A Language-Oriented Analysis of Situation Awareness in Pilots in High-Fidelity Flight Simulation

by

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Abstract

In general aviation (GA), higher critical incident rates have been observed in older pilots as compared to younger pilots. The present research investigates age-related changes in situation awareness (SA) abilities, particularly as it is influenced by the detection and processing of auditory information during a simulated flight. Previous literature, in both aviation psychology and neural auditory processing research, has found older age to be associated with the reduction of both auditory neural resource management and SA abilities. An analysis of radio communication was conducted to determine whether pilot SA is associated with age-related declines in auditory processing and whether certain features of auditory messages may be especially difficult for older pilots to process. The neural auditory pipeline was also inspected using auditory tone stimuli in order to examine at which stages of neural processing do differences in auditory processing arise for older versus younger pilots during flight. Findings showed that aging negatively impacts the integration of aurally presented information into SA efficiency. Additionally, negative age-effects seen in pilot SA abilities may be associated with differences in how information is processed along the auditory neural pipeline. This research is important in informing efforts in creating adaptations of current audiometric pilot testing and training as well as adaptive tools for older pilots.

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Chapter 1: Introduction

Maintaining a healthy and active lifestyle is a key health promotion factor and is linked to better health outcomes in older age. A popular and important activity that older individuals take part in is General Aviation (GA). In Canada, GA directly contributes 2.2 billion dollars toward the total GDP and comprises over 32,200 aircraft (InterVISTAS, 2017). Of note is the estimated average age of GA pilots, which stands at 60 years (Christopher, 2017). Although flying promotes vocational and social activities in older age, GA is also a highly dynamic activity where safety can be impacted by age-related declines in cognitive health, and specifically, reduced situation awareness (SA). The objective of the present research was to examine how aging affected pilot SA related to the processing of aurally presented information during simulated flight. In GA, SA relies heavily on the integration of auditory information from different sources, including radio communication messages, navigational tools, and alerts from the system. Thus, research that specifically extends our understanding of auditory information processing during flight may lead to important discoveries that can be used to promote safety and reduce accidents amongst the older GA pilot population.

Flight simulation research reveals that older pilots are more likely to experience critical incidents when compared to younger pilots, with communication and SA errors frequently associated with older age (Taylor et al., 2007; Van Benthem & Herdman, 2020). Accident statistics confirm the effect of age on the pilot risk of incurring an accident. For example, Li et al. (2005) found that after accounting for risk tendency (driving-while-intoxicated), gender, and hours flown, older age remained one of the strongest predictors of aviation accidents. Furthermore, the risk of fatality is significantly increased in accidents for pilots aged 60 years and older (Bazargan & Guzhva, 2011). Investigating safety factors involved in older pilot performance is therefore critical for developing tools and resources designed to enable older individuals to fly as long as safely possible.

Older pilot risk can be explained due to the normal declines in domain-independent cognition (e.g., working memory, processing speed) seen in older age. As shown by standardized cognitive tests, pilot cognition is subject to the same adverse effects of age as found in the general population (Causse et al., 2001; Hardy & Parasuraman, 1997; Hardy et al., 2007; Taylor et al., 2007; Van Benthem & Herdman, 2016). In addition, domain-dependent cognitive variables can also explain the negative effects of age on pilot accident rates. Situation awareness is a critical domain-dependent cognitive factor with known associations to pilot risk (Van Benthem & Herdman, 2020), and also shows negative effects of older age (Van Benthem et al., 2011).

The present research examined behavioural and electroencephalographic (EEG) data collected during a 60-minute simulated flight in a full-scale Cessna 172 simulator. Flight tasks focused on integrating auditory information from radio communication for the purpose of developing SA models. This work used an auditory "neural pipeline" framework to advance the understanding of the impact of age on auditory processing and subsequent SA during flight. A flight simulation experiment was conducted on 51 pilots aged 17 to 71 years old. Throughout the flight, pilots heard different radio messages from other aircraft and were asked SA questions related to other aircraft characteristics (e.g., aircraft type, call sign, location and intention) during two pauses in the simulation. Pilots also wore an EEG headset throughout the flight to collect neural data pertaining to auditory stimuli. Behavioural data from the experiment investigated age effects in processing individual segments of radio communication used specifically for SA in pilots.

This research also explored age-related effects in the neural auditory "pipeline". Findings from the EEG analyses examined the neurophysiological levels at which normal aging impacts the processing of auditory information during flight. Neural responses in the primary auditory cortex (lower-level cognition such as signal detection) versus frontal cortical regions (higher-level cognitive functions such as decision making) were investigated to better understand the brain regions and stages of the process that are most affected by aging in the GA pilot population.

Chapter 2: Literature Review

2.1 General Aviation Pilot Risk

Among the various types of operations within Canadian airspace (e.g., airline, military, GA), GA pilots experience the highest rate of critical incidents (Transportation and Safety Board of Canada, 2018). Similarly, in the USA, GA accounts for more than 90% of fatal aviation crashes reported in 2010 (General Accounting Office, 2012). Greater risk of GA critical incidents has also been reported in countries such as Australia (Lenné, Ashby, & Fitzharris, 2008), and France (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, 2002). The greater risk of critical incidents observed in GA pilots, as compared to air transport and airline pilots, reveals the imperative to understand the safety factors involved in GA. For the purpose of this research, critical incidents encompass a wide range of events that affect pilot and passenger outcomes as well as public safety (e.g., becoming lost, controlled flight into terrain, landing mishaps).

When establishing laws and regulations in airline, military, and air transport operations, aging is frequently considered a critical human factor that can influence pilot safety. For instance, the US Federal Aviation Regulations (FAA) prohibits commercial airline pilots above the age of 65 to fly as pilot-in-command (Federal Aviation Administration, 2019). This “Age 65 Law” has been debated many times as it is considered to be discriminatory towards older pilots. However, there are reasons to believe that older pilots may be at higher risk for incurring critical incidents. For instance, a substantial increase in fatality rates were found with advancing age in a study examining the causes of fatal crashes for instrument certified (IFR) and non-IFR certified pilots between 2002 and 2011. Data obtained from the American National Transportation Safety Board, showed that pilots aged

65 years and older incurred six times more accidents than their younger peers (Bazargan & Guzhva, 2011).

These findings pertaining to pilot age and safety will become increasingly pertinent over time because by 2030 the ratio of seniors in Canada will be one in four (Government of Canada, 2014). With this shift in demographics, there will be an increase in the retired pilot population who will use GA as a recreational activity in order to fulfill their time and maintain a suitable quality of life. This upward trend of the aging pilot population has been noted by the Canadian Owners and Pilots Association, who reported that the mean age of pilots increased 4.45 years from 2007 to 2017 (Christopher, 2017). With an aging population, efforts need to be made to understand the impact that this shift may have on GA safety. In order to create more inclusive laws and regulations, it is essential to understand the underlying cognitive mechanisms responsible for pilot performance and how aging may affect these abilities. This can also help inform efforts in creating better screening tools and adaptive technologies that allow older pilots to maintain aviation activities as long as safely possible.

2.2 Older Pilot Cognition and Performance

A common misconception is that flight experience protects older pilots from normal age-related cognitive decline. However, studies involving standardized tests, as well as flight simulation tasks, have shown that older pilots are subject to the same negative effects of age on some parts of their cognition as the general population (Hardy & Parasuraman, 1997), and this has been reflected most notably in communication tasks. For instance, in a study examining the effects of age on pilot cognition, older participants showed declines in psychomotor and information processing speed, attention and executive functioning abilities, as well as verbal or visual learning and memory abilities (Hardy et al., 2007). Declines in executive functioning, reasoning, processing speed, attention and working memory abilities have also been found in aviation psychology research (Causse et al., 2001; Hardy & Parasuraman, 1997; Taylor et al., 2007; Van Benthem & Herdman, 2016).

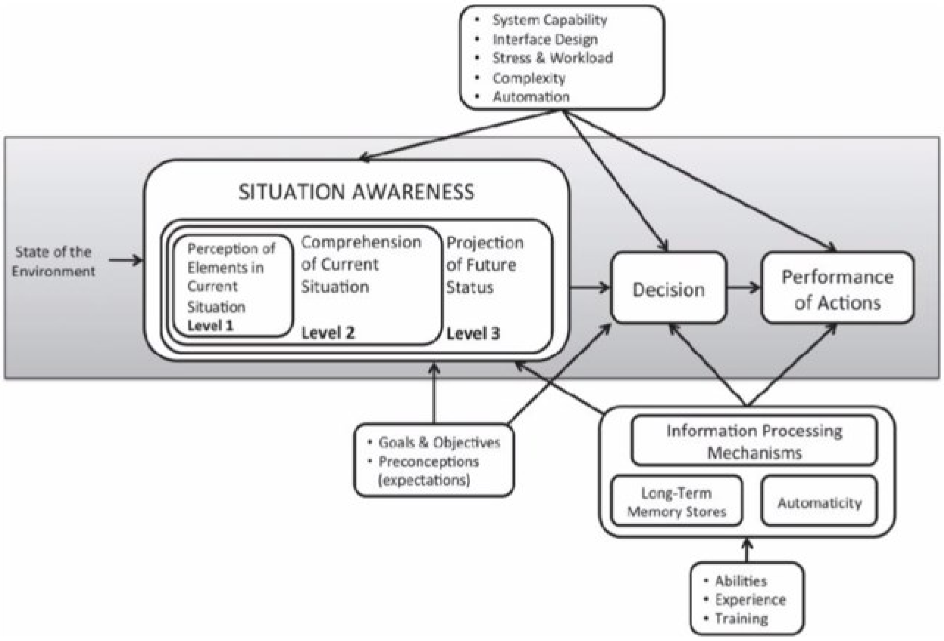
Situation awareness is one of the key domain-specific cognitive abilities that pilots utilize during flight to maintain safety. Endsley (1988) defines SA as the ability to perceive elements in our environment and use this information to further project and plan for action in the future. In aviation, SA drives decision-making and is considered a crucial aspect of safety outcomes for pilots. In the present research, Endsley's 1995 three-level model of SA, outlined below, was used as a framework for interpreting SA as a factor involved in critical incidents during GA.

2.2.1 Situation Awareness Model

The SA model by Endsley described in this section is illustrated in Figure 1. The first level of SA (SA level-1) is the perceptual component. In the context of aviation, this stage involves pilots perceiving the elements in their environment, including recognizing or distinguishing the elements' relevant features, their status, attributes, and dynamics (Endsley, 1995). Elements identified at the perceptual stage include the relevant information about the infrastructure and system that they are working with (e.g., the properties of the aircraft, the tools they utilize), their visual field information (e.g., what they see) as well as auditory information (e.g., the sounds of the aircraft, radio communication). Following this, pilots must comprehend the dynamics of the identified elements (SA level-2). A pilot takes the information provided by all of the features of all the elements they are perceiving and determines how their dynamics fit into their mental model of the environment around them. In the final stage of the model (SA level-3), pilots must take the information they have received from the first two stages and further project these elements into the future in order to make decisions of future actions. SA level-1 is essential for building the second and third levels of SA and was the focus of this research.

Figure 1

Endsley's 1995 Three-level Model of SA



2.2.2 Situation Awareness, Age and Performance

The effects of aging on SA have been examined in both the general population and the pilot population. Bolstad (2001) examined age-related effects of SA in licensed vehicle drivers to better understand drivers' SA capacities and the cognitive factors associated with these abilities. Drivers with varying levels of experience drove in a Systems Technology Interactive Simulator for three 11-minute driving trials. Following each trial, SA queries were presented, and significant age effects were found on the performance of SA scores, such that older adults reported fewer information related to the simulated environment than younger and middle-aged participants (Bolstad, 2001). Lower performance scores on a SA recall questionnaire in older vehicle drivers were also found in a study evaluating the effects of age on SA within various road conditions in a simulated environment (Ou & Liu, 2017).

