: PIC = pilot-in-command.

Table 4

Rating Levels of the Pilots

***N* = 54**

Rating Level	*n*	%
Student	8	14.8
VFR/PPL/Recreation	17	31.5
PPL with Other Ratings	20	37.0
IFR/Military/Commercial/ATPL	9	16.7

Note. VFR = Visual Flight Rules; PPL = Private Pilot’s Licence; IFR = Instrument Flying Rules; ATPL = Airline Transport Pilot’s Licence.

4.4 Flight Performance Difficulty and Scores

Paired-samples t-tests from the downwind legs of the circuits from the two scenarios showed pilots tended to deviate significantly in their altitudes and airspeeds but not in their heading, Table 5.

Table 5

Paired-Samples t-tests in Low and High Workload Conditions.

***N* = 54**

	Low Workload		High Workload		*t* (54) (p)
	M	*SD*	*M*	*SD*	
Altitude	84.44	54.00	140.97	102.01	-4.773 (0.001)
Speed	7.72	2.76	8.44	3.76	2.000 (0.051)
Heading	9.68	2.44	9.27	2.66	0.751 (0.456)

Table 6 shows the loadings of the latent indicators (altitude, speed, heading) for each workload condition. Flight performance scores were created using altitude and speed for the low workload condition and altitude, speed, and heading for the high workload condition.

Table 6

Initial Determination of Factor Loadings Upon Flight Performance

Indicator	Low Workload Flight Performance (p)	High Workload Flight Performance (p)
Altitude	0.878 (< 0.001)	0.808 (< 0.001)
Speed	0.808 (< 0.001)	0.639 (=0.003)
Heading	- 0.477 (=0.091)	0.729 (< 0.001)

4.5 Cognition and Simulated Flight Performance

Initial examination of the CogScreen-AE measures resulted in the extraction of 18 measures for working memory, 17 measures for processing speed, 4 measures for tracking, 8 non-related measures, and Logistic Regression Probability Value (LRPV). Results from further analyses are described below under each construct. See Methodology section 3.5.4 for greater detail.

4.5.1 Working Memory

Further analyses of the 18 working memory measures resulted in 12 measures. Factor analyses of these 12 measures led to 10 measures with loadings of 0.4 and above, Appendix M.

In this study, the ten measures had standard deviations ranging from 0.88 for Backward Digit Span (BDSMSPAN) to 29.12 for Symbol Digit Coding Delayed Recall (SDCDRACC).

4.5.2 Processing Speed

Twelve of the 17 measures in this construct underwent factor analyses. All twelve measures had loadings of 0.4 and above, Appendix M.

4.5.3 Tracking

All loadings on these four measures were greater than 0.55, Appendix M.

4.5.4 Remaining Working Memory and Processing Speed Measures

Correlation coefficients between the discarded measures (six working memory and five processing speed) and the two workload conditions did not show any significant correlations. These results confirmed that appropriate measures were used for further analyses.

4.5.5 Relationship of Cognition to Simulated Low Workload Flight Performance.

Three working memory, one processing speed, and four tracking measures at $p < 0.1$ with moderate to large effect were related to flight performance; thus suggesting that pilots with better memory, processing speeds, and tracking abilities did better in the low workload condition, Table 7.

4.5.6 Taylor Aviation Factor Scores and Simulated Low Workload Flight Performance

Two Taylor factors, Attribute Identification and Tracking were significantly related to flight performance in the low workload condition. Thus, pilots with deductive reasoning (Attribute Identification) would perform better, $r = 0.268$; $p = 0.05$ while pilots with poor tracking abilities would show poor flight performance, $r = -0.401$; $p = 0.003$.

Table 7

Correlation Coefficients Between CogScreen-AE Measures and Low and High Workload Flight Performance

Construct	Low Workload Flight Performance Correlation Coefficients (*p*)	High Workload Flight Performance Correlation Coefficients (*p*)
Working Memory		
MTSACC	0.523 (0.001)	0.355 (0.009)
PFNLCACC	0.410 (0.002)	0.416 (0.002)
DTTPDACC	0.381 (0.005)	0.364 (0.007)
Processing Speed		
VSCRTC	-0.276 (0.044)	-0.340 (0.012)
MATHRTC	___	-0.345 (0.011)
SATINRTC	___	-0.311 (0.022)
Tracking		
DTTDABS	-0.408 (0.020)	-0.258 (0.062)
DTTDHIT	-0.481 (0.001)	---
DTTAABS	-0.315 (0.020)	---
DTTAHIT	-0.240 (0.080)	---

Note. MTSACC = Matching-to-Sample Accuracy; PFNLCACC = average of the accuracies of Pathfinder Number, Letter, and Combined Accuracies; DTTPDACC = Dual Task Previous Number Dual Accuracy; VSCRTC = Visual Sequence Comparison reaction speed; MATHRTC = math reaction speed; SATINRTC = Shifting Attention Instruction reaction speed; DTTDABS = Dual Task Tracking Dual Error; DTTDHIT = Dual Task Tracking Dual boundary Hits; DTTAABS = Dual Task Tracking Alone Error; DTTAHIT = Dual Task Tracking Alone Boundary Hits. See Appendix 0.

4.5.7 Relationship of Cognition to Simulated High Workload Flight Performance

Three working memory measures, three processing speed measures, and one tracking measure at $p < 0.1$ with moderate to large effect were related, and thus suggesting that those pilots with better working memory, faster processing speeds, and tracking abilities performed better in the high workload condition, Table 7.

4.5.8 Taylor Aviation Factor Scores and Simulated High Workload Flight Performance

Speed/Working Memory factor was the only factor significantly related to flight performance in the high workload condition. Therefore, pilots with better working memory/speed would tend to show better flight performance, $r = 0.279$, $p = 0.045$.

4.6 Experience and Simulated Flight Performance

Experienced pilots were significantly better than inexperienced pilots in maintaining their flight path in the downwind leg of the circuits in the low workload condition as illustrated in Table 8.

In the high workload scenario, experience also significantly predicted flight performance as illustrated in Table 8.

Table 8

Correlation Coefficients Between Experience and Low and High Workload Flight Performance

***N* = 54**

Variable	Mean	*SD*	Low Workload Flight Performance Correlation Coefficient	High Workload Flight Performance Correlation Coefficient
Experience	9.93	2.96	0.306*	0.322*

*P = < 0.05

4.7 Age and Simulated Flight Performance

4.7.1 Relationship of Age to Simulated Low Workload Flight Performance

Analysis of age as a continuous variable showed older pilots did not perform as well as the younger pilots, r = -0.406, p = 0.002 Examination between the three pilot age groups revealed the older aged pilots had significantly lower flight performance means than the two younger age group pilots, F (2,51) = 5.693, p =0 .006, η^2 = 0.183, Table 9. Post-hoc analyses (Bonferroni) showed younger pilots performed better than the higher aged pilots (p = 0.005). There was no significant difference between the performance of younger and middle aged pilots. There was a trend for the middle aged pilots to perform better than the higher aged pilots but this was not significant (p = 0.09), *Figure 12*.

Table 9

Descriptive Data of Young, Middle, and High Age Groups in the Low and High Workload Condition

	Low Workload Flight Performance – *Z* Scores		High Workload Flight Performance – *Z* Scores	
Age in years (*n*)	Mean	*SD*	Mean	*SD*
21 to 42 (19)	0.431	0.829	0.277	0.957
43 to 58 (17)	0.124	0.860	-0.062	1.101
59 to 79 (18)	-0.572	1.061	-0.234	0.927

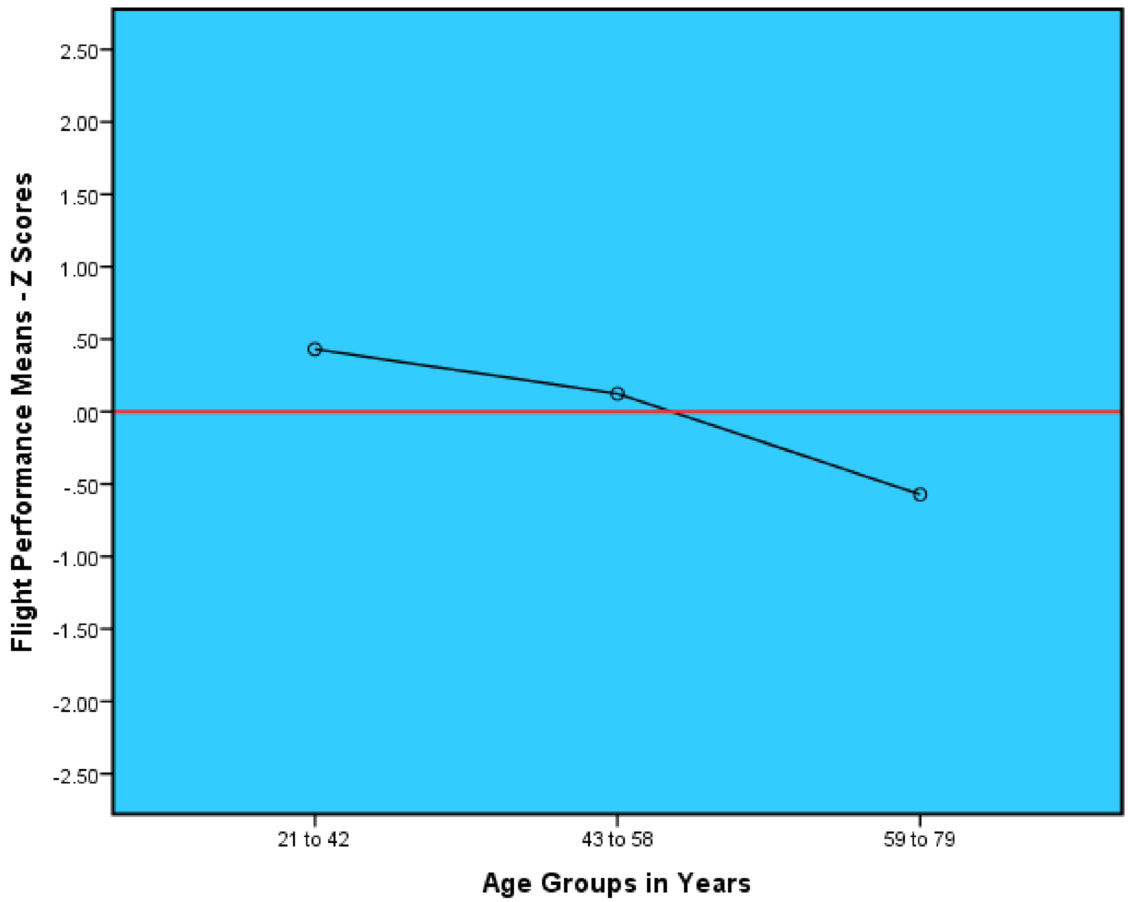

Figure 12. **Pilot age groups and low workload flight performance means.**

4.7.2 Relationship of Age to Simulated High Workload Flight Performance

In the high workload condition, analysis of age as a continuous variable showed a trend for the older pilots not performing as well as the young pilots, r = -0.253, p = 0.065. However, examination between the three pilot groups showed no difference in abilities to maintain flight path accuracy between any of the older or younger pilots, F (2, 51) = 1.266, p = 0.291, η^2 = 0.047. *Figure 13* illustrates the flight performance among the three age groups.

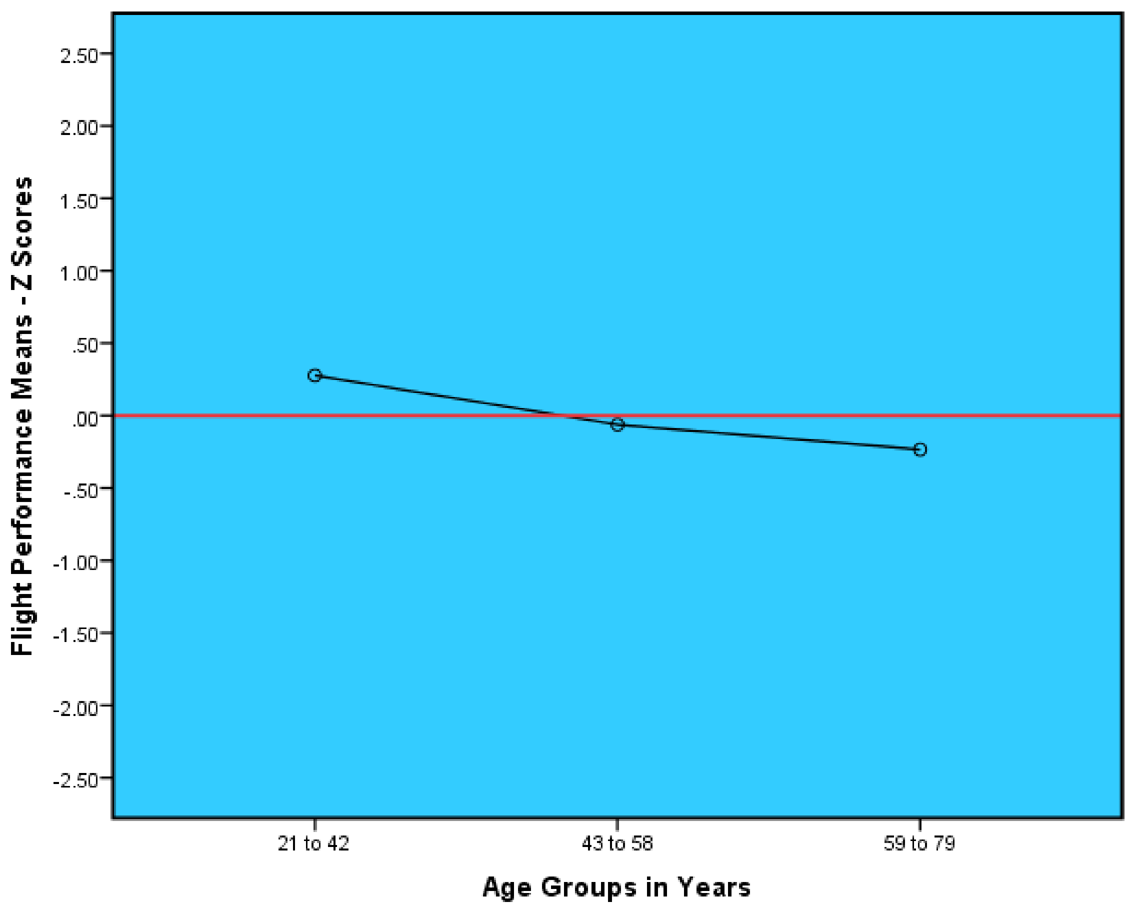

Figure 13. **Pilot age groups and high workload flight performance means.**

4.8 Education and Income and Simulated Flight Performance

Education and income were not statistically related to each other or to simulated flight performance in the low or high workload conditions as shown in Table 10.

Table 10

Correlation Coefficients Between Education and Income and Simulated Flight Performance

***N* = 54**

Individual Factor	Income (*p*)	Low Workload Flight Performance Correlation Coefficients (*p*)	High Workload Flight Performance Correlation Coefficients (*p*)
Education	0.009 (0.947)	- 0.020 (0.885)	0.057 (0.684)
Income	----	- 0.150 (0.290)	- 0.204 (0.146)

4.9 Model Development for Simulated Flight Performance

4.9.1 Model Development for Simulated Low Workload Flight Performance

Significant and stable independent variables were entered into the regression model in five blocks: (1) working memory (MTSACC, PFNLCACC), (2) processing speed (VSCRTC), (3) tracking (DTTDHIT, DTTAABS), (4) experience, and (5) age as a continuous variable.

Experience and the working memory measure MTSACC were the only variables that contributed significant unique variance to the dependent variable of flight performance while the tracking measure, DTTDHIT, made a contribution with $p = 0.104$, Table 11. Thus pilots with experience, better working memory (MTSACC), and better tracking abilities would tend to have better flight performance scores. The final model, *Figure 14*, illustrates the contribution of all significant independent variables in assisting pilots to maintain the desired flight path in the low workload condition, $F\ (8, 45) = 6.457$, $R^2 = 0.496$, $p < 0.001$.

Table 11

Significant Independent Variables in the Low Workload Condition

***N* = 54**

Variable	β	*t* (54) (*p*)	Cumulative R^2
Working Memory			0.327
MTSACC	**0.356**	**2.936 (0.005)**	
PFNLCACC	0.137	0.994 (0.325)	
Processing Speed			0.344
VSCRTC	0.006	0.045 (0.965)	
Tracking			0.434
DTTDHIT	**-0.260**	**-1.657 (0.104)**	
DTTAABS	-0.059	-0.422 (0.675)	
Experience	**0.263**	**2.361 (0.022)**	0.493
Age	-0.078	-0.511 (0.612)	0.496

Note. MTSACC = Matching-to-Sample Accuracy; PFNLCACC = average of the accuracies of Pathfinder Number, Letter, and Combined Accuracies; VSCRTC = Visual Sequence Comparison reaction speed; DTTDHIT = Dual Task Tracking Dual boundary Hits; DTTAABS = Dual Task Tracking Alone Error. See Appendix O for greater details on these measures.

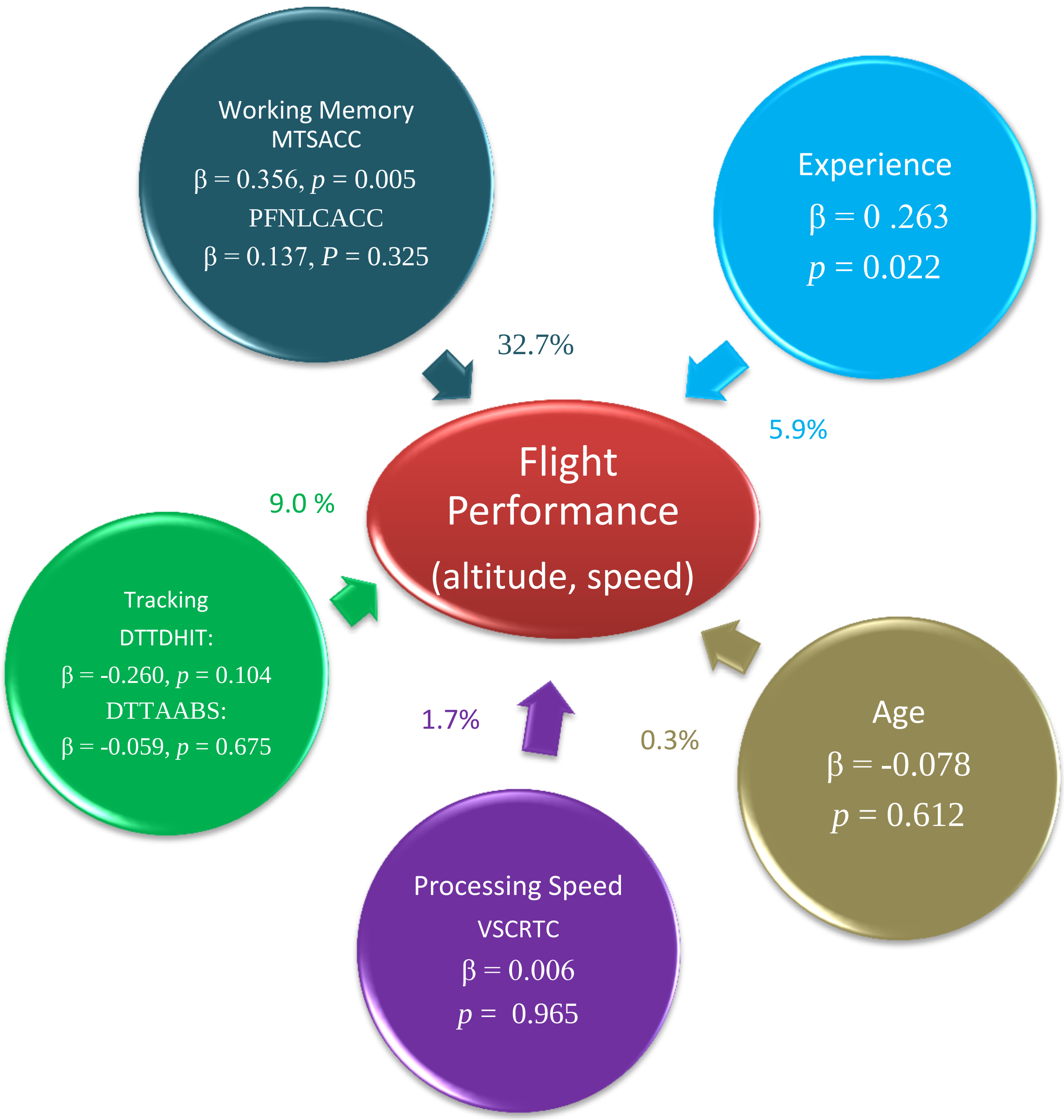

Figure 14. **Model of Simulated Low Workload Flight Performance.** The percentages reflect the unique variance each independent variable contributes to flight performance.

4.9.2 Model Development for Simulated High Workload Flight Performance

All significant independent variables were placed into the regression model in five blocks: (1) working memory (MTSACC, PFNLCACC, DTTPDACC), (2) processing speed (MATHRTC, VSCRTC, SATINRTC), (3) tracking (DTTDABS), (4) experience, and (5) age as a continuous variable.

Experience was the only variable that contributed unique variance to flight performance, Table 12. It is however evident that working memory played an important role and processing speed to a lesser extent in flight performance. The final model, *Figure 15*, illustrates the contribution of all significant independent variables in assisting pilots in maintaining the desired flight path in the downwind portion of the circuits in the high workload condition, $F\,(9, 44) = 2.627$, $R^2 = 0.350$, $p = 0.016$.

4.9.3 Logistic Regression Probability Value (LRPV) and Flight Performance

LRPV value greater than 0.6 suggests the probability of brain dysfunction (Kay, 1995). It was only significant in the high workload condition, $r = -0.346$, $p = 0.01$. LRPV was added as part of the final model for the high workload condition. Addition of LRPV increased the variance by only 1.4% and this difference did not produce a significant *F* change, $p = 0.324$. Thus LRPV does not add any significance to the overall model for high workload. Therefore, the final model for the high workload condition remains unchanged as shown *Figure 15*.

Table 12

Significant Independent Variables in the High Workload Condition

***N* = 54**

Variable	β	*T* (54) (*p*)	Cumulative R^2
Working Memory			0.244
MTSACC	0.189	1.293 (0.203)	
PFNLCACC	0.190	1.279 (0.208)	
DTTPDACC	0.094	0.512 (0.611)	
Processing Speed			0.279
MATHRTC	-0.147	-0.941 (0.352)	
VSCRTC	-0.084	-0.547 (0.587)	
SATINRTC	0.028	- 0.166 (0.869)	
Tracking			0.279
DTTDABS	0.012	0.066 (0.948)	
Experience	**0.271**	**2.110 (0.041)**	0.349
Age	0.012	-0.058(0.954)	0.350

Note. MTSACC = Matching to Sample Accuracy; PFNLCACC = average of the accuracies of Pathfinder Number, Letter, and Combined Accuracies; DTTPDACC = Dual Task Previous Number Dual Accuracy; VSCRTC = Visual Sequence Comparison reaction speed trials; MATHRTC = math reaction speed; SATINRTC = Shifting Attention Instruction reaction speed; DTTDABS = Dual Task Tracking Dual Error. See Appendix O for greater details on these measures.

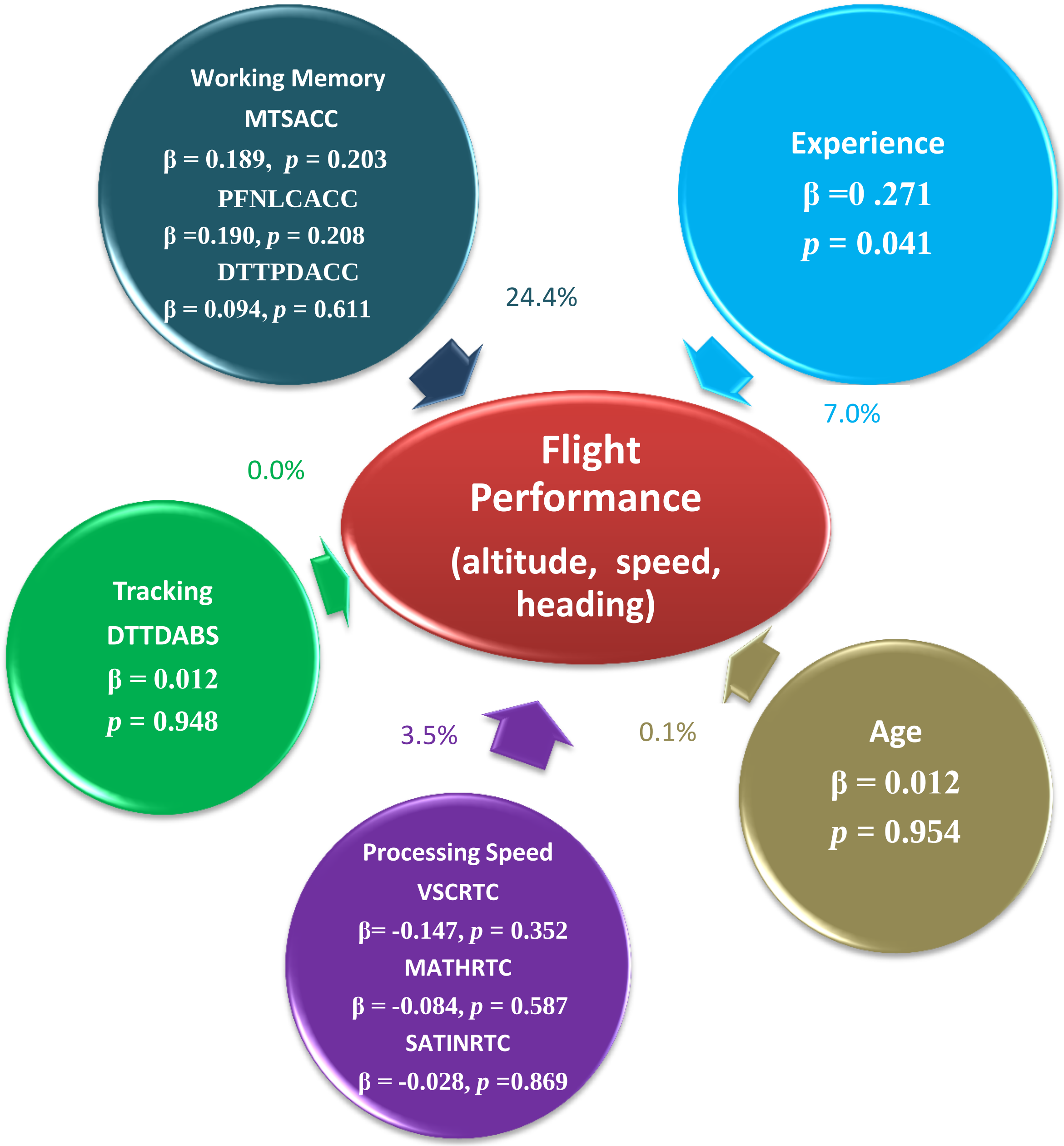

Figure 15. **Model for Simulated High Workload Flight Performance.** The percentages reflect the unique variance each independent variable contributes to flight performance.