In aviation psychology research, lower SA performance scores of various tasks have also been observed in older pilots as compared to younger ones. In one study, licensed pilots flew in a medium-scale flight simulator, and while maintaining a predetermined altitude, the participant pilots were asked to click on a yoke-mounted button when experiencing simulated critical events (Coffey et al., 2007). It was found that although both older and younger pilots were able to maintain consistent control of the aircraft, older pilots missed significantly more critical events than the younger ones. In another study, Van Benthem and Herdman (2020) found that older pilots incurred greater critical incidents than younger pilots during a simulated flight while also scoring worse on SA performance tasks.

2.2.3 Situation Awareness and Communication

In Endsley's (1995) SA model, auditory information is perceived in SA level-1, usually in the form of radio communication or other aircraft-related sound signals. One of the main sources of auditory information feeding pilots' mental models during flight are radio calls between aircraft and communication with ground services or air traffic controllers. Communication between pilots and ground services provides pilots with important information related to other aircraft flying simultaneously within the airspace. This information is essential in building SA models during flight. Pilots utilize ATC calls to communicate where they are located and their planned trajectory. Radio communication is also used to signal pilots to change the direction or altitude of their aircraft, wherein pilots are required to read-back or repeat messages in order to confirm to the broadcaster that the message was clearly received (Morrow et al., 2001). In the aviation psychology literature, older age has been associated with a reduction in abilities to integrate message information into mental models, as evidenced through various tasks.

Using a read-back task, Morrow et al. (2001) found that younger pilots read-back radio communication messages more accurately than the older pilots. As part of a longitudinal flight simulator study exploring the use of cognitive predictors and tools, Taylor et al. (2005) investigated the effects of pilot age on the execution of air traffic controller communication tasks in simulated environments. Participants performed domain-specific, as well as domain-general tasks, to examine whether there were expertise or age-related effects on the executions of air traffic control communications that can be associated with possible differences or changes in related cognitive functions. The findings of this study showed significant age-related effects on communication performance tasks such that older age was associated with lower performance scores.

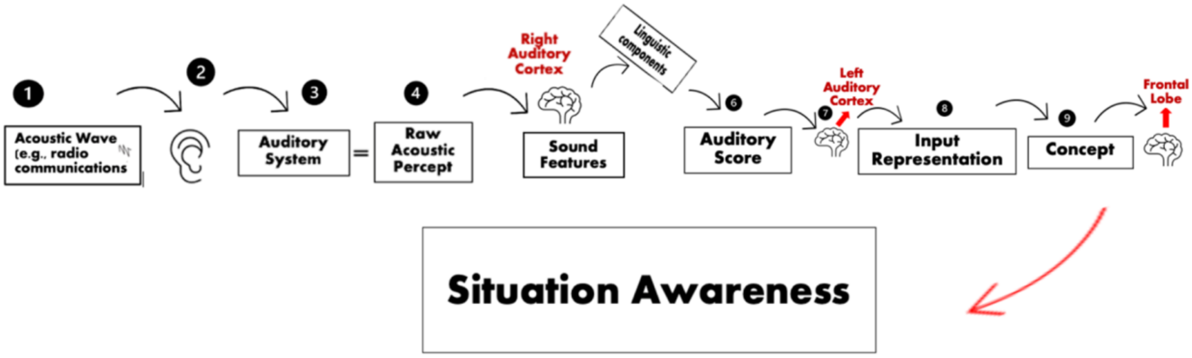
Although radio call communication has been investigated from a performance viewpoint, there is little literature that discusses these results from a linguistic processing perspective. Accordingly, it is not clear what cognitive-linguistic factors play a role in how younger and older pilots process and utilize radio call communication. Therefore, the field of linguistics needs to be integrated into the study of communication during aviation to get a language processing perspective on the matter.

2.3 Language Processing

To understand why older pilots do not perform as well as younger pilots on tasks involving processing aurally presented information, it is important to understand the auditory processing pipeline. To this end, the present research examined the cognitive processes that pilots utilize to conceptualize sounds during flight. An adapted version of Hale and Reiss' (2008) *Galilean-style Phonology* model was utilized as a framework for understanding these mechanisms. This framework has been used and transformed many times by different researchers in the field of speech production. Nonetheless, there is a component that involves speech processing and was used in this thesis to discuss the transition in which speech waves transform from acoustic cues into concepts of the mind. The original version of the framework is presented in Appendix A. An illustration of the adapted version of the framework, better suited for the purposes of this thesis, is illustrated in Figure 2.

Figure 2

Adapted Gilligan Phonology Model (Hale & Reiss, 2008)



In the context of communication during flight, the process starts at the point of the acoustic wave. A physical acoustic wave has been created by the broadcasted message. This wave is listener-specific, meaning that depending on the dynamics of the listening pilot, it will be received differently by the ear. The waveform is then subjected to a range of physical and cognitive effects within the auditory system of the listener which creates what is called a raw auditory percept (Hale & Reiss, 2008). This is used by the brain to break a message down into its component elements, like the speaker's voice quality or speech rate. Also, at this stage, is the sound and feature detection, which will eventually feed into the grammar or other cognitive modules of the brain of the listener to produce a concept. Other cognitive functions are simultaneously executed by the brain at this point. The next step of speech processing consists of taking those linguistic-specific features of the percept and creating an auditory score which is the linguistically relevant information. The brain then further parses this information using the cognitive mechanisms responsible for computing a representation of an auditory item, such as a word, which will then be further processed, to create a concept.

For pilots who are receiving radio messages, these concepts will then be utilized in updating SA models and decision making. It is important to note that at many points along this pipeline, the effects of aging can impact how messages are processed, and in turn, how they are integrated into mental models.

2.4 Electroencephalogram (EEG)

Neural studies are not as common in the domain of aviation psychology when discussing the processing of auditory information. However, electroencephalogram (EEG) is a useful, reliable, and objective neural technique that has been used in auditory processing research. An EEG system detects electrical activity from the brain by placing small electrodes on specific areas of the human scalp. The technology records electrical activity on the scalp surface of brain regions. When examining the brain's neural responses to aurally presented information, EEG studies oftentimes use auditory tone stimuli in various study paradigms. One paradigm commonly used is the Go/NoGo task, whereby participants are required to perform a certain function in relation to one sound and inhibit that function when presented with another specific sound. Another often used method is the oddball paradigm, whereby participants are presented with repetitive standard stimuli and occasional deviant stimuli and are tasked with producing a certain response that indicates that they have detected the deviant sounds.

Although previous literature in the field of aviation psychology has examined the effects of aging on communication and SA, no studies have been conducted from a neuro-linguistics perspective. Examining auditory processing in pilots from a neural perspective is important to understand if there are underlying cognitive issues or factors that can contribute to older pilots' lower SA abilities from aurally presented information. In the present study, auditory tones were frequently presented to participants, and they were asked to press on a thumb switch on the left yoke column when they heard the sounds. EEG was used to collect neural data on the tonal processing and the pilot button response. This method was used in order to better understand how the pilots' brains are responding to auditory stimuli and to gauge the management of neural activity from other flight-related tasks.

The electrode locations of interest were selected due to their association with auditory processing. As illustrated in Figure 2, sound and feature detection was explored in auditory electrode locations, particularly associated with Brodmann's areas 42 (BA42) and 27 (BA27) (Trans Cranial Technologies, 2012; Mirz et al., 1999). The first phase of input representation was explored using electrodes typically related to language processing areas; specifically in Brodmann's areas 8 (BA8), left 44 (left BA44) and 47 (BA47) (Anderson et al., 1994; Trans Cranial Technologies, 2012; Crozier et al., 1999; Cutting et al., 2006; De Carli et al., 2007; Heim et al., 2008; Kübler et al., 2006; Rama et al., 2001; Sahin et al., 2006; Volz et al., 2003). Finally, cognitive and motor inhibition in the second phase of input representation were explored in electrode locations typically associated to Brodmann's areas 45 (BA45) and right 44 (right BA44) (Trans Cranial Technologies, 2012; Picton et al., 2007). Due to its prominent function in the brain, inhibition was also examined in the first and second phases of the pipeline. Of key interest was the effect of age on the auditory processing neural pipeline as described above. Two main EEG measures were used to analyze the data in the selected areas of the brain: Event-Related Potentials (ERPs) and Event-Spectral Perturbation (ERSP). As will be discussed in the following sections, both these methods of analysis are useful as they are two distinct approaches to examining cognition that can provide the field with a deeper knowledge of pilots' neural management of auditory information.

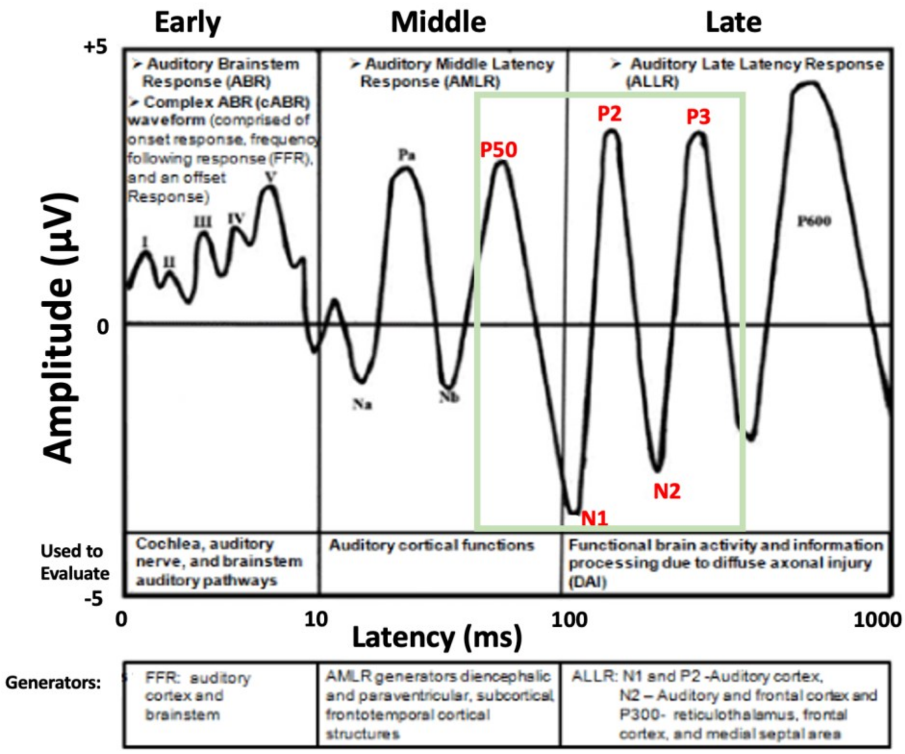
2.4.1 Event-Related Potentials (ERPs)

One type of neural measure used in EEG studies are Event-Related Potentials (ERPs). ERPs are measured brain activity responses to specific stimuli presented to individuals via different input senses, measured in hertz (Hz). ERPs are commonly used when investigating neural responses temporally, as they are time-locked. This means that ERP data present particular responses to stimuli presented at very specific latencies. In ERP analyses, systematic or characteristic deflections in the data (components) are used to investigate and compare brain responses as a result of different variables in various brain regions.

2.4.1.1 Auditory Evoked Potentials. Auditory Evoked Potentials are ERP responses to auditory stimuli, beginning in the central auditory system. In the idealized auditory ERP, illustrated in Figure 3, it can be seen that the auditory ERP responses can be divided into three stages.

Figure 3

Modified Example of an Auditory Evoked Potential (P et al., 2020)



In the early stage, there are seven peaks, known as the Auditory Brainstem Response (ABR), occurring in approximately the first 10 ms of a presented sound (P et al., 2020; Trainor, 2008). These peaks occur in the auditory cortex when there is a discharge of auditory neurons, in synchrony, along their nerves and brainstem structures (Noel, Ryan, & Aiken, 2014; Trainor, 2008). The middle stages, around approximately 10 to 100 ms, represent auditory cortical functions. The late ERP components, beginning around 50 to100 ms after the onset of the stimulus, represent higher-order cognitive processing of the information or functional brain activity, chiefly in the auditory and frontal regions, among other areas.