4.10 Secondary Analysis

4.10.1 Moderating Effect of Experience

In the low workload condition, experience, working memory (MTSACC), and marginally tracking (DTTDHIT) were significantly related to flight performance. Further analyses were assessed to determine if experience was having a moderating effect between working memory (MTSACC) and flight performance. The interaction, experience X MTSACC, accounted for a significant proportion of the variance in flight performance, $\Delta R^2 = 0.079$, $\Delta F(1, 45) = 8.36$, $p = 0.006$, $\beta = 0.316$, $t(54) = 2.89$, $p = 0.006$. The interaction, experience X DTTDHIT was not significant, $\Delta R^2 = 0.019$, $\Delta F(1, 45) = 1.714$, $p = 0.192$, $\beta = -0.151$, $t(54) = -1.324$, $p = 0.192$.

The interaction graph for experience X MTSACC showed an enhancing effect, *Figure 16*, *17*. Overall, increase in experience improved flight performance as the scores on MTSACC increased. Pilots with high experience but low WM started off with better flight performance scores. Significant differences were found between participants who had:

- low WM at low and medium experience and participants with high WM and high experience (LSD, $p < 0.05$), and
- low WM at medium experience and participants with low WM and high experience (LSD, $p = 0.078$).

Thus, pilots with low experience are not likely to improve too much in their flight performance regardless of their working memory. Pilots with medium and high experience will likely perform better if they also have higher working memory with pilots with high experience and high working memory producing the best flight performance.

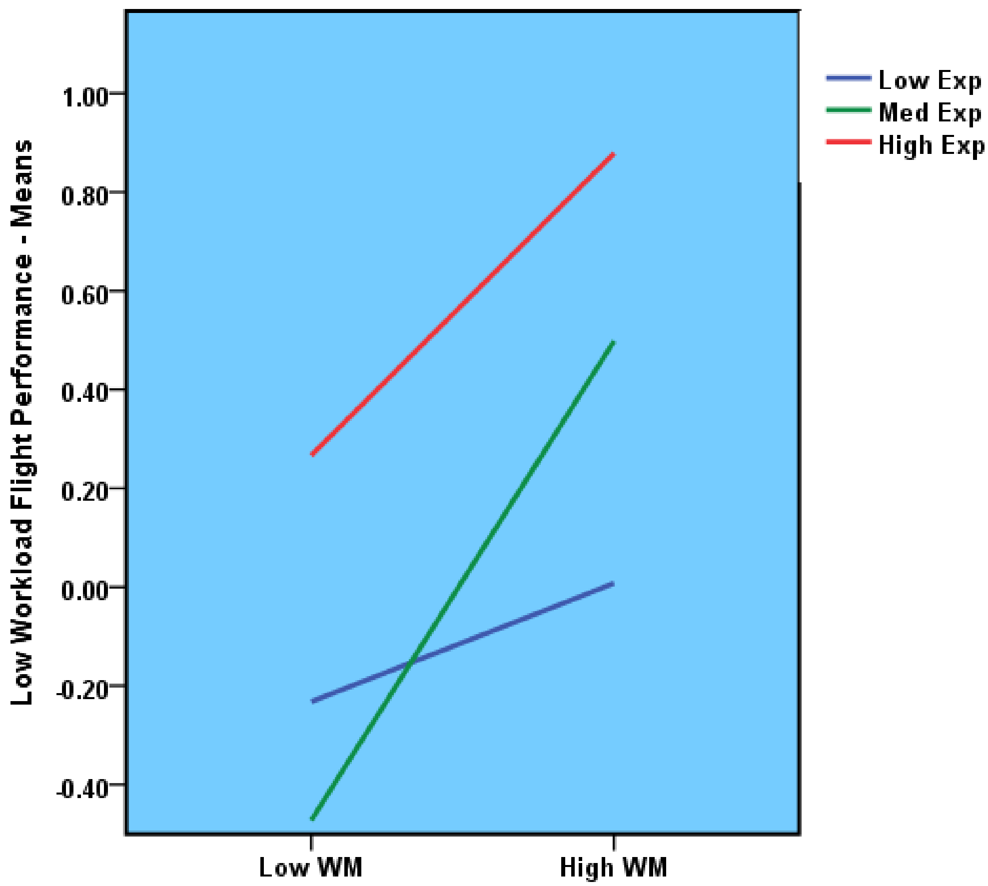

Figure 16. **Moderating effect of experience between working memory and low workload flight performance.** WM = working memory measure of MTSACC. Exp = experience.

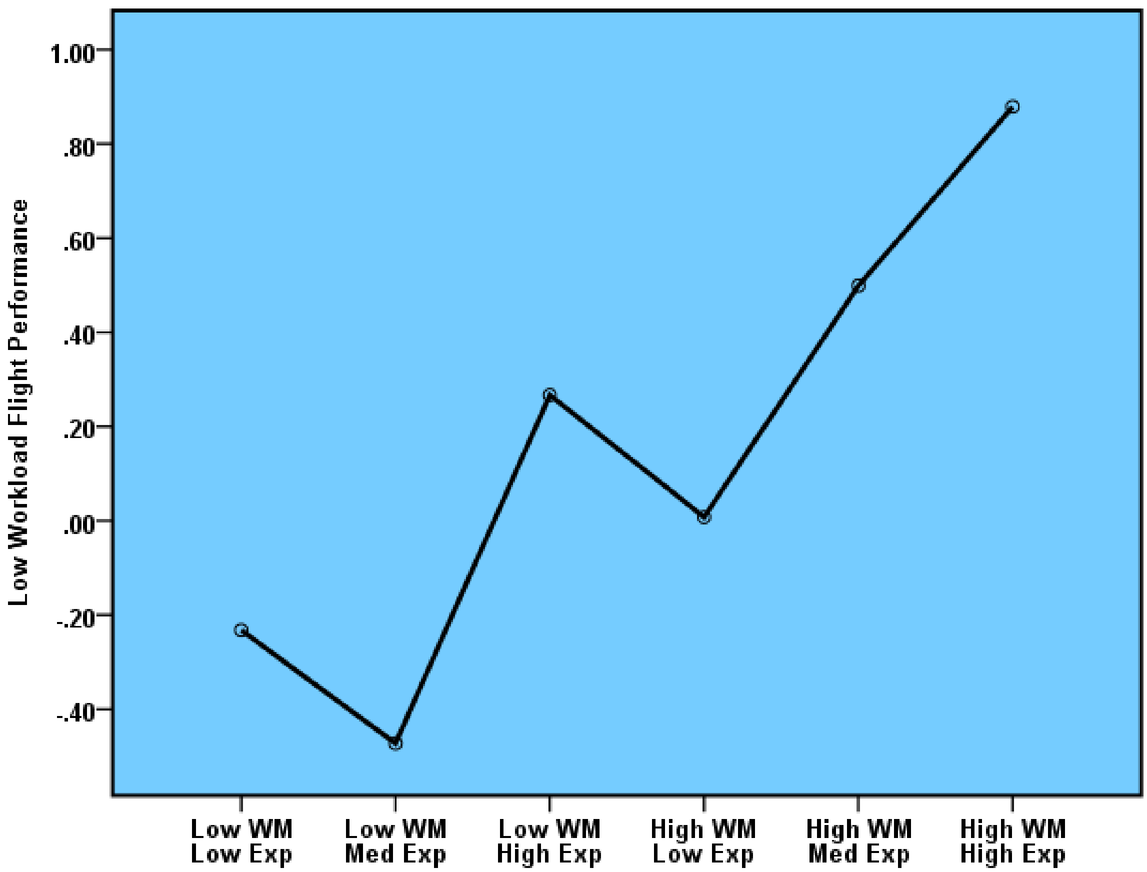

Figure 17. **Interaction of working memory and experience and low workload flight performance.** WM = working memory. Exp = experience.

4.11 Power Analysis

With a sample size of 54, this study had a power of 82% to detect significant results at a correlation of 0.37 or above. Thus this study was able to determine significance for age and tracking in the low workload condition and working memory in the low and high workload conditions.

In the low workload condition, at the multiple regression level of analysis, 24 participants were required with a cumulative R squared of 0.49 and a power of 83%. In the high workload condition, the R squared value was lower at 0.35 and hence 39 participants were required for a power of 81%. Thus at the multiple regression level of analysis, this study of 54 participants had enough power.

5 Discussion

5.1 Objective

The objective of this research was to explore the relationship of individual pilot factors to flying performance in a simulated task environment. The specific aim was to determine if age, cognitive abilities, education, experience, and income played any significant role in a general aviation (GA) pilot's flight performance. The relationship of the factors to flight performance was examined in low and high workload conditions. The key findings of this research were:

(1) younger pilots tend to perform better than older pilots,

(2) experience improves flying performance, and

(3) working memory (WM), processing speed (PS), and tracking are important constructs of cognition beneficial to flying performance.

The demographic and flying characteristics of the participants will be first summarized, followed by a discussion regarding the determination of flight performance scores. The findings and their implications are then examined in greater detail, followed by limitations of the study.

5.2 Summary of Demographic Data and Flying Characteristics

Demographic characteristics of the 54 participants showed all but one to be male with an average age of 48.1 years, 77.8% held a college or university degree and a range of incomes below and above $80K. The participants ranged from student pilots to those with many ratings other than a recreational or a private pilot's licence. The range of experience is highlighted in the number of years licensed (0 to 63 years) and total flying hours (5 to 5440 hours). Simulator time also varied (0 to 1000 hours) but was not necessarily related to actual flying simulator experience as many participants were desktop simulator enthusiasts.

5.3 Flight Performance Difficulty and Scores

Flight performance (dependent variable) scores portray a pilot's flying ability in this study. Flight performance scores can be a composite of its three latent variables (altitude, speed, heading) which are discussed below in relation to the two workload conditions. Greater details and actual values can be found under Methodology 3.5.3 and Results 4.4.

Paired-samples t-tests from the downwind legs of the circuits from the two scenarios showed pilots deviated significantly (Table 5) in their altitudes and airspeed but not their heading. The two workload scenarios took place at actual aerodromes in Canada with the low workload scenario being a prairie rural setting, *Figure 6*. The high workload scenario was located in the Rocky Mountains surrounded by mountains on all sides, with a large river before the mountains on the approach to the landing with the runway being at a higher elevation than the town by the river's edge, *Figure 7*, *8*. Due to the surrounding mountains, the participants likely conducted tighter circuits and thus produced fewer fluctuations of their headings in the high workload scenario. It was also possible that some practice effects may have taken place as the high workload scenario was always completed after the low workload scenario by all participants.

For the low workload scenario, altitude and speed loaded significantly (Table 6) and were used to create the low workload flight performance scores. For the high workload condition, altitude, speed, and heading loaded significantly (Table 6) and were used to create the high workload flight performance scores. Since the two scenarios were different and recorded as separate entities, it was decided that the factor loadings did not need to be identical for the two scores. The two performance scores were created as z – scores as the units are quite different for the three latent indicators (altitude in feet, speed in knots, and heading in degrees).

5.4 Hypothesis 1: Relationship of Age to Simulated Flight Performance

The hypothesis that aviators with increasing age will have lower levels of simulated flight performance was partially correct. In the low workload condition, this hypothesis showed statistical significance, $r = -0.406$; $p = 0.002$ while in the high workload condition, a trend was seen for older pilots not to perform as well as younger pilots, $r = -0.253$; $p = 0.065$.

A number of possibilities exist as to why the flight performance of the older pilots did not vary greatly from the other pilots in the high workload condition. One possibility is that older pilots were more experienced and able to deal with the difficult condition due to quicker retrieval of episodic and long term memory. If this is the case, the offset decline in performance with age in demanding conditions as the result of rising experience may explain why age alone is not correlated well with flight safety and accident risk, as accidents will be more likely to occur in demanding conditions. However 11 (61%) of the 18 older pilots were in the moderate or high experience category and 10 (53%) of 19 pilots in the younger group. Visual Sequence Comparison (VSC) reaction speeds were implicated in both low and high workload conditions. In the difficult condition, older pilots (11 – 61%) had moderate to high performance scores but poor or moderately poor VSC reaction speeds compared to 5 (26%) pilots in the younger group. Examining the reverse scenario, 9 (47%) younger pilots had better performance scores and faster reaction speeds while only 1 (6%) older pilot was in this category. In the low workload condition, similar results were obtained except fewer older pilots had better performance scores. This suggests that while the younger and older pilots may be in similar flying experience groups, the actual experiences that pilots are relying on may be quite different. Another possibility is that older pilots were able to retrieve relevant information by selective attention. The difficult condition presented the older pilots with relevant visual cues for the older pilots to perform better. Murray et al. (2013) showed that selective attention, especially task relevant cues can restore forgotten items to visual short-term memory especially if some information is “lost or unavailable to retrieval processes” (p. 553). Other possibilities include: practice effects as the high workload condition always followed practice and low workload scenario or volunteer bias – older pilots with better flying performance participating in the study.

When all pilot factors were taken into account in the final models, age contributed less than 1% of the total variance. The study by Causse et al. (2011) of GA pilots also did not find any significant relationship between age and flight path deviation. Other studies (Taylor et al., 2005; Yesavage et al., 1999) have found older pilots have decreased flight performance which was demonstrated in this study. In the 3 year longitudinal study, even though the older pilots initially performed worse than younger pilots, they had less longitudinal decline than younger pilots (Taylor et al., 2007). Schmiedek et al. (2013) have shown that even though older adults have lower performance levels, their day-to-day level of performance is more stable than younger adults.

5.5 Hypothesis 2: Relationship of Cognition to Simulated Flight Performance

The hypothesis that aviators with higher levels of cognition will tend to have higher levels of simulated flight performance was supported in both low and high workload conditions. Of all the CogScreen-AE measures, the impact on flight performance was the greatest by the Working Memory measures, contributing 32.7% of the unique variance in the low workload condition (PS: 1.7%, Tracking: 9.0%) and 24.4% in the high workload condition (PS: 3.5%, Tracking 0.0%). Similar results were obtained by Taylor et al. (2000) between Processing Speed/WM and overall flight performance. PS and WM were combined in their study and produced 33% of the variance in overall flight performance with Tracking contributing an additional 3% of the variance.

In the present study, of the 10 measures used for WM, only three measures (MTSACC[8], PFNLCACC[9], DTTPDACC[10]) were significant to be part of the final model (*Figure 14*, *15*) and only MTSACC was statistically significant at $p < 0.05$ when examined with the other individual pilot factors. MTS-measures visual-perceptual and spatial-processing skills as well as short-term memory (Kay, 1995). Other short-term memory and visual-perceptual processing measures such as Visual Sequence Comparison Accuracy (VSCACC) and Symbol Digit Coding Accuracy (SDCACC), immediate and delayed call, were not significantly correlated with flight performance. The difference between MTS and the remaining tasks is that spatial-processing is required for MTS and such a skill is an asset in flying.

Neuroimaging studies show incongruent MTS causes more activation of the brain than congruent MTS (Elliott & Dolan, 1999; Zhang et al., 2008). The mismatch information requires larger attention from the prefrontal cortex (PFC) to process the conflict (Zhang et al., 2008). Pilots with abilities to control attention when conflicting

[8] MTSACC – Matching-to-Sample Accuracy.
[9] PFNLCACC – Composite accuracy of Pathfinder – number, letter, and combined number and letter.
[10] DTTPDACC – Dual Task Previous Number Dual Accuracy.
Additional information on these tasks can be found in Appendix O.

information is presented and with greater spatial-processing abilities will be able to form better three dimensional mental model (Johannsdottir et al., 2003) of other aircraft in relation to the pilot, airport, runway, and ATC instruction.

Pathfinder measures number and sequencing skills, systematically apply an organizing principle, immediate memory, motor coordination, visual scanning, and ability to shift mental set (Kay, 1995). Alternating from letter to number in a sequence is an executive function which requires flexibility but also places greater demands on WM. Information needs to be kept in storage/rehearsal while the alternate value in the sequence is visually located. Similarly in the DTTPDACC task, (tracking and N-1 back) requires "maintenance of the last stimuli (in order) and updating of these stimuli each time a new stimulus occurs" (Fletcher & Henson, 2001; p. 855). Neuroimaging studies have shown these tasks to activate various regions of the PFC (Fletcher & Henson, 2001).

Processing speed's contribution in both workload conditions was not significant in the final model in this study. PS in the study by Causse et al. (2011) was examined separately from WM using other cognitive tests than the CogScreen-AE battery. PS was not a predictor of simulated flight performance but WM was predictive of flight performance. Since ageing affects long range networks, PS is affected (Tomasi & Volkow, 2012). Therefore it is not unexpected to have longitudinal PS declines with age predicting flight performance as in the study of Yesavage et al. (2011) which may not be seen in cross-sectional studies such as this study. However, it should be noted that three

PS variables (VSCRTC[11], MATHRTC[12], SATINRTC[13]) in the high workload versus one (VSCRTC) in the low workload condition were implicated. Pilots with better PSs would be able to react faster to executive function and episodic memory interactions and thus apply them rapidly to their high workload condition.

Tracking abilities were only significant at $p = 0.10$ in the low workload condition. It is possible that due to the less stressful condition, pilots were able to perform appropriate flying tasks and along with WM able to obtain higher flying performance. In summary, pilots with greater WM, the ability to maintain and manipulate information, tend to do better at their simulated flying performance.

5.6 Hypothesis 3: Relationship of Experience to Simulated Flight Performance

The hypothesis that aviators with higher levels of flying experience will tend to have higher levels of simulated flight performance was supported in both the low and high workload conditions as well as the final models. Other studies (Cause et al., 2011, 2011a; Kennedy et al., 2010; Morrow et al., 1994, 1996; Taylor et al., 2007) have shown experience to be predictive of total flight performance or specific aspects of flying such as following ATC instructions.

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[11] VSCRTC – Visual Sequence Comparison reaction speed
[12] MATHRTC – reaction speed in solving Math problems
[13] SATINRTC – Shifting Attention Instruction reaction speed
See Appendix O for additional information on these tasks.

Total hours of flying do not necessarily predict better flying abilities (Ebbatson et al., 2010; Taylor et al., 2005). In the Hilton Age 60 Study (Hyland et al., 1994), simulator time in the last 30 days correlated better with flight performance in experienced B727 pilots rather than actual flying hours in the last 30 days or total flying hours. Similarly, it was cross-country time flown in the last 30 and 90 days that determined how quickly pilots diverted from adverse weather conditions in long cross-country flights (Wiegmann et al., 2002).

In this study, experience was a composite score of the number of hours flown in the last year, total hours flown, simulator time, and rating. Total years licensed was not included, as years licensed do not necessarily equate to greater flying hours. Rating was included under the experience category as this specifies a certain amount of formal, regulatory training has taken place and thereby meeting a specified standard of knowledge and competence. Thus expert pilots would tend to have better flight performance especially in dealing with complex situations as the high workload scenario in this study. Through additional training (ratings), expert pilots could be expected to learn strategies in allocating attention, improve scanning patterns, and better management of task switching and interruptions (Wickens & McCarley, 2008). The integration of information by the episodic buffer and by the visuospatial sketchpad with the central executive was most readily noted by pilot verbalization post scenario in relation to aircraft avoidance strategies and explanations of similar previous incidents to their present situation.

This study examined flight path deviation from the “perfect” circuit and not specifically a pilot’s response to difficult situations in relation to previous experience. However, Morrow et al. (2009) did examine responses to complex flying situations in pen and paper scenarios. Experienced pilots were able to make better flying decisions than novice pilots.

Flying expertise, whether it is through ratings, recent flying hours, total flying hours, years of flying or a composite of all of these and possibly other variables, affecting flying performance supports the concept of domain-relevant experience. To become an expert requires ten years of deliberate practice in the appropriate domain (Ericsson et al., 1993). Kaufman & Kaufman (2007) found even though there was variability, it took 10.6 years for a writer to be considered an expert defined as the time from first publication to the best publication.

Expert status also allows for quicker linkage and retrieval of information between episodic and long-term memory than for non-experts (Draganski, 2006; Groussard et al., 2010) which would enable expert pilots to focus attention on more critical information in complex situations (Morrow et al., 2009). If jugglers have changes in their visual areas (Draganski, 2004), it is possible for pilots especially expert pilots to also have such structural changes as piloting involves tremendous amount visual-spatial attentiveness, both inside and outside of the aircraft. Thus, it is not surprising in this study for pilots with flying experience to have better flying performance in both workload conditions.

5.7 Hypothesis 4: Relationship of Education and Income to Simulated Flight Performance

The hypothesis that aviators with higher levels of education and income will tend to have higher levels of simulated flight performance was not supported in this study in either workload condition. This finding was somewhat unexpected. Pilots in this study with a college or university education or income above $80K represented almost 90% of the participants. It is possible that the small sample size, lack of variability in the education and income parameters, and volunteer bias prevented the exposure of subtle differences.

There may be another possibility for education and flight performance not to demonstrate a relationship. Attainment of higher education, better working memory (Alloway & Alloway, 2010; Mayer, 2011), denotes the achievement of certain domain specific knowledge but also an ability to learn (Mayer, 2011). Actual flying involves very domain specific knowledge and motor abilities. Thus, any type of higher education may not correlate with actual flying performance but may be more predictive of pilots being able to learn additional flying education and thereby improve their flying performance.

There are very few studies that examine education and its association to flight performance. Adamson et al. (2012) found education to have a moderating effect on brain size and thus indirectly affecting simulated flight performance. They had also found that education to be positively correlated to expertise but this relationship was not significant. Taylor et al. (2007) found no significant correlation between education and aviation expertise. Similarly, in this study education was not associated to flying experience.

Similar results were obtained to Lee et al. (2006) with respect to finding no association between education and income. Wealth rather than income (Cagney & Lauderdale, 2002) and family rather than individual income (Evans & Schamberg, 2009) are often better predictors of cognition and achievement. This study only collected individual income data. Different results may have been produced if data had been collected on family income or wealth.

5.8 Moderating Effects of Experience

Since experience and WM measure (MTSACC) were both significantly correlated with flight performance in the low workload, analysis was undertaken to determine if experience was having a moderating effect between WM (MTSACC) and flight performance. Indeed, the interaction of experience X MTSACC accounted for nearly an additional 8% of the variance in flight performance. As seen in *Figure 16*, pilots with high working memory but low experience saw minimal gains in flight performance and pilots with high working memory and high experience made the largest gains in flight performance scores. Also, pilots with higher experience but with low memory start off with higher flight performance scores than less expert pilots. In the longitudinal study by Yesavage et al. (2011), expert pilots also had higher baseline performances. These results support domain-relevant experience having a positive effect on flying performance.

5.9 Logistic Regression Probability Value (LRPV) and Flight Performance

Logistic Regression Probability Value is a value ranging from zero to one (0 – 1.0) provided in the results of the CogScreen-AE battery. The higher the value of the LRPV, the higher probability of brain dysfunction (Kay, 1995). In this study LRPV was only significant with flight performance scores in the high workload condition but this significance did not hold when other pilot factors were taken into consideration. Scores greater than 0.60 on the LRPV can be suggestive of brain dysfunction (Kay, 1995). In this study 28 (51.9%) of the pilots scored above 0.60. Four of these pilots (7% of the total participants) were under or equal to age 45. In the U.S. normative data 29.4% of the pilots above age 45 had LRPV greater than 0.60 while 10% of the pilots under age 45 had a LRPV greater than 0.60. The participants in this study were GA pilots while the LRPV derivation occurred with airline pilots. These results highlight the fact that caution should be used in interpreting these results especially outside of the sample from which LRPV derivation took place (Kay, 1995).

5.10 Taylor Aviation Factor Scores

An additional comparison can be carried out between the results obtained by the methodology used in this study and the results provided by CogScreen-AE related to the Taylor Aviation Factor Scores for the same participants. Taylor factors of Attribute

Identification (deductive reasoning) and Tracking (error score) were significantly related to flight performance in the low workload condition. In this study Tracking and WM correlated with flight performance. The Shifting Attention Test (SAT) measures used for Attribute Identification, in particular those measures related to accuracy were not significant in this study. In the high workload only the Taylor factor Speed/WM was significant. In the final model of this study, WM was not significant but did provide a large percentage (24%) of the variance toward flight performance.

Similarity in the results by somewhat different methodologies does provide assurance of the validity of the results. It also highlights that different CogScreen-AE measures can be used by researchers to obtain similar results.

5.11 Limitations

One of the major limitations of this study was its small size which likely was affected by the voluntary time commitment of approximately four hours. Many pilots enquired about participating but were unable to due to their work and travel commitments. Nonetheless, this study size is comparable to and larger than many of the studies reviewed on this subject.

Volunteer bias may have affected the results as volunteers tend to be more educated, come from a higher social class, more intelligent, and more sociable (Boughner, 2010).

Large amount of data handling was involved in this study. For flight performance, data retrieval of the downwind leg of the circuit from two scenarios for each participant was an intricate task as was the retrieval of the raw data of the CogScreen-AE's 99 measures. To reduce any errors, random checks were performed with individual participant records, partial analysis of the results, examining data points that looked abnormal and then verifying them with the original raw data. As discussed earlier, all CogScreen-AE measures were individually examined and oddities verified with the raw data. It is possible that errors may have occurred in coding and inputting large amounts of data onto the statistical programme even though the utmost care was taken with handling of the dataset.

CogScreen-AE is composed of 99 measures and determining how to utilize these measures can be challenging. There are many possible combinations of measures that could be utilized to study various constructs. This study did not examine interference, inhibition, motor co-ordination, or reasoning. However, this study undertook to study cognition by examining working memory, processing speed, and tracking from experimental data related to these constructs rather than using calculated CogScreen-AE data.

Many scenarios could have been used to test flight performance. However, the reproduction of the "perfect" circuit by the participants was a simple but an effective method of obtaining flight performance data. It is possible the circuit flying was too "simple" for some participants and may be the reason why heading did not load in the low workload condition.   Also, the mountainous terrain in the high workload condition may have made the participants fly a tighter circuit and thus leading to little variability in heading.