The focus of this research included the middle to late stages of the auditory ERP. Specifically of interest were the P50, N1, P2, N2 and P3 components. The P50 refers to the first ongoing positive deflection normally around the 50 ms latency and is associated with the pre-attentive filtering of information processing (P et al., 2020; Shen et al., 2020; Trainor, 2008). The following negative ongoing deflection represents the N1 component associated with neural activity occurring during the brain's stimulus detection phase of processing information, normally around the 100 ms latency (Hyde, 1997; Näätänen et al., 1988). Early feature or information processing of stimuli occurs at the P2 component, normally around the 200 ms latency. The N2 component is the second negative peak that occurs after approximately 100 ms, following the P2 deflection. It has been commonly associated with cognitive control, whereby an individual is planning a behaviour in response to a stimulus, as well as action inhibition processes (Folstein & Van Petten, 2008; Kopp et al., 1996). Lastly, the P3 component is the deflection of higher-order processing in response or preparation for action that follows the stimuli, occurring between 200 and 400 ms post-stimulus.

Table 1

Auditory ERP - Components' Cognitive Associations Summary

Component	Cognitive Association
P50	Pre-attentive filtering of information processing
N1	Stimulus detection
P2	Early feature or information processing of stimuli
N2	Cognitive control/response planning
P3	Higher-order processing/response preparation

2.4.1.2 Auditory ERP Regions and Aging Effects. In auditory tasks, the P50 has been found to be generated mainly in temporal regions, primarily the auditory cortex and sometimes in frontal regions (Korzyukov et al., 2006; Stothar & Kazanina, 2016). P50 amplitudes are normally reduced in sensory gating tasks as irrelevant information is being filtered out. Previous literature has reported that the P50 gating mechanism gets weakened with increased age such that older individuals show higher P50 amplitudes than do younger individuals (Chao & Knight, 1997; Patterson et al., 2008; Stothar & Kazanina, 2016). Sources of neural activation for the N1 component in both Go and NoGo tasks have been identified in the primary and secondary auditory cortices and auditory association regions (Fogarty, Barry & Steiner, 2020). It has been observed in the literature that for auditory detection tasks, similarities between younger and older individuals' N1 component amplitudes exist, suggesting that sound detection may not be affected by age at a neural level (Ostroff et al., 2003; Pfefferbaum et al., 1980).

In higher-order processing of Go/NoGo tasks, frontal and temporal regions were associated with the P2 component of the Go condition, related to the pressing of a button when certain sounds were detected (Fogarty et al., 2020). Previous studies on the P2 component show conflicting findings regarding the effects of age on its amplitude, whereby in some studies, advanced age elicits a decrease in amplitude (Anderer, 1996) and in others an increase in amplitude (Pfefferbaum et al., 1980). Meanwhile, the literature shows attenuated N2 amplitudes with increased age (Anderer, 1996; Cheng, Tsai & Cheng, 2019). Lastly, in Go/NoGo tasks, older individuals have shown higher amplitudes in the P3 component than do younger individuals in frontal areas for NoGo tasks (Hong et al., 2014; Kropotov et al., 2016).

2.4.2 Event-Spectral Perturbation (ERSP)

Another type of neural measure that is analyzed using EEG is Event-Spectral Perturbation (ERSP). As described by Makeig (1993), ERSPs reflect changes in spectral power that result from the brain's response to repeated stimuli. As with ERPs, ERSPs are time-locked and are a representation of a time-frequency matrix. Note that frequency, oscillatory, and spectral power are different terms for the concept referring to the rate at which groups of neurons are firing, measured in Hz. The spectral power perturbations represent how much the power in decibels (dB) increased, decreased, or stayed the same from the baseline of a presented stimulus. Each frequency band is independent of the other frequency levels, meaning that they can respond independently to various stimuli. Bands of frequencies have been associated with cognitive factors and are of interest for this research.

2.4.2.1 Frequency Bands Cognitive Associations. There are three types of frequency bands that will be analyzed in this study, listed as follows; theta (4-7 Hz), alpha (8-12 Hz), and beta (13-30 Hz) (Nayak & Anilkumar, 2020). Theta bands are highly associated with memory functions, such as with spatial memory during changes in scenery or self-motion, working memory or declarative and short-term memory (Buzsáki, 2005; Vertes, 2005). In auditory detection tasks, the theta band has been mainly associated with response inhibition in frontal regions, specifically with the decision to withhold a response wherein a decrease in power indicated deficits in inhibition abilities (Barry, 2009; Harper, Malone & Bernat, 2014; Kamarajan et al., 2004; Yamanaka & Yamamoto, 2009). Additionally, theta band increase has also been associated with the stimulus detection phase of neural processing (Ng, Schroeder & Kayser, 2012).

Alpha bands have been found to be associated with spatial attention (Foster et al., 2017). This band has also been associated with wakefulness during resting states in meditation studies (Cahn and Polich, 2006). In auditory tone detection tasks, the alpha band has been evoked in the frontal lobe regions, in higher-order cognitive processing, typically related to the cognitive inhibition (Jensen & Mazaheri, 2010; Klimesch, Sauseng & Hanslmayr, 2007). This means that these oscillations play a role in inhibiting neural activity in task-irrelevant brain regions (Wisniewski, Thompson, & Iyer, 2017), thereby contributing to neural efficiency during tasks.

Beta bands have been associated with movement and motor or sensorimotor functions (Baker, 2007; Pogosyan et al., 2009). In auditory tone detection tasks, the beta was evoked in the temporal lobe regions, typically related to the left and right primary auditory cortices, as well as frontal regions, for both sound detection and higher-order cognitive processing of the sounds (Christov & Dushanova, 2016; Fujioka, Ross & Trainor, 2015). In a Go/NoGo experiment, this band has been associated with the preparation and execution of motor movements as a result of Go tasks (Schmiedt-Fehr et al., 2016). Studies investigating the effects of aging on the beta oscillatory band energy indicate that older individuals elicit greater beta band decrease in motor response tasks than do younger individuals in both temporal and frontal regions (Christov & Dushanova, 2016; Schmiedt-Fehr et al., 2016).

2.5 Present Study

The primary goal of the present research was to investigate how the brain integrates aurally presented information into mental models of SA during flight. A second goal was to examine how aging may affect this process. Behavioural data collected during a simulated flight was used to examine the effects of aging on pilot SA. Auditory processing was investigated from a neural perspective, using an EEG system to collect data from pilots during the flight.

2.5.1 Behavioural Hypotheses

1. Older age and lower situation awareness will be associated with a greater number of critical incidents during flight.
2. Older age will be associated with lower accuracy in reporting details of radio messages (SA level-1).
3. Older age will be associated with lower performance on grouping static information pertaining to each broadcasted aircraft (SA level-2).
4. Older pilots will perform worse on locating other aircraft on a map (SA level-2).

2.5.2 Neural Hypotheses

2.5.2.1 Neural Hypotheses - Event-Related Potential (ERP). The hypotheses for the neural ERP responses to the tones are as follows:

1. In the sound and feature detection electrode locations, there are no expected age-related effects in the amplitude of the brain's neural response at the N1 component, since both older and younger pilots should be audiometrically matched.

2. In the language processing electrode locations associated with the first phase of input representation, both younger and older pilots are expected to have P2, N2 and P3 amplitudes closer to 0 µV as a result of neural activity caused by ongoing flight task-related neural activity (such as radio communication). No age effects are expected because higher-order cognitive processing in these language-related areas should not be affected by the non-language sounds.
3. In cognitive and motor inhibition electrode locations, differences between both the younger and older pilots' P2, N2 and P3 deflections are expected. Age effects are expected because later latency components have shown age effects on the amplitudes in higher-order sound processing in previous studies due to the older brain having greater difficulty with inhibition.

2.5.2.2 Neural Hypotheses - Event spectral perturbation (ERSP). The hypotheses for the neural ERSP responses to the tones are as follows:

1. In the sound and feature detection electrode locations, there are no expected age-related effects in the theta and beta oscillations around the P50 and N1 component latency ranges, since both older and younger pilots should be audiometrically matched.
2. In the language processing electrode locations, age-related differences in the power of the *alpha* oscillatory bands compared to the pre-stimulus baseline are expected as a result of cognitive inhibition of ongoing flight task-related neural activity in the P2, N2 and P3 latency ranges. Age effects are expected in later latencies for the alpha band as it is related to cognitive inhibition in task-irrelevant regions and this cognitive function has shown age-related effects in later latencies.

3. In cognitive and motor inhibition electrode locations, an age effect is expected in the theta and beta oscillatory power. In the *theta* band, a greater decrease in power is expected in older participants because a decrease in theta power has been associated with inhibition deficits, and older individuals have been shown to exhibit issues with inhibition. There are no expected *alpha* band differences between both groups as this is a tone processing related area. Greater *beta* oscillatory decrease is expected in older pilots because this has been found in literature related to motor response tasks.

Chapter 3: Methodology

3.1 Study Background

The research outlined in this thesis used data collected as part of a larger study performed in the Advanced Cognitive Engineering Laboratory at Carleton University in 2018. To do this, the participants completed two experimental sessions, one involving an aircraft simulator and the other in a VR flight simulator. The methods and findings discussed here are in relation to the first session, where the pilots were tasked with flying a route in the aircraft simulator. The study was approved by the university ethics committee operating under the Canadian Tri-Council Code of Ethics for psychological research (see Appendix B for the ethics clearance form).

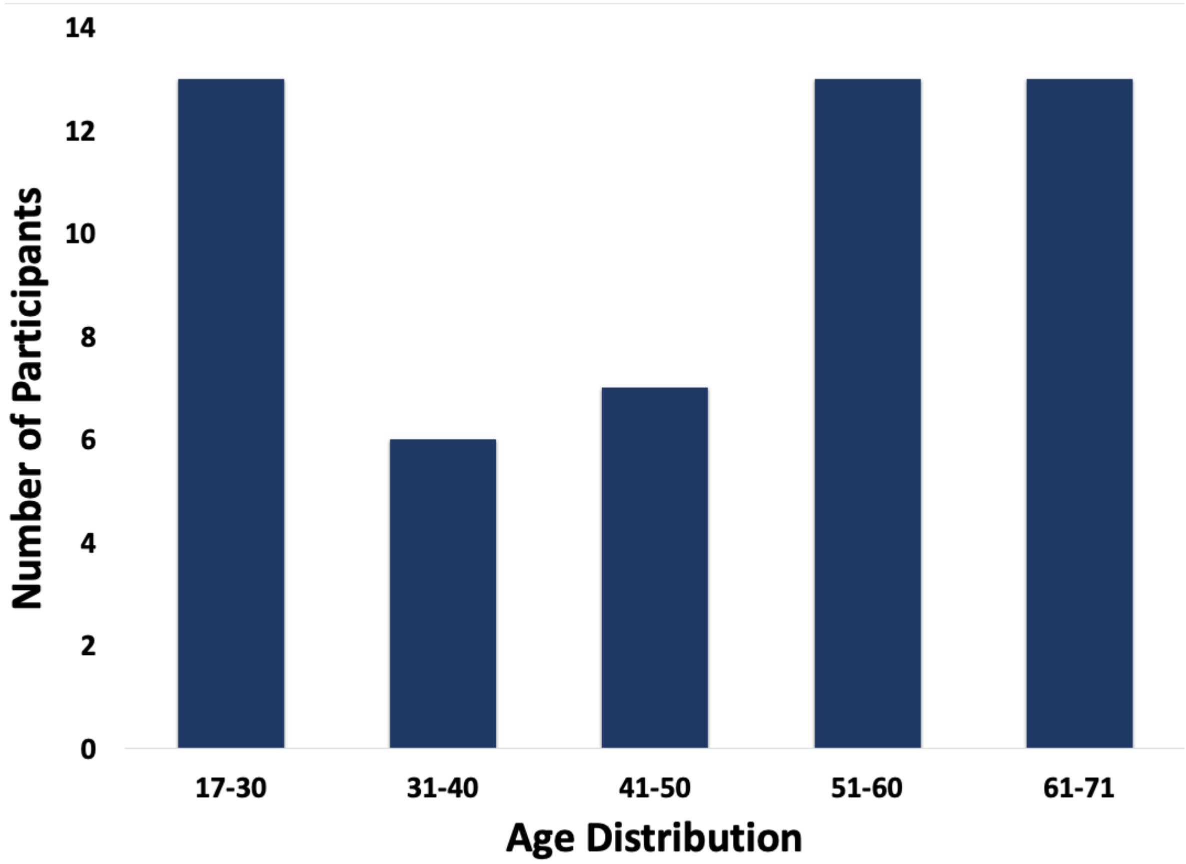
3.2 Participants

To recruit licensed pilots from local pilot associations, flying schools and clubs, poster advertisements were distributed on their bulletin boards, electronic newsletters, and websites (see Appendix C for a sample of the participant recruitment poster). Inclusion criteria included having a pilot permit and medical certification to fly. Pilots flew at least one hour as pilot-in-command in the past 24-months prior to the study. The final sample included 51 pilots (4 female) with varying levels of experience. Pilot age also varied to provide this study with a good cross-section of pilot age ($\mu = 46.29$, $\sigma = 17.44$). For analyses, the participants were divided into a younger ($n = 26$, aged 17-50) and an older group ($n = 25$, aged 51-71). The cut-off at age 50 years allowed for even sample sizes in both groups (see the distribution of the participants' ages in Figure 4). Pilots provided written informed consent and received refreshments and paid parking as compensation for their participation.