The flight testing order was the same for all participants, four practice circuits followed by the low workload scenario, and finally the high workload scenario. Practice effects may have taken place by the time participants encountered the high workload scenario.

As mentioned in the Introduction, physical, mental, and environmental stressors were not taken into consideration which may have had an unfavourable effect on domain-independent skills such as reducing working memory capacity (Hardy & Parasuraman, 1997).

6 Conclusions, Implications, and Recommendations

This study's aim was to examine the relationship of the individual pilot factors of age, cognition, education, experience, and income to flight performance in general aviation (GA) pilots determined in low and high workload conditions. The following Conclusion is followed by Implications, and Recommendations and Need for Future Research.

6.1 Conclusions

In this study, 53 of the 54 participants were male, ranging from 21 to 79 years, highly educated, and reported varied amounts of flying experience. Cognition, and in particular working memory (WM), and experience were important predictors of flight performance. Older pilots had slower processing speeds. Pilots with better WM and greater flying experience obtained the greatest gains to their flight performance. Chronological age itself was not a good predictor of flying performance.

In this study, the neuropsychological battery, CogScreen-AE was employed to test cognition as it is often used by the Federal Aviation Administration (FAA) to assess cognitive performance in pilots. Raw scores were used for analysis rather than the reports that this battery generates on each pilot. CogScreen-AE produces a variable known as the Logistic Regression Probability Value (LRPV); a value greater than 0.60 signifies greater probability for brain dysfunction (Kay, 1995). In this study, almost 52% of the GA pilots had scores greater than 0.60. Since the LRPV was derived from data from airline/commercial pilots, its use in GA pilots should be interpreted with caution.

6.2 Implications

I. Cognitive abilities, especially WM, are predictive of flying performance. It seems reasonable to suggest that some form of cognitive battery could be used prior to starting aviation training. Some flying schools already use some form of cognitive/personality testing but such testing is geared for young professional pilots (OAS, 2014). The purpose of such testing in this context is to control the entry of pilots into training who are not suitable for either training or a flying career. However, this form of testing is not undertaken for GA pilots and the author is not aware of any tailored screening batteries relevant to GA flying performance requirements.

If testing for GA pilots was to exist, flying schools may not be eager to implement such tests as testing might potentially lead to a decrease in the number of students learning to fly in the GA category. The time and/or financial burden might also be a hindrance for potential students.

II. Knowing that cognition is important for flying performance, should there be formal ongoing testing of GA pilots? Normal ageing research shows that cognitive decline accelerates after age 70 (Scahill, 2003). Should testing, if implemented start at age 70 or another age as in driving in some provinces of Canada? In Ontario, drivers over 80 years, every two years, needed to pass a vision test, driver record review, attend a group education session, written knowledge test, and possibly a road test . However, starting in April 2014, octogenarians will no longer write the knowledge test as it relies more on education and long term memory. The knowledge test will be replaced by two non-computerized in-class screening tests – drawing the face of the clock and placing the numbers inside it (visual-spatial, planning, organizing) and marking out all the "hs" (attention) in a group of letters (Clark, 2014).

Screening cognitive tests in pilots will not be equivalent to the actual flying performance but may allow pick-up of early cognitive problems, with verification from a follow-up flying test. Performing screening tests at time of the aviation medical certification may provide a regular opportunity to implement these tests starting perhaps at age 70.

III. Experience benefits flight performance and has a moderating effect between cognition and flight performance. All flying rental organizations have a policy of how often a pilots needs to fly otherwise the pilot needs to undergo a check ride before renting an aircraft; e.g. flying every 30 days. For renters this often provides an incentive to rent on a regular basis and keep familiar with flying tasks. However, there is no such incentive for those pilots who own their own aircraft, or who may co-operatively share an aircraft with a number of other pilots. Should there be minimum requirements of frequency and/or hours for pilots to fly? This is an area where insurance companies may have an impact on the flying habits of GA pilots. Some insurance policies already dictate the number of hours required on a GA pilot's aircraft before insuring the pilot/aircraft. At a local non-instructing flying club, the insurance company requires a pilot to fly minimum six hours annually with the pilot flying once every 90 days.

As shown in the literature review total flying hours or years licenced do not necessarily parallel better flying performance. Therefore, insurance companies may in the future dictate the type of flying required, such as practicing or being checked out by an instructor in emergency procedures. During this research an insurance company representatives, through a local instruction based flying club, visited the laboratory where this research was being conducted.

IV. Findings of older pilots' flight performance not varying greatly from the other pilots in the high workload condition can imply that older pilots are trainable. Learning to pick-up cues, focusing attention, and purposefully practicing a skill are all trainable tasks (Mather, 2010; Schmiedek et al., 2013). Wiggens et al. (2003) showed GA pilots could be trained to make appropriate decisions in adverse weather conditions with computer-based training or even reflective learning (O'Hare et al., 2010). Large airlines already use simulators to practice events, especially emergency related events which would be impossible to practice in an actual, large 575 passenger aircraft such as the Airbus A380.

The author has noted over the years the increase in simulators at many flying clubs, often to reduce the costs of learning to fly. However, there are implications for increasing the use of simulators with GA pilots to practice and improve skills.

V. In addition to IV above, research has shown stressful situations can reduce the ability of the prefrontal cortex to focus attention and error monitoring (Arnsten, 2009). However with normal ageing, older adults retain the ability or improve in learning from their environments especially with emotional information impacting positively on attention and memory (Mather, 2010). These attributes of the older normal ageing adult has inferences to the manner in which learning/education may be delivered to the older pilots.

VI. In everyday functioning most adults are not required to perform at one's maximum and therefore declines in cognition or performance are not noted (Salthouse, 2012). In this study middle aged and older pilot flying performances scores were less than the younger pilots. In conjunction with IV and V above, determining/learning the limits of one's ability may be useful in heightening awareness and improvement in flight safety.

VII. In this study almost 52% of the GA pilots had LPRV scores suggestive of brain dysfunction . Such implications need to be interpreted very cautiously. This and other studies using CogSCreen-AE have always used the raw scores as opposed to the results generated by the battery. This suggests that this neuropsychological battery may be difficult to use in its present form without obtaining further knowledge and statistical expertise.

6.3 Recommendations and Need for Future Research

- Research is still required to determine the majority of the factors that may influence flight performance of general aviation (GA) pilots as most studies including this one are only able to predict less than 50% of the variance.
- Since experience is predictive of flying performance and has a moderating effect between cognition and flying performance; determining some of the nuances of flying experience for GA would be most beneficial for flight safety.
- Research into cognition as applicable to GA from various research groups around the world would be beneficial in bringing forth different viewpoints and strategies. Certainly basic research using neuroimaging studies will likely provide the biggest benefit in determining how our brains function.
- The neuropsychological battery used in this study needs to be used with caution with GA pilots especially when using the generated report(s) or the LPRV score.
- Development of a neuropsychological tool designed, tested, and validated with GA pilots would be beneficial for GA.
- Screening tool(s) to determine cognition declines might be instituted with regular pilot medical certification at a particular age. This would require some thought as to

which tool would provide the best results. Conversations with the GA pilots and organizations representing them may be beneficial before instituting such a tool.

Awareness at the local level for the local pilot of the constituents of flight safety may provide some of the biggest benefits in improving safety. Some pilots do not obtain further training or knowledge after having obtained their licence. Some of the GA pilots in the study suggested having access to a simulator to try similar scenarios for education purposes. In this regard, education by way of seminars, summary reports, fun simulator sessions, e-mails, social media as well as involvement of GA organizations, regulatory bodies, and local flying schools and clubs is necessary to bring forth awareness of concerns related to GA pilots. In this regard, American Owners and Pilots Association (AOPA) has a list of useful recommendations ranging from physical, mental to operational that are geared for the ageing GA pilot, Appendix P (AOPA ASI, 2013).

Appendix A

Certificate of Ethics Clearance

Carleton University
Psychology Research Ethics Board

Certificate of Ethics Clearance

Principal Investigator	Department	StudyNumber
Chris Herdman	**Psychology**	**10-034**

Institution(s) where research will be conducted:

Carleton University

Co-Investigators and other researchers:

Researcher	Study Role	Position
Chris Herdman	Faculty Sponsor	Faculty

Study Title: **The Usefulness of a Cognitive Assessment Battery in Evaluating General Aviation Performance**

Approval Date: **09/01/2013** Validity Term: **1 Until Aug 31st Next** Approval Type: Final

Submitted Date	Study Component	Approval Date
09/12/2011	Addendum	09/13/2011
08/26/2010	Report	09/01/2010
08/19/2011	Report	08/30/2011
08/17/2012	Report	08/21/2012

Comments:

Certification

The protocol describing the above-named project has been reviewed by Carleton University Psychology Research Ethics Board and the research procedures were found to be acceptable on ethical grounds for research involving human participants.

Shelley Brown

Chair, Ethics Committee for Psychology Research

This Certificate of Clearance is valid for the above term provided there is no change in the research procedures.

Close Print

Appendix B

Flying Organization Permission Recruitment Form

Flying Organization Recruitment Permission: General Aviation Study

I, ____, ____ of

(NAME) (TITLE)

____, grant the ACE Lab at Carleton University,

(ORGANIZATION)

permission to recruit participants for a general aviation study.

Recruitment advertising will include personal referrals and/or a poster display.

A copy of the proposed poster details is attached.

____, ____________________________

(SIGNATURE) (DATE)

Please return via email (by PDF) to kvbenthe@connect.carleton.ca or rgtolton@gmail.com or

Fax to 613-341-8954. Thank You.

Appendix C

Recruitment Poster

Full-Scale Cessna Simulator Study

The ACE Lab at Carleton University is looking for participants for a study to explore cognition and general aviation.

If you are: a pilot or a pilot in training
medically licensed to fly
at least 18 years of age and
interested in flying a full-scale Cessna 172 simulator

Please contact one of us to learn more and/or to arrange a time to participate in the study.

The study session is approximately four hours and takes place at Carleton University.

Participation is completely voluntary. You will not be compensated monetarily or otherwise for participating in this study but parking costs will be paid by the study.

Thank you,

Kathleen Van Benthem	Rani Tolton
kvbenthe@connect.carleton.ca	rgtolton@gmail.com
PhD Program	Masters Program

Appendix D

Informed Consent Form

Informed Consent Form

Study: The Usefulness of a Cognitive Assessment Battery in Predicting General Aviation Performance

Faculty Sponsor: Dr. Chris M. Herdman, Department of Psychology Carleton University, tel. 613-520-2600 x.8122

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation. The informed consent must provide you with enough information so that you have the opportunity to determine whether you wish to participate in the study. Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel:

In addition to the Faculty Sponsor named above, the following people are involved in this research and may be contacted at any time should you require further information about this study: Kathy Van Benthem (613-520-2600 ext 2527), Rani Tolton (613-341-8954) or Matthew Brown (613-520-2600 ext 2487).

Should you have any ethical concerns regarding this study then please contact: Dr. Janet Mantler, Chair, Department of Psychology, janet_mantler@carleton.ca, ext 2648.

Should you have any other concerns about this study then please contact: Dr. Anne Bowker, Carleton University Ethics Committee for Psychological Research, psychchairChair @carleton.ca (613-520-2600 ext. 8218).

Purpose:

The purpose of this study is to assess the effects of mental workload on situation awareness and flying performance using a Cessna aircraft simulator.

Task:

Your first task will be to complete a brief questionnaire about your experience as a general aviation pilot and a cognitive assessment using touch screen technology. You will then be instructed in the requirements for flying a "perfect circuit." Your next task will be to fly six circuits (including touch-and-go landings) using a medium-fidelity Cessna simulator. Other aircraft will be gradually introduced into this circuit pattern as you progress through the experiment. Notification of these additional aircraft will be made via radio calls. Each circuit will require approximately six minutes to complete. While you are flying the circuits, the simulation will "freeze" twice, at which point you will be required to remember the details of your circuit and the other aircraft in the circuit.

Locale, Duration, and Compensation:

Testing will take place in VSIM 1214 at Carleton University and will take approximately 4 hours. You will not be compensated monetarily or otherwise for participating in this experiment. This research is not affiliated with any flying club, flight school or aviation program. There is no compensation to you by the university, flight club, flight school or aviation program for your participation.

Potential Risks/Discomfort:

There are no potential psychological risks associated with participation in this experiment. Please note that your performance on the task in this experiment does not provide an indication of your skills as a pilot. However, if you feel anxious and/or uncomfortable about your performance in this experiment or feel effects of the simulator, please bring your concerns to the researcher's attention.

Anonymity/Confidentiality:

All data collected in this experiment will be kept strictly confidential through the assignment of a coded number. The information provided will be useful for research purposes only and you will not be identified by name in any reports produced from this study. Further, the information is made available only to the researchers associated with this experiment.

Right to Withdraw/Omit:

You have the right to withdraw from this experiment at any time without penalty. Your participation in this experiment is completely voluntary.

I have read the above description of the study examining the usefulness of a cognitive assessment battery in predicting general aviation flight performance.