Consent information consisted of elements such as the purpose of the study, the research personnel, participant eligibility, study tasks, terminological definitions, logistics (e.g., locale, duration, and affiliation), compensation, risk or discomfort factors, and confidentiality (see Appendix D for a sample of the consent form). A summary of the pilot-relevant information pertaining to the participants is represented in Table 2.

Figure 4

Participant Age Distribution by Decades



Note. Due to small numbers, the youngest pilots were grouped with the 20-30 age group.

Table 2

Pilot-Relevant Information

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	51	54	17	71	46.3	17.4
Total Flight Hours	51	11998	2	12000	1311	2592.3
Total Years Licensed	51	69	1	70	14.4	14.5
Pilot Level	51	5	1	6	4.1	1.3

Note. Pilot level was ranked as follows: 1 – Student, 2 – Recreational, 3 – Private Pilot (PPL) no extra rating, 4 – PPL extra ratings, 5 – PPL with IFR or commercial, 6 – Airline Transport (ATP).

3.3 Procedure

3.3.1 Briefing

The researchers guided the pilots through an introductory PowerPoint presentation in order to familiarize the participants with the study purpose, the task requirements, and the equipment that would be used for both the practice and experimental sessions. The presentation also contained information about the planned flight route, including the two legs they would be flying and the flight parameters, such as altitudes, headings, and airspeeds for the outbound and inbound segments of the route.

3.3.2 Materials

The pilots flew in a Cessna 172 Level 6 Flight Training Device simulator. Within the cockpit, the flight instruments included a yoke, throttle, and flaps (see Figure 5 for the cockpit). For navigation material, traditional paper charts, as well as digital navigation material via the ForeFlight Type B Electronic Flight Bag device were used. Both navigational methods were utilized by each participant depending on the leg in which they were flying. The order was counterbalanced across participants. To record data pertaining to their physiological states, participants wore two biometric recording devices, an EEG headset and an electrocardiogram tracking wristband. The EEG headset that was used was the EMOTIV EPOC+ 14 channel wireless EEG system (see Figure 6 for the EEG headset). To record the EEG data, the EMOTIV software TestBench was used (an open-source software running on MATLAB v. 2019, applying a bandwidth of 0.2 to 45 Hz before further processing in EEGLAB. Additionally, pilots wore an E4 Empatica lightweight wristband, whose recorded data was not analyzed in this thesis.

Figure 5

Cessna 172 simulator cockpit controls and visual displays

Figure 6

14-channel wireless EMOTIV EPOC+ EEG headset

3.3.3 Practice Leg

Participants ran through a practice session before beginning the experiment and were encouraged to ask questions if they were unsure of any tasks or procedures. The practice session included three full circuits at a local aerodrome. Before the pilots took off, the experimenters provided a full briefing of the cockpit instruments and controls. In the first practice circuit, the pilots simply flew in the Full-Scale Cessna 172 Simulator, in order to familiarize themselves with the equipment, how the simulator works, and the flight involved in the study. The second practice circuit consisted of, once again, the pilots flying the flight but with an additional prospective memory task. The prospective memory task involved responding to event-based visual cues displayed on a cell phone screen in the form of a video of changing arrows. Verbal radio call responses were required by the pilots when they detected right-oriented arrow visual cues. Their verbal responses were not further explored in this thesis.

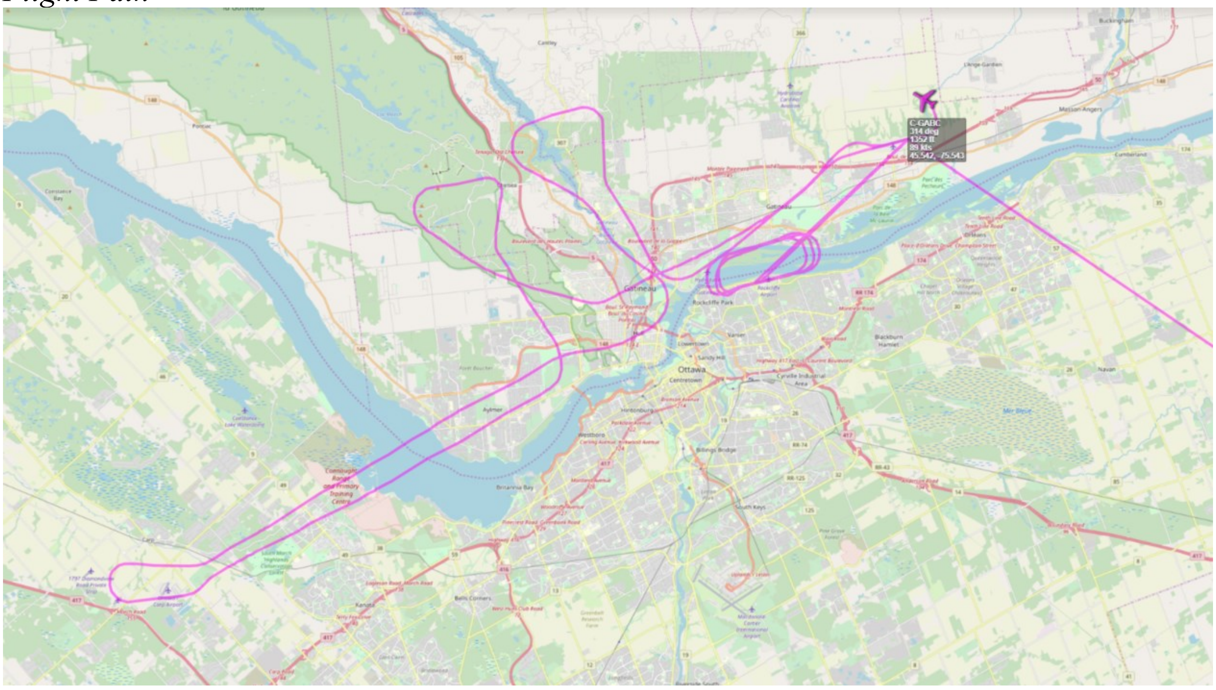
In the final circuit, pilots were introduced to the Peripheral Detection Task (PDT), which was to click a button on the yoke whenever they detected an auditory tone. Details regarding the PDT task are discussed below. Following the third circuit, the majority of pilots were ready for the experimental session, however, some did use a fourth round just to solidify their comfort with the flight tasks. After all practice sessions were completed, pilots were given a resting period before beginning the experimental flight task.

3.3.4 Flight Task Design

Participants were instructed to fly the first leg of the route, adhering to the planned headings, airspeed, and altitudes. Half of the participants began navigation with paper charts, while the rest used a tablet in the first leg. In the second leg, these were reversed and counterbalanced. The route began at a small general aviation aerodrome at the Gatineau airport, heading westerly along two rivers. There was then a 10-minute cross-country portion before reaching the Carp local general aviation aerodrome (see Figure 7 for the flight path). The total duration of the flight was approximately 60 minutes.

Figure 7

Flight Path



During the flight, air-to-air radio messages were broadcasted from local pilots. Participants were instructed to listen for these messages as they would then be asked questions about their content. The messages were presented in earbuds that the pilots wore during the flight. There were 14 radio messages in total, which contained information about other aircraft flying simultaneously (e.g., other pilot's aircraft type, call sign, location, and intention). After completing a touch and go at the second aerodrome in both legs, the experimenters paused the flight and participants were asked to indicate where other aircraft were located on a map and report on the other details of the radio messages heard.

Throughout the flight, 1000 Hz auditory tones (the target stimuli of the PDT) were presented every four to seven seconds and pilots were told to respond to them by clicking on a button on the yoke, where the left thumb would normally rest when they heard them. The tones were 100 ms in length and were played by two speakers that were placed behind the simulator. The tones were played loudly in order to be heard through the earbuds that pilots wore to hear the radio messages. Although pilots were asked to click on the button when they heard the tones, they were told to maintain the "aviate, navigate, and communicate" priorities and to ignore the tones if they were busy attending to more important flying tasks.

Throughout their flight, pilots wore a 14-channel wireless EEG headset in order to record EEG data throughout the flight. EEG calibration involved applying saline solution to felt pads and monitoring the signal quality, assuring impedance levels remain in the 10–20 k Ω range. Electrodes were located at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, with the channel placements following the international 10-20 system, referenced to electrodes P3 and P4. Using a stimulus presentation software called Psychopy 3.0, the 1000 Hz tones were presented to the participants, and markers (triggers) were inserted into the EEG data to mark the onset of each tone, when the pilot responded, or no response by the pilot (3 seconds after the tone). The EEG recordings were collected at 2048 Hz, and then down sampled to 256 Hz and were transmitted wirelessly via Bluetooth to an iMac desktop computer. The EEGLAB software was used to further down sampled to 128 Hz.

3.3.5 Pilot Audiometry

To maintain an aviation certification, pilots must perform medical audiometric testing at the beginning of their licensing and at 55 years old (Transport Canada, 2019). Pilots are tested using a "whisper" test where they need to hear and understand a whispered set of speech signals (words or sentences) at a distance greater than 2 metres. Every pilot in the study was medically certified and therefore, auditory acuity was not considered a confounding variable in the experiment. To further confirm that both the older and younger participants were matched audiometrically, data pertaining to the PDT was analyzed. During the simulated flight, auditory tones were presented, and pilots were tasked with clicking on a button on the yoke when they detected a tone. A Univariate ANOVA with age as the between group factor was conducted for the tone hit rate. Results showed no significant effect of age for hit rate, $p > 0.1$. Similarly, as shown in Table 3, there was no significant effect of age on the response time variables. The mean response time to tones in both groups were very similar (see Table 3). Thus, there was no evidence from the PDT task that the older group heard fewer tones than the younger group.

Table 3

Peripheral Detection Task Results

Measure	Age Group	N	Mean	Std. Deviation
Hit rate for responding correctly to the auditory tones in leg 1 of the flight	Younger (17-50)	21	78.4	15.2
	Older (51-71)	20	78.6	13.9
Hit rate for responding correctly to the auditory tones in leg 2 of the flight	Younger (17-50)	21	77.9	14.8
	Older (51-71)	20	79.1	15.3
Number of times the pilots' response times to the tone were greater than their own average in leg 1 of the flight	Younger (17-50)	21	22.9	10
	Older (51-71)	20	24.2	9.6
Number of times the pilots' response times to the tone were greater than their own average in leg 2 of the flight	Younger (17-50)	21	21.5	8.9
	Older (51-71)	20	26.1	9.9
Average response time for responding to the auditory tones in leg 1 of the flight	Younger (17-50)	21	1.2	0.2
	Older (51-71)	20	1.3	0.2
Average response time for responding to the auditory tones in leg 2 of the flight	Younger (17-50)	21	1.2	0.2
	Older (51-71)	20	1.2	0.2

3.6 Behavioural Variables

Behavioural measures analyzed in the study are based on the situation information provided through the radio call messages as well as the frequency of critical incidents.

3.6.1 Critical Incidents

Throughout the flight, pilots may have incurred different types of unplanned critical incidents. These incidents included getting lost, crashing, flying contrary to circuit procedures or landing poorly. These events were not a part of the experimental simulation, but rather occurred as outcomes from the pilots' flying. Research assistants recorded these critical incidents in each leg. Critical incidents variables were created for each leg as well as for the total flight.

3.6.2 Radio Communication Accuracy

Each communicated message was broken apart into the four main components that pilots usually include in broadcasting messages – aircraft Type, Call Sign, Location, and Intention. Note that in real flying scenarios, pilots do not always verbalize all the components when making every call, and this was represented in the radio messages. To create behavioural variables, the four main components were divided into two subgroups, SA level-1 information and SA level-2 information.

3.6.2.1 SA Level-1 Information Measures. SA level-1 information represents broadcasted information that was consistently the same for each aircraft every time they made a call. This static information includes the aircraft type, call sign and intention. Naturally, as these characteristics were constant throughout the flight, the frequency that this information was presented can be computed. The message segment Type was the first segment of the radio call messages ($n = 6$). The Type describes the make or model of the aircraft. There were three different aircraft in total and were named as follows: Cirrus, Mooney, and Cessna 150. The second segment was the Call Sign of the addressing aircraft ($n = 15$). The Call Sign segment is the information about who is broadcasting the message.

There were four broadcasters in total and were named as follows: Alpha November Romeo, Victor Papa November, Delta Echo Foxtrot, Sierra Tango November. The Intention segment is also communicated at the end of messages to describe the planned actions (n = 13).

Pilots reported on the details of the radio messages that were presented. SA level-1 information variables were created based on the accuracy of the information pertaining to the three message segments. An accuracy score for the stated aircraft Type, Call Sign, and Intention of all four aircraft was created from 0 to 2, where 0 means that they got no information correct, 1 means that they got partial information correct, and 2 means they were fully accurate. Each message segment score was then added together to create a total score for each participant for each message segment in all the aircraft put together (a score on 8).

3.6.2.2 SA Level-2 Grouping Measure. A grouping measure was also created for each aircraft. This represented how many bits of SA level-1 information were accurately combined and recalled for each of the aircraft. The accuracy score was from 0 to 3, where 0 represents no information correctly grouped, 2 represents two bits of information correctly grouped and 3 represents all of the information correctly grouped.

3.6.2.3 SA Level-2 Location Measure. As pilots are in constant motion, the SA level-2 information presented in radio messages, namely the aircraft's location, constantly changes. Therefore, the Location is a highly dynamic part of the communication as it is something that pilots need to consistently update and manipulate cognitively. This creates a constantly flowing picture in the mind. For that reason, the accuracy score for this variable was created by asking pilots to locate on a physical map where other aircraft would be at the pause of the simulated flight. The score was based on the proximity of the indicated location to the actual position of the other aircraft. Scores ranged from 0 (beyond a reasonable perimeter) to 2 (very close to the actual aircraft position).

3.7 EEG Variables

3.7.1 Electroencephalography Recording and Processing

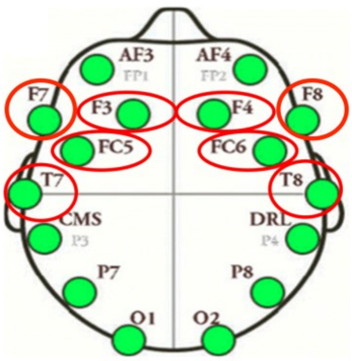
As discussed in section 3.3.4, the EEG recordings were collected at 2048 Hz, and then down sampled to 256 Hz. Further down sampling was conducted in EEGLAB to 128 Hz using an open-source software running on MATLAB v. 2019 (Delorme et al., 2004). The EEG data were recorded using the EMOTIV software TestBench, applying a bandwidth filter of 0.2 to 45 Hz before further processing using EEGLAB. Using Independent Component Analysis (ICA), the raw EEG data was decomposed to determine 14 independent components. Ocular and movement artifacts, as well as noisy data, were identified and removed from the data. Following the automated pre-processing, the data was visually inspected and remaining high probability artifacts such as electrode "pops" or remaining blinks/lateral eye movements were removed. Visual inspection of files with numerous datapoints containing electrode noise, missing triggers, and experimenter recording errors resulted in the elimination of 18 datasets, leaving a final subset of 33 participants. Datasets were grouped according to age of participant (split at age 50-years) to permit the examination of age effects on neural responses to the tones. Using the triggers inserted into the data during the recording, epochs based on the onset of the tones were created at -2000 to +2000 ms. The Study function in EEGLAB created grand averages of the ERPs and ERSPs across the 33 participants.

3.7.2 Electrode Regions of Interest

The brain regions of interest for these analyses are auditory cortex regions and frontal lobe regions. The electrodes analyzed for sound and feature detection were explored in auditory cortex regions, from electrodes T7 and T8. Electrodes F3, F4, F7 and FC5 were analyzed for the language processes in the first phase of input representation. Finally, the electrodes analyzed for cognitive and motor inhibition in the second phase of input representation are FC6 and F8. For an illustration of the EEG electrode location of the areas of interest, see Figure 8. For a description of the relation between the electrodes and Brodmann's Areas, see Appendix E.

Figure 8

Electrode Location Areas of Interest



3.7.3 Event-related Potential (ERP) Analyses

Using the EEGLAB Darbalai plugin, amplitudes (minimum for negative-going deflections or maximum for positive-going deflections) were extracted for key deflections at the P50, N1, P2, N2, and P3. The extraction process was repeated for electrodes in the auditory cortex (T7 and T8 electrodes) and the frontal lobe regions (electrodes F3, F4, F7, F8, FC5, and FC6). As shown in Table 4, specific amplitude ranges were selected for each of the five ERP components of interest (see Figure 3).

Table 4

Component Latency Ranges

Component	Latency Range
P50	20 ms to 80 ms
N1	50 ms to 150 ms
P2	130 ms to 250 ms
N2	174 ms to 300 ms
P3	230 ms to 350 ms

3.7.4 Event-related Spectral Perturbation (ERSP) Analyses

Average ERSPs were created using the Fast-Fourier Time-Frequency Transformation method to determine the spectral power across the tone epochs for the 2-40 Hz frequency bands. To test for significant differences between the two groups in the changes of oscillatory power in the frequency bands, the EEGLAB software conducted *t*-tests at every millisecond post-stimulus for the selected epoch length in the auditory cortex regions (electrodes T7 and T8) and frontal lobe regions (electrodes F3, F4, FC5, FC6, F7 and F8) of the brain. The focus of the analyses was on the darkest threads of red in the *p*-value figures. All frequency bands were examined to determine whether there were differences in the changes in power for both the older and younger group in any of the oscillatory bands.

Chapter 4: Results

4.1 Behavioural Results

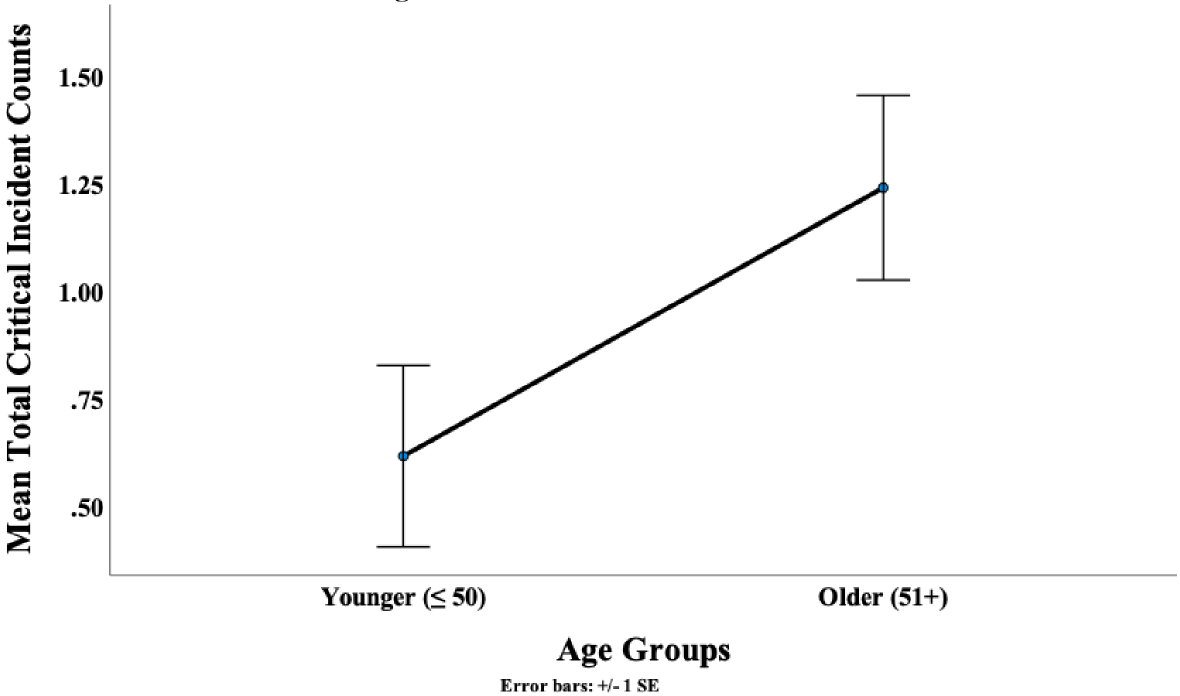
The first results presented in this section are the analyses of the relationships between critical incidents, age, and SA abilities. Key outcome variables for this first section are the frequency of critical incidents during the simulated flight. The second section examined the performance on recall tasks for static bits of information broadcasted during the simulated flight. The outcome variables for this second section are the mean performance scores for older and younger pilots for the three message segments (Type, Call Sign and Intent). The following section examined grouping scores corresponding to the SA level-1 bits of information (aircraft type, call sign and intention) of each aircraft broadcasted during flight (a SA level-2 ability). The outcome variables for this second section are the mean performance scores for older and younger pilots for the grouping of the four types of aircraft (ANR, VPN, STN and DEF). In the last section, the SA level-2 information performance scores on identifying the location of other aircraft were analyzed. The outcome variables for this section are the mean Location performance scores for older and younger pilots in each leg of the flight. The last section looks at the effects of age on critical incidents, with the outcome variables being the frequency of critical incidents in each leg and in total. Significance thresholds were determined by $p < 0.1$ with a minimum "small" effect size $\eta_p^2 \geq 0.01$, where effects were either small = 0.01 to 0.12, medium = 0.13 to 0.25, or large > 0.26 (Cohen, 1988). Using these two criteria for significance assured that no small but important relationships were missed.

4.1.1 *Critical Incidents*

As expected, many pilots did not incur a critical incident during the hour-long flight (45%). For those who did incur an incident, the majority were involved with one event (33%). The remaining 22% incurred either 2, 3 or 4 events, with 4 being the more extreme result. A Univariate ANOVA was conducted to examine the effect of age on total critical incidents experienced between the younger and older groups throughout the 60-minute flight. As shown in Figure 9, there was a significant main effect of age on the amount of critical incidents such that older participants ($M = 1.24$, $SD = 1.3$) incurred more critical incidents than the younger participants ($M = 0.61$, $SD = 0.80$), $F(1,50) = 4.29$, $p = 0.04$, $\eta_p^2 = 0.08$.

Figure 9

Critical Incident Counts in Younger and Older Pilots



4.1.1.1 Relationship of Critical Incidents to Situation Awareness. A Pearson correlational analysis was conducted to quantify the relation between overall radio call scores and critical incidents. The correlation confirmed a link between pilot risk for accidents and situation awareness performance. There was a significant negative correlation between the SA performance score and number of critical incidents, $r = -0.284$, $p = 0.02$.