Name: ______________________________

Date: _______________________________

Signature: ___________________________

Witness: _____________________________

Date: _______________________________

Appendix E

Demographic Information

Participant #: ________

Background Information

Gender: M / F

Is your vision 20/20? yes / no

If no,

Do you wear corrective eyewear? yes / no

If yes,

What kind of eyewear? glasses / contact lenses

Do you have a current medical certification? yes/no Category ___________

Flexibility Limitations ______________________ (i.e. monocular vision)

DOB: Day _____Month____ Year 19________

Current License: __________________ Current Rating ____________________________

Number of years with a valid pilot's license:_________________________

Recreational:	years
Private:	years
Commercial:	years
Airline Transport: Military	years years

Approximate number of flight hours:

Aircraft Type	Flight Hours

How many hours have you been Pilot in Command (PIC) in the last year?

Participant #: _________

When was the last time you flew a circuit?

Do you have any experience with Yorkton Airport in Saskatchewan?

Yes / No

Do you have any experience with Kaslo Airport in British Columbia?

Yes / No

If yes, please provide details (e.g., instructed there, stopped for refueling).

Are you comfortable flying a Cessna 172? Yes / No

What percentage of your flight time do you spend in an uncontrolled aerodrome?

___________%

Have you used flight simulation software previously? Yes/No

If yes,

For approximately how many hours? ___________

Could you briefly describe the simulator system you have used most?

____

Highest level of completed education:______________________

1= grade school, 2= High School, 3= College, 4=University

5= Other (please specify__________________)

Optional....Income bracket (current or last year of work) _____________

1 = Below 40, 2= 40-80, 3= 80-130, 4 = >130

Other relevant information:____

____

Appendix F

Circuit Instructions

Circuit Instructions

We begin with four warm-up circuits at your own local airport in a Cessna 172 Skyhawk. Your call sign is whatever you wish.

A. You will be asked to fly four "warm up" left-handed circuits to give you a "feel" for the aircraft and to practice making your six radio calls per circuit.

1. The first warm up circuit will start on the ground just before takeoff and requires you to do a full stop.
2. After you come to a full stop you will don a headset through which you will hear faint background "chatter". Later on in the experimental circuits you will also hear aircraft in your own circuit via this headset. You will also be given a small thumb switch to wear and will practice "clicking" the switch each time you hear a small "beep". You will wear the switch and respond to the beeps during the remainder of your simulated flight today.
3. The second warm-up circuit will begin from a full stop and you are to perform a touch-and-go into the third circuit and then again into the fourth circuit.
4. You are to perform a full stop after the fourth circuit.

   There will be no other traffic in the circuit during this warm-up phase.

B. Following the warm up circuits, the simulation will be reset

   1. **Middleton #1**:After a short break you will be asked to fly left-handed circuits starting from a full stop on the runway. Please proceed to the second and third circuits via a touch and go landing. There will be other traffic in the circuit making their own radio calls. Their calls may overlap yours, do not ignore their communication, you should complete your call once the other aircraft has stopped communicating.

The simulation will be halted at a random time where your "situation awareness" will be assessed. Please remain in the aircraft during the freeze

   2. **Middleton #2**: Finally you will be asked to fly left-handed circuits again, beginning from a full stop on the runway, with touch and go landings between each of the remaining circuits. Their calls may overlap yours, do not ignore their communication, you should complete your call once the other aircraft has stopped communicating.

The simulation will be halted at a random time where your "situation awareness" will be assessed once more.

Between each set of three circuits you will be given two short scales to complete where you will evaluate your own situation awareness and sense of task workload.

You will then be debriefed.

Your goal during flight is to adhere as closely as possible to the prescribed "typical" circuit, including making the required radio calls, while maintaining awareness of other aircraft.

Please respond to the beeps you hear as quickly as possible.

Circuits are to be flown as follows:

- Takeoff from runway at Airport. **Radio call – takeoff (or rolling...)- also when on runway between touch and go.**
- Adhere to a rate of climb, at 75 knots, that results in you being at 500'AGL when 1 nm from the end of the runway. **Radio call - when successfully off runway (airborne...)**
- Turn to the crosswind, flying at 75 knots, continue climbing to 1000'AGL before turning to the downwind.
- Maintain an altitude of 1000' AGL for the downwind and a speed of 100 knots. **Radio call – going downwind.**
- **Radio call – mid-downwind**
- Turn to base when you have traveled 1nm past the end of the runway reduce your speed to 75 knots. **Radio call – going base.**
- Follow a rate of decline on the base such that you are traveling at 75 knots and you are at 500' AGL when beginning your turn to final. **Radio call – going final**
- Travel at 65 knots when on final.
- You should attempt to touch down on the numbers, traveling at 60 knots and perform a touch-and-go.

You are to make radio calls at the following times (you may make more if you wish):

- Takeoff (Rolling)
- Airborne (or away)
- Turning downwind
- Mid Downwind
- Turning Base
- Turning Final

If you select to change your circuit in anyway please indicate your intentions with a new radio call- such as changing a landing to an overshoot.

Appendix G

CogScreen-AE

www. Cogscreen.com

COGSCREEN™

Aeromedical Edition
Overview
Sample Report

Applications
Aviation
Pharmaceutical
Industrial

Sub Test Description
References
About the Developer

Downloads
Providers
Order Form
Email

HOME

727-897-9000
202-686-6870

OVERVIEW

- CogScreen-Aeromedical Edition (CogScreen-AE) is a computer-administered and scored cognitive-screening instrument designed to rapidly assess deficits or changes in attention, immediate- and short-term memory, visual perceptual functions, sequencing functions, logical problem solving, calculation skills, reaction time, simultaneous information processing abilities, and executive functions.
- CogScreen-AE was initially designed to meet the Federal Aviation Administration's (FAA) need for an instrument that could detect subtle changes in cognitive functioning: "changes which left unnoticed may result in poor pilot judgment or slow reaction time in critical operational situations" (Engelberg, Gibbons, & Doege, 1986, p. IS89).
- CogScreen-AE meets the FAA's requirement for a sensitive and specific neurocognitive test battery for use in the medical recertification evaluation of pilots with known or suspected neurological and/or psychiatric conditions CogScreen-AE is not a test of aviation knowledge or flying skills, but rather a measure of the underlying perceptual cognitive, and information processing abilities associated with flying (Imhoff & Levine, 1986).
- CogScreen-AE consists of a series of computerized cognitive tasks, each self-contained and presented with instructions and a practice segment. The subtests are listed and described below.

DESCRIPTIONS OF COGSCREEN-AE SUBTESTS

Subtest	Description
Backward Digit Span (BDS)	Recall of a sequence of visually presented digits in reverse order.
Math	Traditional math word problems with multiple choice answer format.
Visual Sequence Comparison (VSC)	Comparison of two simultaneously presented series of letters and numbers.
Symbol Digit Coding (SDC)	Substitution of digits for symbols using a key, followed by immediate and delayed recall of symbol-digit pairs.
Matching to Sample (MTS)	Immediate recognition for a checkerboard pattern.
Manikin (MAN)	Mental rotation task requiring respondent to identify the hand in which a rotated human figure is holding a flag.
Divided Attention (DAT)	Task employs a visual monitoring task, which is presented alone and in combination with the Visual Sequence Comparison task.
Auditory Sequence Comparison (ASC)	Comparison of two series of tone patterns.
Pathfinder (PF)	Visual sequencing and scanning task that requires respondents to sequence numbers, letters, and an alternating set of numbers and letters.
Shifting Attention (SAT)	Rule-acquisition and rule-application test requiring mental flexibility and conceptual reasoning.
Dual Task (DTT)	Consists of two tasks, each of which is performed alone and then together as a simultaneous test. One task is a visual-motor tracking test. The second task is a continuous memory task involving serial digit recall.

Appendix H

Permission to Use CogScreen-AE

CogScreen® 200 Central Avenue, Suite 1230, St. Petersburg, FL 33701 Tel 202-686-7520

Rani Tolton
Kathleen Van Benthem
Institute of Cognitive Science
Carleton University
Ottawa, ON, Canada

To Whom It may Concern,

CogScreen, LLC has granted Rani Tolton and Kathleen Van Benthem a license to use CogScreen-AE in their academic research project studying cognition in general aviation.

If you have any questions please don't hesitate to contact me.

Sincerely,

Gary G. Kay, Ph.D.
President, CogScreen LLC

Appendix I

Debriefing

Debriefing

The Usefulness of a Cognitive Assessment Battery in Predicting General Aviation Flight Performance

The purpose of this study is to determine the usefulness of a cognitive assessment battery in predicting general aviation performance. In this experiment, general aviation performance, specifically situation awareness and decision-making was assessed in three ways. First, it was measured by recall of the location and details of your own and other aircraft in your flying environment. Second, it was measured in terms of flying the simulator in the "perfect circuit." Thirdly, information was collected with respect to responses to the unexpected runway incursion.

Being able to predict general aviation performance using a standardized and objective assessment tool (such as the computerized tests used in this experiment) is critically important. Knowing the capabilities and limitations of the human mind in this context is important for the safety and well-being of the general aviation community. If you are interested in learning more about cognitive assessment in general aviation flight performance, then please see the following:

Yesavage, J. A., Jo, B., Adamson, M. M., Kennedy, Q., Noda, A., Hernandez, B., & Taylor, J. L. (2011). Initial cognitive performance predicts longitudinal aviator performance. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 66*, 444-453.

This study has received ethics clearance by the Carleton University Psychology Research Ethics Board (Ethics Approval: 10-034). Should you have any ethical concerns regarding this study then please contact: Dr. Monique Sénéchal (Chair, Carleton University Ethics Committee for Psychological Research, 613-520-2600 ext. 1155).

Should you have any other concerns about this study then please contact: Dr. Jo-Anne LeFevre (Director, Institute of Cognitive Science, 613-520-2600 ext. 2693) or any of the following individuals:

Name	Title	Department	Study Role	Contact Info.
Kathleen Van Benthem	Ph.D. Student	Cognitive Science	Principal Researcher	520-2600 x. 2527
Matthew Brown	Research Scientist	Psychology	Principal Researcher	520-2600 x. 2487
Rani Tolton	M.H.S. Student	Aviation Medicine	Principal Researcher	520-2600 x. 2496
Anne Barr	Simulation Specialist	Psychology	Simulator Technician	520-2600 x. 2496
Chris Herdman	Professor	Psychology	Faculty Advisor	520-2600 x. 8122

Appendix J

CogScreen-AE Example Report

The following is a sample report of one of the participants from the study. The report has not been altered in any fashion.

LRPV SCORE

Logistic Regression Estimated Probability of Brain Dysfunction.

The following probability score (range 0 - 1.0) was generated using a model derived from a forward step-wise likelihood-ratio logistic regression analysis. A higher LRPV score indicates a higher probability of brain dysfunction. The LRPV score is for classification estimates only. Note that LRPV is significantly correlated with age and does not predict the magnitude or severity of dysfunction.

LRPV = 0.5794

BASE RATE ANALYSIS

Determines the number of scores falling at or below the 5th percentile and 15th percentile compared to a selected normative comparison group:

	Number of scores at or below 5th percentile	Percentile	T-Score
Speed	3	10	37
Accuracy	5	2.5	30
Thruput	4	5	34
Process	2	10	37

	Number of scores at or below 15th percentile	Percentile	T-Score
Speed	5	22.5	42
Accuracy	6	5	34
Thruput	5	15	40
Process	2	45	48

TAYLOR AVIATION FACTOR SCORES

Factor	Description	Z-Score	T-Score
Attribute Identification	Measure of deductive reasoning.	-1.79	32.14
Motor Coordination	Measure of motor coordination under speeded conditions.	-0.43	54.31
Visual Association Memory	Measure of visual learning and recall.	-2.45	25.47
Speed/Working Memory	Measure of visual scanning, perceptual speed, and working memory.	-0.32	46.76
Tracking	Measure of visual/psychomotor tracking accuracy.	-0.66	56.60

CogScreen Speed Scores

Baseline Database : **Major US Carriers - Age Group 1, <35**

This area has bar graphs

Percentile

Variables

VARIABLE	DESCRIPTION	SCORE	PERCENTILE	T-SCORE
ASCRTC	Auditory Sequence Comp	0.89	35.00	46
DATDRTC	Visual Monitoring Dual	0.58	75.00	57
DATIRTC	Visual Monitoring Alone	0.30	95.00	66
DATSCRTC	Div Attn Seq Comp	1.64	80.00	58
DTTAABS	Tracking Alone	2.71	97.50	71
DTTDABS	Tracking Dual	47.51	45.00	48
DTTPARTC	Previous Number Alone	0.62	12.50	38
DTTPDRTC	Previous Number Dual	0.53	77.50	58
MANRTC	Manikin	2.10	12.50	38
MATHRTC	Math	20.25	47.50	50
MTSRTC	Matching to Sample	1.85	2.50	31
PFCRTC	Pathfinder Combined	0.96	60.00	53
PFLRTC	Pathfinder Letter	0.62	42.50	48
PFNRTC	Pathfinder Number	0.81	32.50	46
SATACRTC	Arrow Color	0.76	2.50	31
SATADRTC	Arrow Direction	0.53	32.50	46
SATDIRTC	Discovery	1.72	2.50	31
SATINRTC	Instruction	0.80	17.50	41
VSCRTC	Visual Sequence Comp	1.94	42.50	48