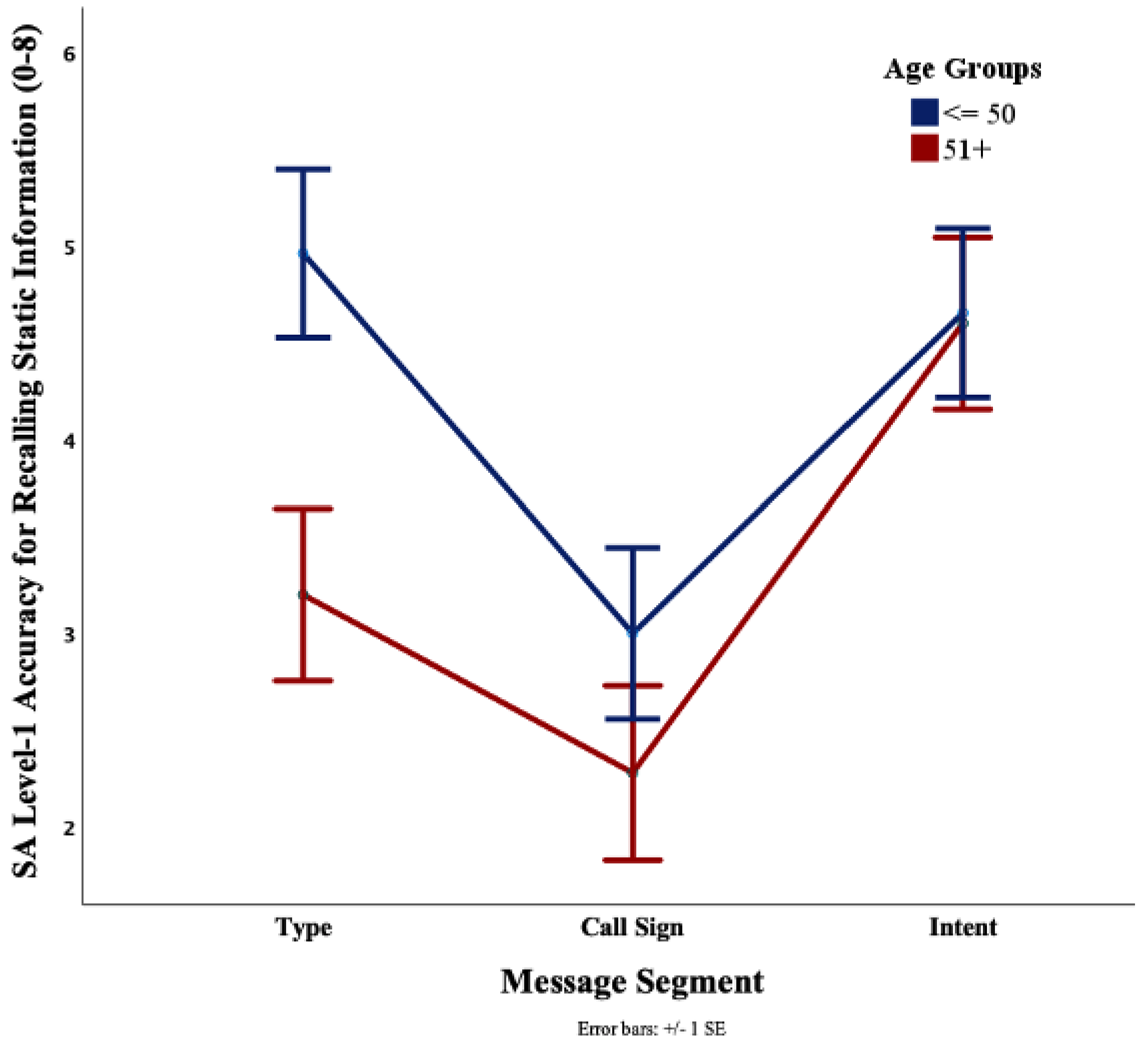
4.1.2 SA Level-1 Information Results

To examine the effects of age on the mean performance scores corresponding to SA level-1, a mixed-design ANOVA, with one within-subject effect (the radio call segments) and one between-subject (age group), was conducted. There was a significant main effect of message segment SA level-1 information performance scores $F(2,98) = 16.08$, $p < 0.001$, $\eta_p^2 = 0.24$. Post Hoc pairwise comparisons (Bonferroni) found that the main effect of the message segment was driven by significant differences between the Call Sign segment ($M = 2.64$) with the Type ($M = 4.08$) and Intention ($M = 4.62$) segments, $p < 0.001$. There was no significant difference between Intention and Type, $p > 0.1$.

There was a small between-subject main effect of age on the performance scores such that older pilots scored lower on SA level-1 information scores than did the younger group, $F(1,49) = 27.3$, $p = 0.07$, $\eta_p^2 = 0.063$. As illustrated in Figure 10, the message segment Type shows the greatest effect of age on performance scores. To further test this observation, post hoc one-way ANOVAs were conducted to examine the effect of age group on the performance scores for the individual message segments. The strongest effect of age was seen for Type, such that lower SA scores were seen in the older ($M = 3.2$, $SD = 2.41$) as compared to younger participants ($M = 4.96$, $SD = 2$), $F(1,50) = 8.04$, $p = 0.007$, $\eta_p^2 = 1.14$. In contrast, there was no significant effect of age for the Intention or Call Sign segments $p > 0.1$.

Figure 10

Mean Performance Scores for SA Level-1 Information

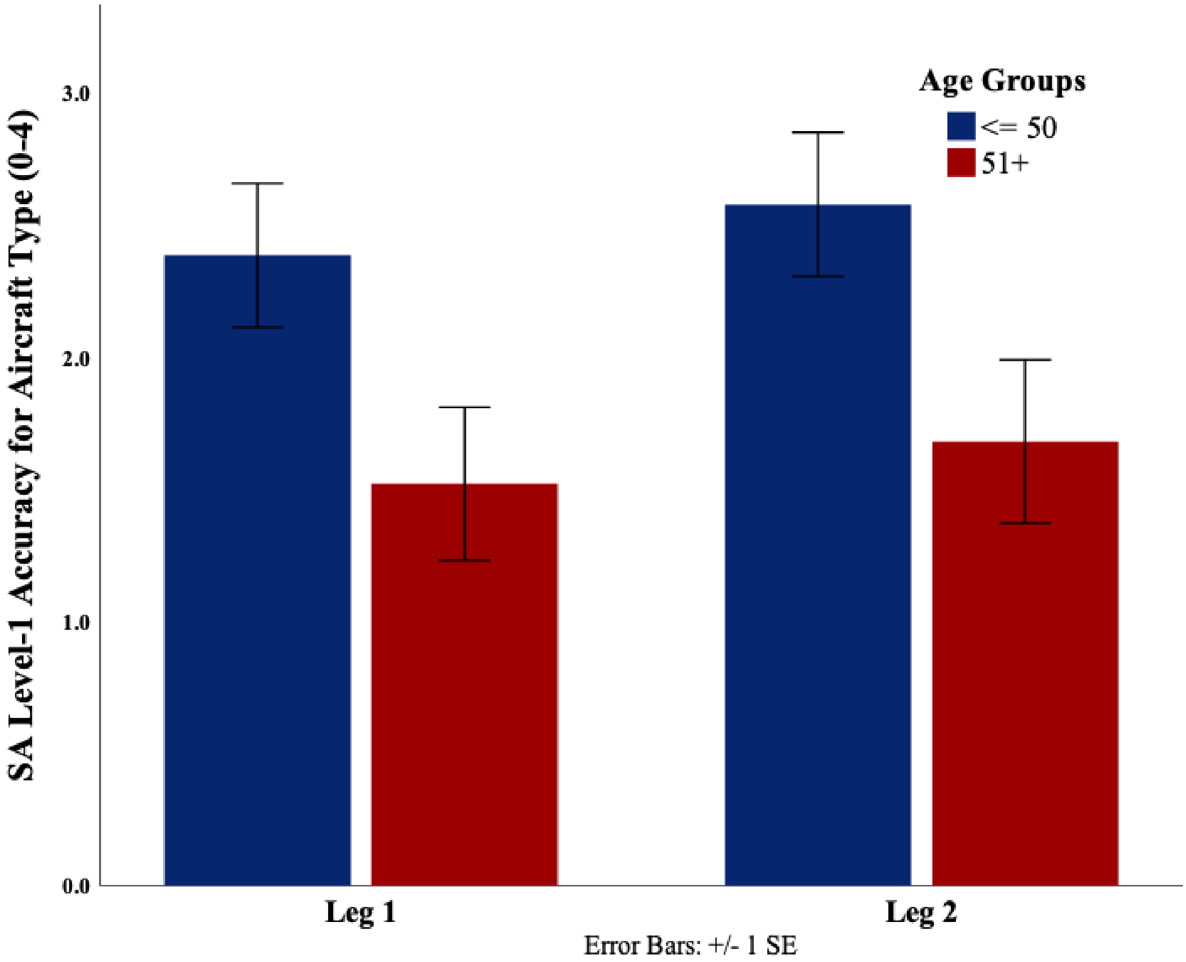


To further investigate the factors contributing to the effects observed above, univariate ANOVAs were conducted to investigate the effects of age on the mean performance scores in each leg of the flight. In the first leg of the flight, there was a significant main effect of age on the Type segment, such that older pilots ($M = 1.52$) were less likely to recall SA level-1 information pertaining to Type than younger pilots ($M = 2.38$), $F(1, 50) = 4.74$, $p = 0.03$, $\eta_p^2 = 0.08$. There was also a main effect of the message segment Type in the second leg such that such that older pilots ($M = 1.68$, $SD = 1.54$) were less likely to recall SA level-1 information pertaining to Type than younger pilots ($M = 2.57$, $SD =$

1.39), $F(1, 50) = 4.74$, $p = 0.03$, $\eta_p^2 = 0.08$. For an illustration of the mean performance scores of the Type segment in each flight leg, please see Figure 11.

Figure 11

Mean SA Level-1 Accuracy for Aircraft Type in Each Leg by Age Group



4.1.2.1 Ad Hoc Linguistic Analysis of Message Segments. As discussed above, of the three message segments, older participants performed significantly worse on the performance scores for the Type segment, illustrated by the large distance between the blue line (representing the younger group) and the red line (representing the older group) in Figure 10. A possible contributing factor to the performance differences between the message segments could be the suprasegmental aspects of the radio calls, including the message segments' pitch and intensity. To examine whether there were differences in the average pitch and intensity of the three message segments associated with SA level-1 scores, an ad hoc analysis was conducted on the recordings pertaining to the radio calls.

Using the recordings for each communicated message, the segments of the recordings pertaining to the type (n = 6), the call sign (n = 15), and the intention (n = 14) were separately extracted, for a total of 35 sub-recordings. Praat (Boersma & Weenink, 2018), an open-source software package for analyzing the phonetic and suprasegmental properties of sounds, was used to decompose each of the 35 sub-recordings spectrograms. For each sub-recording, the average pitch (Hz) and intensity (dB) was then extracted from the software, and average pitch and intensity measures were created. Using SPSS, ranking of the scores was conducted, using the Rank Cases function to order the values from smallest to largest and then assigning a rank to each value. This function was used in order to avoid potential confounding effects from outliers.

A Univariate ANOVA revealed an overall effect of the message segment on the ranked average pitch, $F(2, 34) = 4.85$, $p = 0.01$, $\eta_p^2 = 0.23$ (see Figure 12). Post Hoc pairwise comparisons (Bonferroni) revealed that the average ranked pitch of the Type segment ($M = 39$) was significantly higher than that of the Call Sign segment ($M = 21$), $p = 0.01$ and that of the Intention segment ($M = 21$), $p = 0.05$.