CogScreen Accuracy Scores

Baseline Database : **Major US Carriers - Age Group 1, <35**

Percentile

Variables

VARIABLE	DESCRIPTION	SCORE	PERCENTILE	T-SCORE
ASCACC	Auditory Sequence Comp	90.00	47.50	50
BDSACC	Backward Digit Span	62.50	12.50	38
DATSCACC	Div Attn Seq Comp	90.63	67.50	54
DTTPAACC	Previous Number Alone	93.75	37.50	47
DTTPDACC	Previous Number Dual	90.38	62.50	53
MANACC	Manikin	50.00	2.50	31
MATHACC	Math	80.00	50.00	50
MTSACC	Matching to Sample	95.00	45.00	48
PFCACC	Pathfinder Combined	100.00	97.50	71
PFLACC	Pathfinder Letter	100.00	97.50	71
PFNACC	Pathfinder Number	100.00	97.50	71
SATACACC	Arrow Color	83.33	5.00	34
SATADACC	Arrow Direction	100.00	97.50	71
SATDIACC	Discovery	37.50	5.00	34
SATINACC	Instruction	93.75	17.50	41
SDCACC	Symbol Digit Coding	100.00	97.50	71
SDCDRACC	Symbol Digit Delayed Recall	16.67	5.00	34
SDCIRACC	Symbol Digit Immediate Recall	0.00	2.50	31
VSCACC	Visual Sequence Comp	100.00	97.50	71

CogScreen Thruput Scores

Baseline Database : **Major US Carriers - Age Group 1, <35**

Percentile

Variables

VARIABLE	DESCRIPTION	SCORE	PERCENTILE	T-SCORE
ASCPUT	Auditory Sequence Comp	60.88	27.50	45
DATSCPUT	Div Attn Seq Comp	33.22	82.50	59
DTTPAPUT	Previous Number Alone	91.31	17.50	41
DTTPDPUT	Previous Number Dual	103.10	80.00	58
MANPUT	Manikin	14.31	2.50	31
MATHPUT	Math	2.37	42.50	48
MTSPUT	Matching to Sample	30.76	2.50	31
PFCPUT	Pathfinder Combined	62.57	65.00	54
PFLPUT	Pathfinder Letter	97.24	42.50	48
PFNPUT	Pathfinder Number	73.80	32.50	46
SATACPUT	Arrow Color	65.53	2.50	31
SATADPUT	Arrow Direction	113.21	35.00	46
SATDIPUT	Discovery	13.07	2.50	31
SATINPUT	Instruction	70.67	12.50	38
SDCPUT	Symbol Digit Coding	33.00	35.00	46
VSCPUT	Visual Sequence Comp	31.01	45.00	48

CogScreen Process Scores

Baseline Database : **Major US Carriers - Age Group 1, <35**

Percentile

Variables

VARIABLE	DESCRIPTION	SCORE	PERCENTILE	T_SCORE
DATDPRE				
	Indicator Dual Premature Resp	2.00	55.00	51
DATIPRE				
	Indicator Alone Premature Resp	4.00	30.00	45
DTTAHIT				
	Boundary Hits - Single Task	1.00	50.00	50
DTTDHIT				
	Boundary Hits -Dual Task	1.00	67.50	54
PFCCOOR				
	Combined Coordination	0.92	97.50	71
PFLCOOR				
	Letter Coordination	1.33	67.50	54
PFNCOOR				
	Number Coordination	1.21	80.00	58
SATDIFAI				
	Discovery - Fail to Maintain Set	6.00	2.50	31
SATDIPER				
	Discovery - Perseverative Errors	0.00	97.50	71
SATDIRUL				
	Discovery - Rule Shifts	0.00	2.50	31

Calculated CogScreen Scores

VARIABLE	DESCRIPTION	SCORE
BDSMSPAN	BACKWARD DIGIT SPAN MAXIMUM SPAN	6.00
BDSTOTAL	BACKWARD DIGIT SPAN TOTAL SCORE	5.00
DATILAPS	DIVIDED ATTENTION TEST MONITOR ALONE LAPSES	0.00
DATDLAPS	DIVIDED ATTENTION TEST MONITOR DUAL LAPSES	1.00
SDCRTC	SYMBOL DIGIT CODING RESPONSE SPEED	1.82
SDCCOR	SYMBOL DIGIT CODING CORRECT RESPONSES	59.00
VSCSDRT	SPEED VARIABILITY VISUAL SEQUENCE COMP	0.72
MATHSDRT	SPEED VARIABILITY MATH	4.42
SDCSDRT	SPEED VARIABILITY SYMBOL DIGIT CODING	0.86
MTSSDRT	SPEED VARIABILITY MATCHING TO SAMPLE	0.59
MANSDRT	SPEED VARIABILITY MANIKIN	0.49
DATISDRT	SPEED VARIABILITY VISUAL MONITORING ALONE	0.12
DATDSDRT	SPEED VARIABILITY VISUAL MONITORING DUAL	0.36
DATSCSDRT	SPEED VARIABILITY SEQUENCE COMP DUAL	0.58
ASCSDRT	SPEED VARIABILITY AUDITORY SEQUENCE COMP	0.17
PFNSDRT	SPEED VARIABILITY PATHFINDER NUMBER	0.24
PFLSDRT	SPEED VARIABILITY PATHFINDER LETTER	0.28
PFCSDRT	SPEED VARIABILITY PATHFINDER COMBINED	0.82
SATINSDRT	SPEED VARIABILITY SAT INSTRUCTION	0.41
DTPNASDRT	SPEED VARIABILITY PREVIOUS NUMBER ALONE	0.27
DTPNDSDRT	SPEED VARIABILITY PREVIOUS NUMBER DUAL	0.34

Multitasking Impact Scores

VARIABLE	DESCRIPTION	SCORE
DIFINDRTC	DIVIDED ATTN TEST INDICATOR SPEED	0.27
DIFINDPRE	DIVIDED ATTN TEST INDICATOR PREMATURE HITS	-2.00
DIFSCRTC	DIVIDED ATTN TEST SEQUENCE COMP SPEED	-0.30
DIFSCACC	DIVIDED ATTN TEST SEQUENCE COMP ACCURACY	-9.38
DIFSCPUT	DIVIDED ATTN TEST SEQUENCE COMP THRUPUT	2.21
DIFTRERR	DUAL TASK TEST TRACKING ERROR	44.80
DIFTRHIT	DUAL TASK TEST TRACKING BOUNDARY HITS	0.00
DIFPNRTC	DUAL TASK TEST PREVIOUS NUMBER SPEED	-0.09
DIFPNACC	DUAL TASK TEST PREVIOUS NUMBER ACCUR	-3.37
DIFPNPUT	DUAL TASK TEST PREVIOUS NUMBER THRUPUT	11.79

Appendix K

CogScreen-AE Raw Data Example

Example of the results of four measures for 6 participants.

Tests.SDCCOR	Tests.SDCACC	Tests.SDCPUT	Tests.SDCRTC
42	97.6744	25.0447	2.34
63	100	32.8048	1.829
58	96.6667	33.0296	1.756
59	100	33.0033	1.818
79	100	42.3131	1.418
60	100	32.6264	1.839

Appendix L

Computerized Participant Raw Data Results

Sample of a portion of a participant's computerized raw results from the study.

```
BACKWARD DIGIT SPAN EXERCISE
	Tue Oct 18 14:25:23 2011 : Time and date of exercise
	 : Subject identification
	1 : Session number
	600000 : Test time (milliseconds)
	1000 : Stimulus time (milliseconds)
	1000 : Inter-stimulus time (milliseconds)
	pair #  String  Answer  Response       Result
	1       642     246     246            Correct
	2       871     178     178            Correct
	3       4651    1564    1564           Correct
	4       3864    4683    4683           Correct
	5       51792   29715   29715          Correct
	6       83174   47138   47138          Correct
	7       825931  139528  139528         Correct
	8       287564  465782  465782         Correct
	8 : Total number of digit spans
	8 : Total number of spans correct
	0 : Total number of spans incorrect
	0 : Total number of spans unanswered
	6 : Maximum span correct

Database opened
	Database write: Data.Tests.BDSACC: 100.0000
	Database write: Data.Tests.BDSMSPAN: 6.0000
	Database write: Data.Tests.BDSTOTAL: 8.0000
Database closed

Database closed


Database opened
	Database write: Data.AVAILABLETESTS:
ae;math;vsc;sdc;sdcir;mts;mt;dat_ind;dat_dual;asc;pf_num;pf_let;pf_com;sdcdr;sat_bord;sat_d
rct;sat_arrw;sat_inst;sat_dscv;dtt_ta;dtt_pna;dtt_dual
Database closed

Database closed

	MATH PROBLEM EXERCISE
	Tue Oct 18 14:28:02 2011 : Time and date of exercise
	 : Subject identification
	1 : Session number
	300000 : Test time (milliseconds)
	Problem Item #  Answer  Response       Time   Window  Accuracy
	1       0       1       1              17679  60000   Correct
	2       1       2       2              22266  60000   Correct
	3       2       3       1              28787  60000   Incorrect
	4       3       3       3              21095  60000   Correct
	5       4       1       1              29631  60000   Correct
	   5 : Total number of trials
	   4 : Total number of trials correct
	   1 : Total number of trials incorrect
	   0 : Total number of trials unanswered
	22266 : Median reaction time for all response
	21680 : Median reaction time for correct response
	5146.979 : St. Dev. of reaction time of all
	5033.535 : St. Dev. of reaction time of correct
	 2.214 : Throughput
	80.000 : Accuracy Percent
```

Appendix M

CogScreen-AE Measures Used in Analysis

Working Memory Measures

Working Memory results are given in percentages of correct trials (accuracy) or as the number of correct responses. A high accuracy value or a high number of correct responses denotes better performance on the test.

1.*	BDSMPAN	Backward Digit Span Maximum Span
2.*	MATHACC	Math Accuracy
3.	VSCACC	Visual Sequence comparison Accuracy
4.*	SDCCOR	Symbol Digit Coding Correct Responses
5.	SDCACC	Symbol Digit Coding Accuracy
6.*	SDCIRACC	Symbol Digit Coding Immediate Recall
7.*	MTSACC	Matching to Sample Accuracy
8.	MANACC	Manikin Accuracy
9.*	DATSCACC	Divided Attention Sequence Comparison Accuracy
10.	ASCACC	Auditory Sequence Comparison Accuracy
11.*	SDCDRACC	Symbol Digit Coding Delayed Recall Accuracy
12.	SATADACC	Shifting Attention Test Arrow Direction Accuracy
13.*	SATACACC	Shifting Attention Test Arrow Colour Accuracy
14.*	SATINACC	Shifting Attention Test Instruction Accuracy
15.	SATDIACC	Shifting Attention Test Discovery Accuracy
16.*	DTTPAAACC	Dual Tracking Task Previous Number Alone Accuracy
17.*	DTTPDACC	Dual Tracking Task Previous Number Dual Accuracy
18.	PFNACC	Pathfinder Number Accuracy
19.	PFLACC	Pathfinder Letter Accuracy
20.	PFCACC	Pathfinder Comparison Accuracy
21.*	PFNLCACC	Combination of the average of measures 18,19, and 20

* Measures used in Confirmatory Factor Analysis

Processing Speed Measures

Reaction speed refers to the median response time on correct trials. A high reaction speed denotes poor performance on the test.

1.*	MATHRTC	Math Reaction Speed
2.*	VSCRTC	Visual Sequence Comparison Reaction Speed
3.	SDCRTC	Symbol Digit Coding Response Reaction Speed
4.*	MTSRRTC	Matching to Sample Reaction Speed
5.	MANRTC	Manic Reaction Speed
6.	DATIRTC	Divided Attention Visual Monitoring alone Reaction Speed
7.*	DATSCRTC	Divided Attention Sequence Comparison Reaction Speed
8.*	DATDRTC	Divided Attention Dual Reaction Speed
9.	ASCRTC	Auditory Reaction Speed
10.	SATADRTC	Shifting Attention Test Arrow Direction Reaction Speed
11.*	SATACRTC	Shifting Attention Test Arrow Colour Reaction Speed
12.*	SATINRTC	Shifting Attention Instruction Reaction Speed
13.*	SATDIRTC	Shifting Attention Test Discovery Reaction Speed
14.*	DTTPARTC	Dual Task Previous Number Alone Reaction Speed
15.*	DTTPDRTC	Dual Task Previous Number Dual Reaction Speed
16.	PFNRTC	Pathfinder Number Reaction Speed
17.	PFNLRTC	Pathfinder Letter Reaction Speed
18.	PFCRTC	Pathfinder Combined Reaction Speed
19.	PFNTOT	Pathfinder Number Total Time to Complete PFNACC
20.	PFLTOT	Pathfinder Letter Total Time to Complete PFLACC
21.	PFCTOT	Pathfinder Combined Total Time to Complete PFCACC
19.*	PFNLCRTC	Average of Measures 16, 17, and 18
20.*	PFNLCTOT	Average of Measures 19, 20, and 21

*Measures used in Confirmatory Factor Analysis

Tracking Measures

Tracking measures values represent errors. A high value denotes poor performance on the test.