Figure 12

SA Level-1 - Message Segment Average Pitch

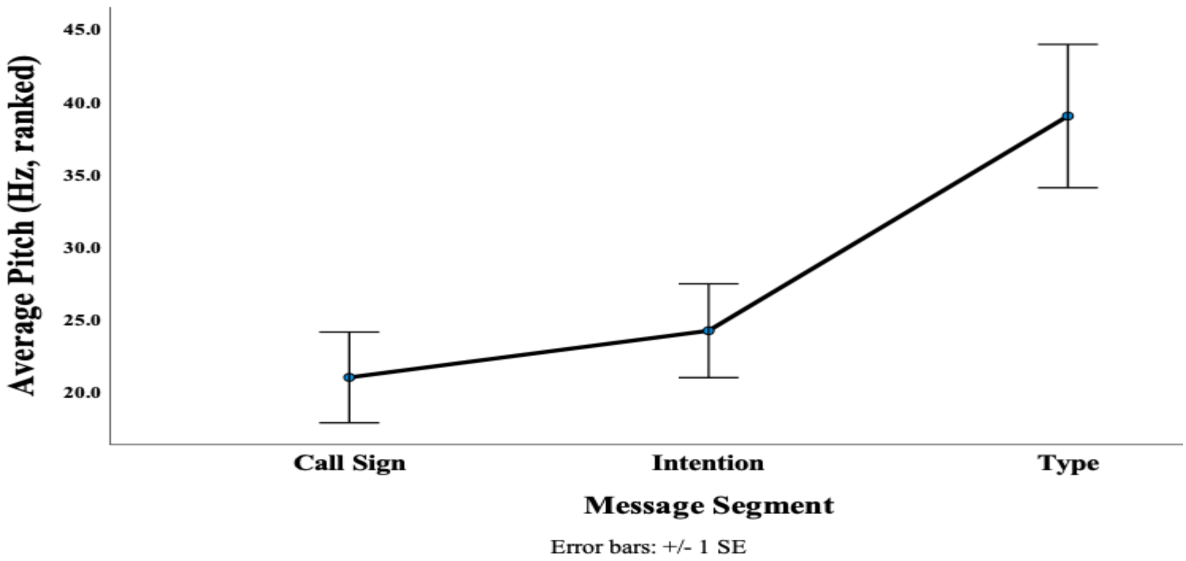
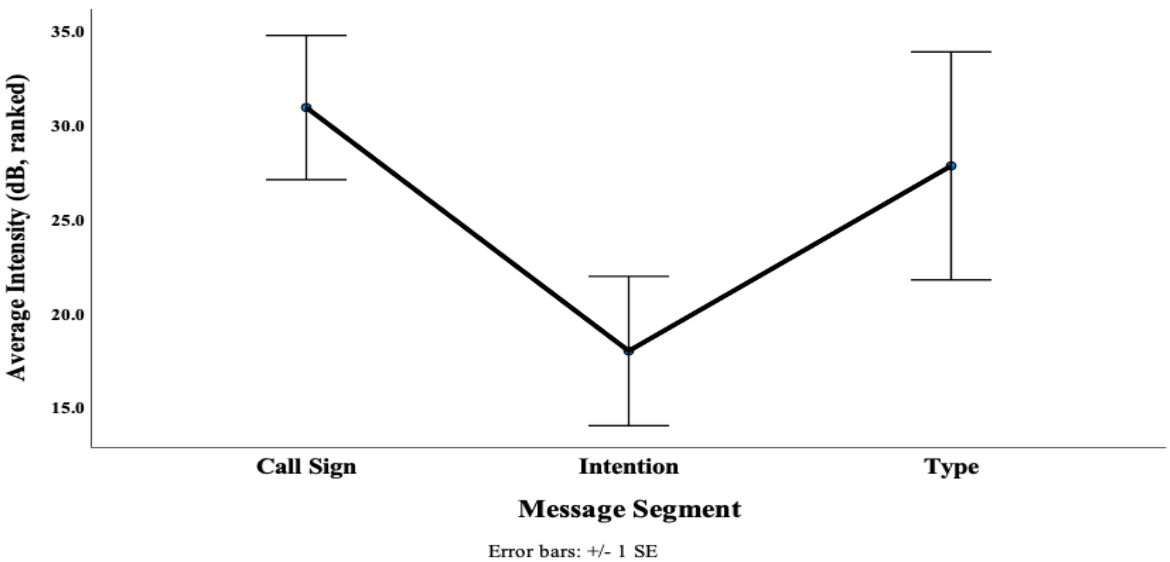


Figure 13

SA Level-1 - Message Segment Average Intensity



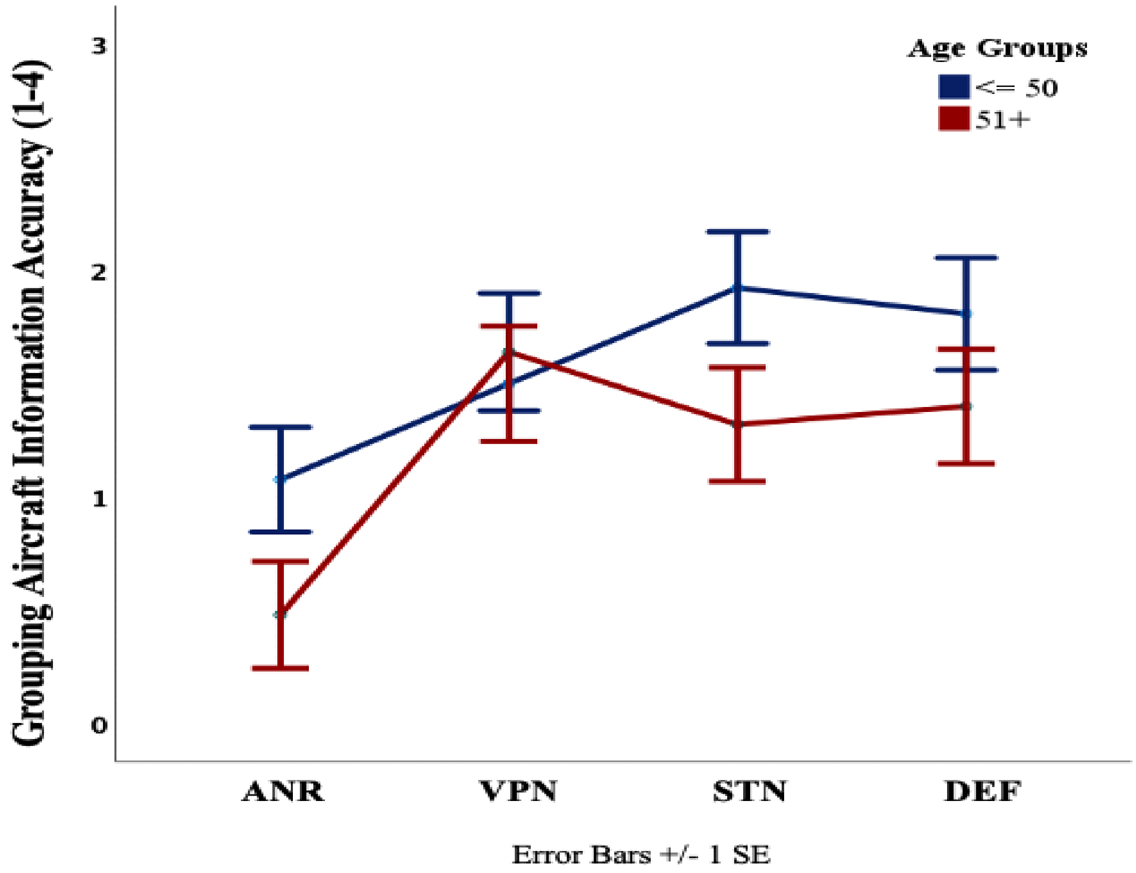
4.1.3 SA Level-2 Grouping Results

To examine the effects of age on the mean performance scores of grouping static information (aircraft type, call sign and intention) for each aircraft, a repeated measures

ANOVA, with one within-subject effect (aircraft) and one between-subject (age group) was conducted. There was a significant within-subject main effect of aircraft on performance scores $F(3,49) = 8.80$, $p < 0.001$, $\eta_p^2 = 0.15$. Post Hoc pairwise comparisons (Bonferroni) found that the main effect of the aircraft was driven by significant differences between the ANR aircraft ($M = 0.77$) and the other three aircraft: VPN ($M = 1.57$), STN ($M = 1.62$) and DEF ($M = 1.60$), $p = 0.001$. There was no significant difference between the other aircraft. While there was no main effect of age on grouping scores, pairwise comparisons showed that there were small significant effects of age for two aircraft. As shown in Figure 14, group scores for ANR and STN were significantly lower for the older pilot groups, $p = 0.077$ and $p = 0.093$, $\eta_p^2 = 0.06$ (both).

Figure 14

Mean Grouping Scores for each Aircraft by Age

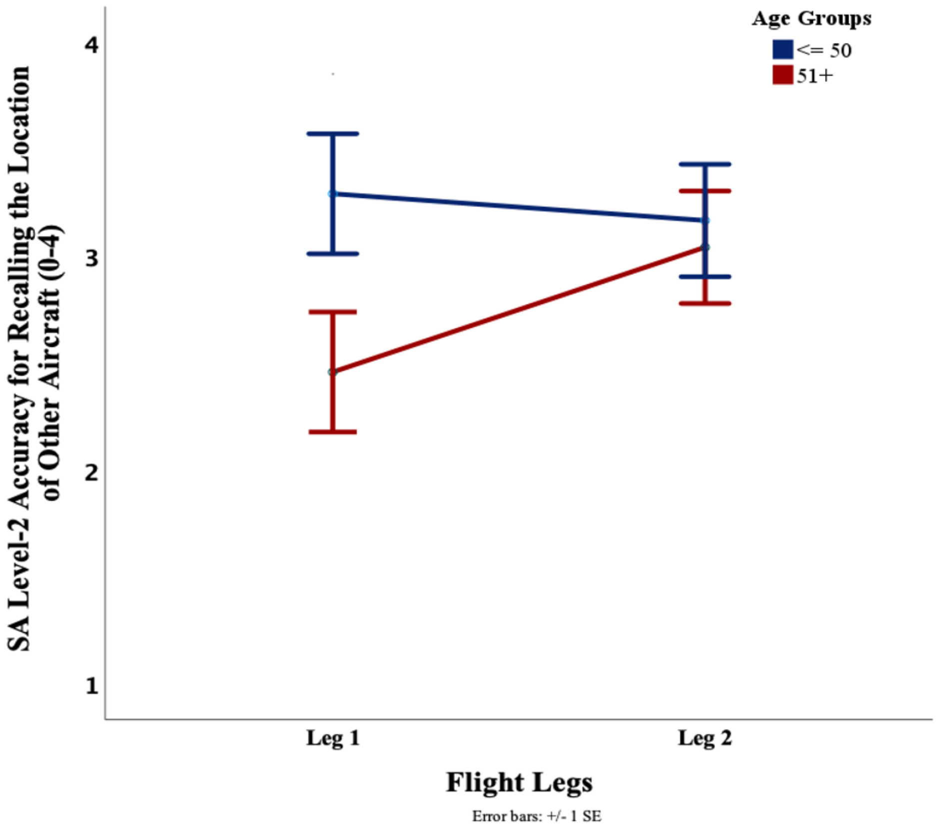


4.1.4 SA level-2 Information Measures

Univariate ANOVAs were conducted to determine the effects of age on the performance scores corresponding to the SA level-2 information (Location) presented in the radio messages in each leg of the simulated flight. In the first leg of the flight, a significant main effect of age group was observed between the younger (M = 3.32, SD = 1.14) and older (M = 2.52, SD = 1.55) participants, such that older age was associated with poorer recall scores $F(1, 49) = 4.28$, $p = 0.04$, $\eta_p^2 = 0.08$. No significant effects of age on performance scores for SA level-2 information was found in the second leg of the flight, $p > 0.1$.