1.*	DTTDHIT	Dual Task Boundary Hits
2.*	DTTDABS	Dual Task Tracking Alone
3.*	DTTAABS	Dual Task Tracking Dual
4.*	DTTAHIT	Dual Task Boundary Hits Single Task

*Measures used in Confirmatory Factor Analysis

Appendix N

Pearson Correlation Coefficients Between The Three CogScreen-AE Construct Measures and Low and High Workload Flight Performance

FP = Flight Performance

Correlations

		Low Workload FP	High Workload FP
Tests.BDSMSPAN	Pearson Correlation	.180	.124
	Sig. (2-tailed)	.194	.372
	N	54	54
Tests.MATHACC	Pearson Correlation	.041	.024
	Sig. (2-tailed)	.766	.863
	N	54	54
Tests.VSCACC	Pearson Correlation	.233	.223
	Sig. (2-tailed)	.090	.105
	N	54	54
Tests.SDCCOR	Pearson Correlation	.197	.107
	Sig. (2-tailed)	.153	.441
	N	54	54
Tests.SDCACC	Pearson Correlation	-.167	-.128
	Sig. (2-tailed)	.228	.356
	N	54	54
Tests.SDCIRACC	Pearson Correlation	.225	.164
	Sig. (2-tailed)	.102	.237
	N	54	54
Tests.MTSACC	Pearson Correlation	.523	.355
	Sig. (2-tailed)	.000	.009
	N	54	54
Tests.MANACC	Pearson Correlation	.156	.213
	Sig. (2-tailed)	.260	.122
	N	54	54
Tests.DATSCACC	Pearson Correlation	.169	.329
	Sig. (2-tailed)	.221	.015
	N	54	54
Tests.ASCACC	Pearson Correlation	.031	.072
	Sig. (2-tailed)	.822	.606
	N	54	54

PFNLCACC	Pearson Correlation	.410	.416
	Sig. (2-tailed)	.002	.002
	N	54	54
Tests.SDCDRACC	Pearson Correlation	.136	.038
	Sig. (2-tailed)	.326	.785
	N	54	54
Tests.SATADACC	Pearson Correlation	-.015	-.109
	Sig. (2-tailed)	.911	.431
	N	54	54
Tests.SATACACC	Pearson Correlation	.126	.250
	Sig. (2-tailed)	.365	.069
	N	54	54
Tests.SATINACC	Pearson Correlation	.188	.055
	Sig. (2-tailed)	.174	.693
	N	54	54
Tests.SATDIACC	Pearson Correlation	.094	.054
	Sig. (2-tailed)	.501	.697
	N	54	54
Tests.DTTPAACC	Pearson Correlation	.182	.044
	Sig. (2-tailed)	.193	.753
	N	53	53
Tests.DTTPDACC	Pearson Correlation	.381	.364
	Sig. (2-tailed)	.005	.007
	N	53	53
Tests.MATHRTC	Pearson Correlation	-.079	-.345
	Sig. (2-tailed)	.572	.011
	N	54	54
Tests.VSCRTC	Pearson Correlation	-.276	-.340
	Sig. (2-tailed)	.044	.012
	N	54	54
Tests.SDCRTC	Pearson Correlation	-.192	-.101
	Sig. (2-tailed)	.164	.467
	N	54	54
Tests.MTSRTC	Pearson Correlation	-.190	-.015
	Sig. (2-tailed)	.168	.913
	N	54	54

Tests.MANRTC	Pearson Correlation	.024	-.061
	Sig. (2-tailed)	.862	.661
	N	54	54
Tests.DATIRTC	Pearson Correlation	-.087	-.199
	Sig. (2-tailed)	.531	.150
	N	54	54
Tests.DATSCRTC	Pearson Correlation	-.075	-.093
	Sig. (2-tailed)	.591	.504
	N	54	54
Tests.DATDRTC	Pearson Correlation	-.178	-.092
	Sig. (2-tailed)	.197	.506
	N	54	54
Tests.ASCRTC	Pearson Correlation	.102	.191
	Sig. (2-tailed)	.465	.166
	N	54	54
PFNLCRTC	Pearson Correlation	.009	-.077
	Sig. (2-tailed)	.949	.578
	N	54	54
PFNLCTOT	Pearson Correlation	-.181	-.220
	Sig. (2-tailed)	.189	.111
	N	54	54
Tests.SATADRTC	Pearson Correlation	.168	-.123
	Sig. (2-tailed)	.225	.374
	N	54	54
Tests.SATACRTC	Pearson Correlation	.052	-.209
	Sig. (2-tailed)	.709	.129
	N	54	54
Tests.SATINRTC	Pearson Correlation	-.116	-.311
	Sig. (2-tailed)	.405	.022
	N	54	54
Tests.SATDIRTC	Pearson Correlation	-.070	-.153
	Sig. (2-tailed)	.615	.269
	N	54	54
Tests.DTTPARTC	Pearson Correlation	.028	.022
	Sig. (2-tailed)	.840	.875
	N	53	53

Tests.DTTPDRTC	Pearson Correlation	.094	-.059
	Sig. (2-tailed)	.505	.677
	N	53	53
Tests.DTTAABS	Pearson Correlation	-.315	-.080
	Sig. (2-tailed)	.020	.564
	N	54	54
Tests.DTTAHIT	Pearson Correlation	-.240	-.124
	Sig. (2-tailed)	.080	.373
	N	54	54
Tests.DTTDABS	Pearson Correlation	-.408	-.258
	Sig. (2-tailed)	.002	.062
	N	53	53
Tests.DTTDHIT	Pearson Correlation	-.481	-.175
	Sig. (2-tailed)	.000	.211
	N	53	53

Appendix O

Description of Significant CogScreen-AE Measures after Factor Analysis

The descriptions of the following CogScreen-AE measures has been obtained from the CogScreen™Aeromedical Edition Professional Manual (Kay, 1995).

In MTS (Matching-to-Sample), a four-by-four grid is presented with empty and filled cells. Then two grids are presented with one having the original pattern just seen and the other pattern differs by one cell. The participant selects the grid that corresponds to the original pattern.

For the Pathfinder Number (PFN) task, the participant sees a number, displayed in the centre of the screen, and then has to touch one of the four boxes displaying the next number in the sequence. After each response, three of the four boxes have their number updated. The number of correct responses provides the accuracy. For the Pathfinder Letter (PFL) task, the number task described above is now replaced by a letter. In the Pathfinder Combined (PFC) task, the number and letter alternate. These three task are very similar. Therefore, one measure was obtained by determining the mean accuracy of the Pathfinder Number, Letter, and Combined tasks.

For the DTTPDACC (Dual Task Previous Number Alone Accuracy) measure, a 1, 2, or 3 shown and then replaced by either 1, 2, or 3. The participant recalls the previous number shown while encoding the current number for the next number presentation. This task is carried out while simultaneously performing the tracking test where the participant tries to maintain a cursor in the centre of the screen by pressing left and right keys. The number of correct responses provides the accuracy for the measure.

For the VSCRTC (Visual Sequence Comparison) measure, the participants are presented with two alphanumeric strings side by side. The participants select “SAME” or “DIFFERENT” for the presented strings. For the strings to be “SAME”, the sequence has to be in the same order for both sequences. The strings vary from four to eight items. Twenty sequence pairs are presented with half being same, and half present a different sequence. The VSC speed is obtained from the median response time on correct responses

The Math subset has 5 multistep math problems at approximately the 10^{th} –grade level of difficulty. The participants select the correct response from among three choices. Math Speed (MATHRTC) is the median response time on correct trials

In the SAT (Shifting Attention Test), participants learn three different rules for selecting the correct response from among four boxes containing an arrow. The three rules pertain to the colour of the border of the box, the direction of the arrow, and matching the colour of the arrow. For the SATINRTC measure, the participant is presented with an instruction identifying the active rule before the presentation of each stimulus. The SAT instruction speed is the median response time on correct trials.

For the DTTAABS (Dual Task Tracking Alone Error) measure, the participant maintains a cursor in the centre of the screen by pressing left and right keys. The absolute tracking error (in pixels) is measured based on displacement of cursor from centre for tracking task alone.

For the DTTDABS (Dual Task Tracking Dual Error) measure, the participant maintains a cursor in the centre of the screen by pressing left and right keys. The absolute tracking error (in pixels) is measured based on displacement of cursor from the centre. The participant simultaneously performs the previous number task.

For the DTTDHIT (Dual Task Tracking Dual Boundary Hits) measure, the participant maintains a cursor in the centre of the screen by pressing left and right keys. If the participant does not actively try to maintain the cursor in the centre, the cursor disappears off the screen and is referred to as a "boundary hit". This task is performed while simultaneously trying to perform the previous number task. This task measures the number of boundary hits in 90,000 milliseconds.

For DTTAHIT (Dual Task Tracking Alone Boundary) measure, the participants maintain a cursor in the centre of the screen by pressing left and right keys. If the participant does not actively try to maintain the cursor in the centre, the cursor disappears off the screen and is referred to as a "boundary hit". This task is performed alone and measures the number of boundary hits in 60,000 milliseconds.

Appendix P

Recommendations for Pilots

“The literature on aging may not offer a simple method by which to group pilots into safety categories, but it does point to several steps that can minimize the toll taken by the aging process. In addition to exercises that can help us maintain or improve our physical and mental capabilities, there are various operational steps we can take to compensate for the kinds of changes that can’t be avoided. In this section, we outline several areas in which older pilots seem to experience similar effects, and suggest ways they might go about adjusting.

VISION

For many pilots, changes in visual acuity are among the earliest and most noticeable issues associated with growing older. Peripheral vision narrows, near vision becomes less acute, eyes no longer focus as quickly, and night vision degrades.

Recommendations:
» Get a full eye exam on a yearly basis.
» Purchase an oxygen system, and/or start using it at **lower altitudes**.
» Allow your eyes more time to adjust at night, and consider switching to low-level white cockpit lighting, which is better than red for focusing.
» Get bifocals, or progressive lenses. Many pilots do fine with off-the-shelf “readers,” but prescription glasses are generally better.
» Wear haze-cutting prescription sunglasses.
» Consider purchasing traffic alert equipment.

HEARING

Particularly in the high-frequency range, hearing diminishes with age. Pilots tend to be worse off than the general population in this respect.

Recommendations:
» Consider purchasing active noise cancelling headsets; many pilots are surprised at the reduction in ambient noise.
» Be prepared to ask controllers to “say again” if necessary.
» Consider purchasing hearing aids.

STRENGTH, FLEXIBILITY, AND ENDURANCE

Many pilots report decreased flexibility and loss of strength as they get older. Most notice that cockpit fatigue sets in earlier than it once did, and some find it more difficult to perform fine motor tasks, like pressing small buttons.

Recommendations:

» Get a yearly physical, starting no later than age 50.

» Maintain an exercise regimen: 30 minutes of physical activity a day, even simple things like walking, can have a tremendous impact on overall well-being.

» Try to schedule flights for the morning, or late afternoon, when it tends to be smoother and cooler. Avoid early mornings and late nights, however. After-lunch flights can also lead to fatigue problems.

» If cockpit fatigue is a problem, allow more time, and plan more frequent stops. Noise-cancelling headsets can be helpful here as well.

» Stay well-hydrated, but avoid coffee and other caffeinated drinks. If in-flight discomfort is an issue, plan shorter legs or carry on-board relief products.

» Stay well-fed. Hypoglycemia (low blood sugar) can take a real toll.

» Proper rest is even more important as an older pilot. Most of us can’t just “power through” as we did in college or our early 30s.

MEMORY

Working memory is used often in flying, and seems to be the type most affected by normal aging. Many older pilots find it more difficult to remember things like altitude ssignments, transponder codes, and radio frequencies.

Recommendations:

» Take notes. Have a pen and paper handy anytime you’re dealing with ATC.

» Consider purchasing an altitude reminder device, or adapt something else to the purpose.

» Try to fly when you’re “fresh.” Older pilots often perform better on memory tests in the morning.

» Enlist the aid of cockpit companions to “back you up” on the numbers and help with things like radio tuning and GPS programming.

DECISION MAKING

Although experience can have a real impact, aging can also make it more challenging to handle decision-making tasks.

Recommendations:
» Spend more time doing preflight and contingency planning. Any "pre-thinking" you do will make things easier later.
» Fly when well-rested, and make it a point to stay particularly alert to changes in the cockpit (e.g., mechanical issues, weather, etc.).
» Always have a solid "Plan B" ready to go ahead of time. Make sure it's realistic—something you're actually prepared to use.

PROFICIENCY

In addition to expertise, recency of experience can have a dramatic effect on overall airmanship, regardless of age.

Recommendations:
» Take an organized approach to recurrent training. Set a schedule—an instrument proficiency check every six months, for example—and stick to it.
» Look for a good instructor who works well with you and isn't afraid to throw challenges your way.
» Get involved in new activities, start work on a new rating, read books, take **Air Safety Institute online courses and quizzes**—anything to keep your mind active.
» If the cost of flying is a concern, mass-market PC flight simulators (like Microsoft Flight Simulator and X-Plane) are surprisingly inexpensive and realistic ways to stay sharp—particularly for instrument flying.

"RIGHT-SIZING"

For most pilots, it makes sense to start adjusting the kinds of flying they do as they grow older.

Recommendations:
» Plan shorter cross-country legs, and shorter flights overall.
» Re-examine your "comfort zone," and increase your personal minimums if necessary.
» Bring along a co-pilot or instructor on more challenging flights—for example, when transiting busy airspace, at night, or in low instrument conditions.
» Use oxygen for night flights, or try to complete flights during daylight hours.
» Consider moving to slower and/or less complex aircraft. Bear in mind, however, that there's a learning curve associated with any new type, particularly if you've been flying one aircraft exclusively for years" (AOPA, ASI, February, 2013; 15-18).

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