Figure 15

Aircraft Location Accuracy in Legs 1 and 2



4.1.5 Summary of the Behavioural Results

Table 5

Summary of the Behavioural Results

Critical Incidents	
Critical Incidents and Age	**Critical Incidents and SA**
Older pilots incurred greater critical incidents than the younger participants	Better SA predicted fewer incidents: The strongest predictors of critical incidents were **the location scores for other aircraft** and **recall of other aircraft Type**. A relationship between critical incidents and a combined score for all SA variables related to radio calls was found.
SA Level-1 Information Results	
Static Information and Age	**Ad Hoc Linguistic Analysis of Message Segments**
A significant main effect of message segment SA level-1 information performance scores The main effect of the message segment was driven by significant differences between the Call Sign segment with the Type and Intention segments Older pilots scored lower on SA level-1 information scores than did the younger group The message segment Type showed the greatest effect of age on performance scores.	An overall effect of the message segment on the ranked average pitch The average ranked pitch of the Type segment was significantly higher than that of the Call Sign segment and that of the Intention segment An overall effect of the message segment on the ranked average intensity The average ranked intensity of the Call Sign segment was significantly higher than that of the Intention segment
SA Level-2 Information Results	
Grouping Results	**Dynamic Information**
A main effect of aircraft on performance scores of grouping static information Grouping scores for the ANR aircraft were significantly lower than the other three aircraft No main effect of age on grouping scores A small significant effect of age on the performance scores for grouping the information of ANR and STN aircraft such that the older pilots performed worse than the younger ones	In the first leg of the flight older age was associated with poorer recall scores for the dynamic information (Location segment)

4.2 EEG Results

The neural responses to the repeated tone stimuli were analyzed to examine possible neural age-effects of processing auditory information during flight. ERPs were used to analyze the amplitude of neural activity for earlier and later processing of the tones in older and younger pilot participants. ERSPs were used to investigate tone-related changes in spectral power as a response to the tones in both age groups. The primary electrode areas of interest for this study were the auditory cortex regions (electrodes T7 and T8) and frontal lobe regions (electrodes F3, F4, F7, F8, FC5 and FC6) of the brain. Sound detection, language processing as well as cognitive and motor inhibition were the primary functional processes of interest for analyses.

To determine the effects of age on tone-related ERP components, a series of repeated measures ANOVA, with one within-subject factor (latency) and one between-subject factor (age group) were conducted for each of the chosen electrodes. Post-hoc pairwise comparisons (Bonferroni) were conducted to quantify the effect of age at each latency. Significance thresholds were established by setting a minimum p-value of < 0.1 and an effect size $\eta_p^2 > 0.01$. Small effects ranged from 0.01 to 0.05, medium effects ranged from 0.06 to 0.13, and large effects were ≥ 0.14 (Cohen, 1988). Using these two criteria for significance assured that no small but important relationships were missed.

To determine the effects of age on tone-related changes in power in oscillatory bands, EEGLAB conducted a series of t-tests at every millisecond post-stimulus (from 0 to 400 ms) for the selected epoch length in the auditory cortex regions and the frontal lobe regions of the brain.

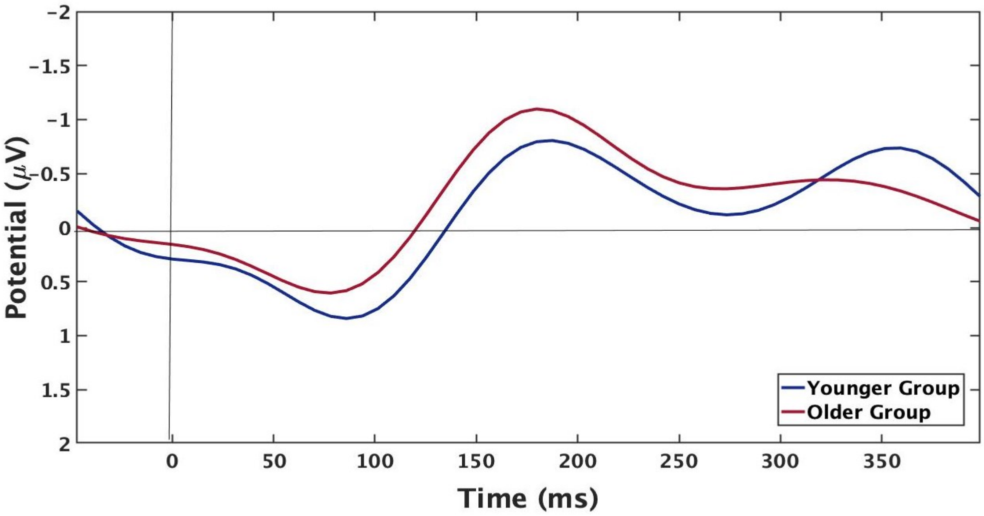
4.2.1 Sound Detection Areas

4.2.1.1 Electrode T7.

4.2.1.1.1 ERP Analysis of Electrode T7. Illustrated in Figure 16 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots of electrode T7.

Figure 16

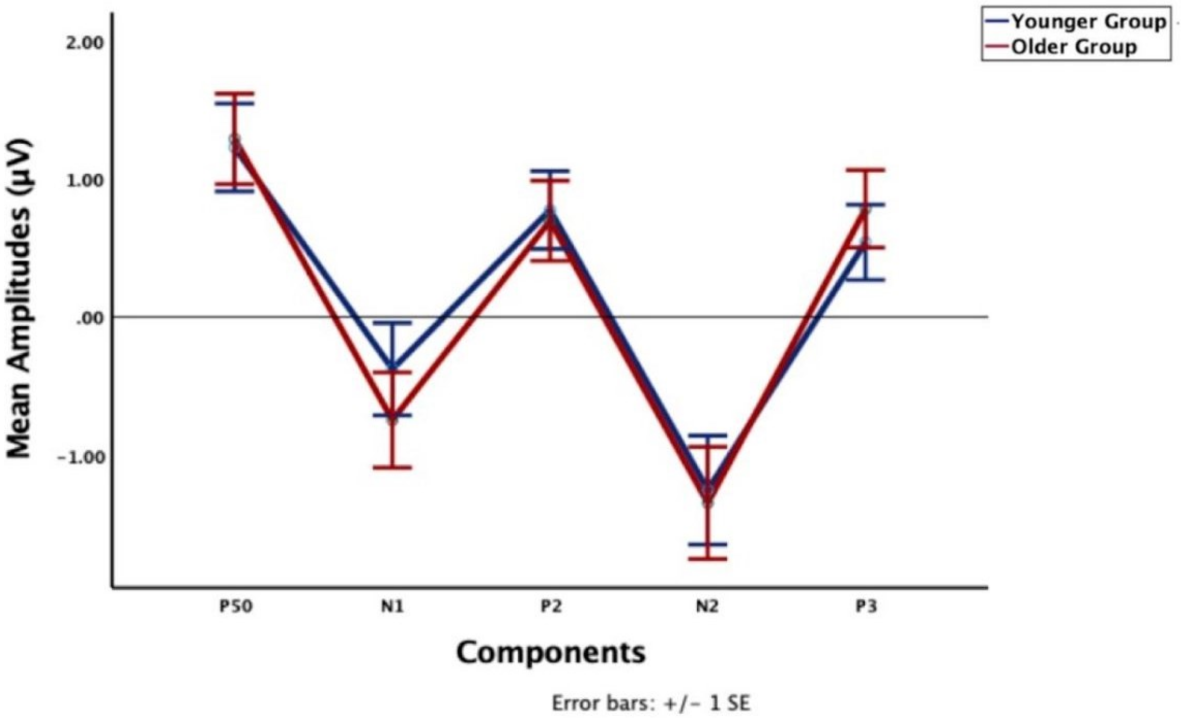
ERPs for Both Age Groups of Electrode T7



As shown in Figure 17, pairwise comparisons revealed, as predicted, that in electrode T7, there was no effect of age on the N1 component amplitudes as the difference between the younger (M = -0.37) and older (M = 0.74) participants' mean amplitudes did not meet the threshold for significance, $F(1, 31) = 0.58$, $p = 0.44$, $\eta_p^2 = 0.01$. This is represented in Figure 17, where the amplitude means for both groups at the key components are plotted.

Figure 17

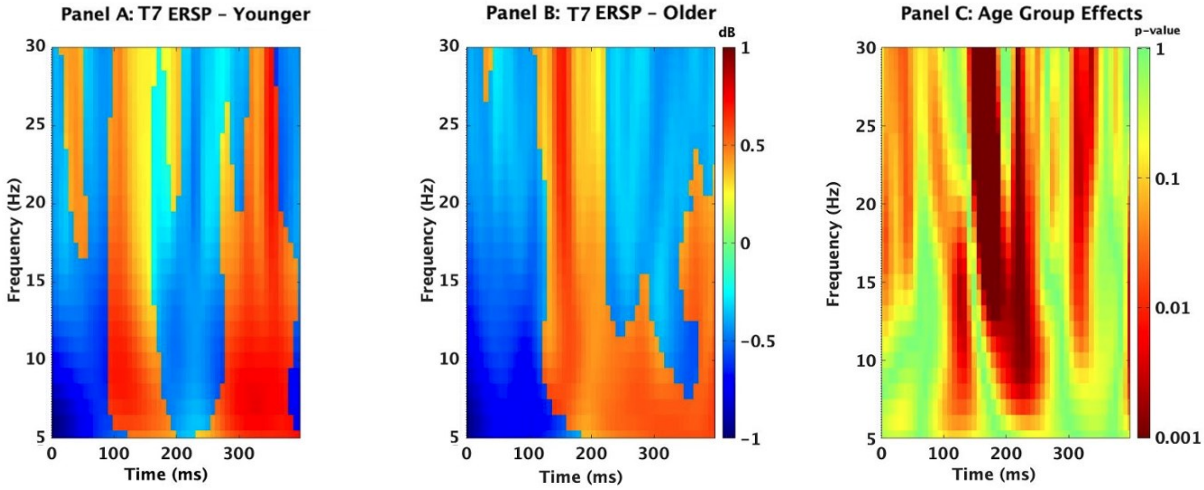
Component Mean Amplitudes for Both Age Groups of Electrode T7



***4.2.1.1.2 ERSP Analysis* of Electrode T7.** Illustrated in Figure 18 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode T7.

Figure 18

ERSPs for Both Age Groups of Electrode T7



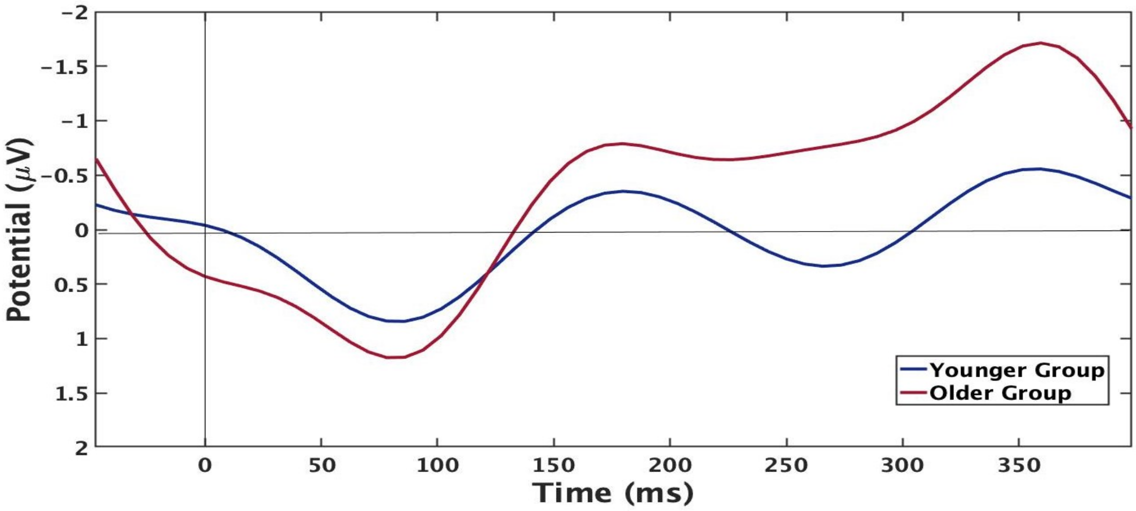
As can be observed in Panel C of Figure 18, in earlier latencies of tonal processing, there were no significant effects of age ($p > 0.05$) on the change in energy of any of the oscillatory bands identified from electrode T7.

4.2.1.2 Electrode T8.

4.2.1.2.1 ERP Analysis of Electrode T8. Illustrated in Figure 19 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode T8.

Figure 19

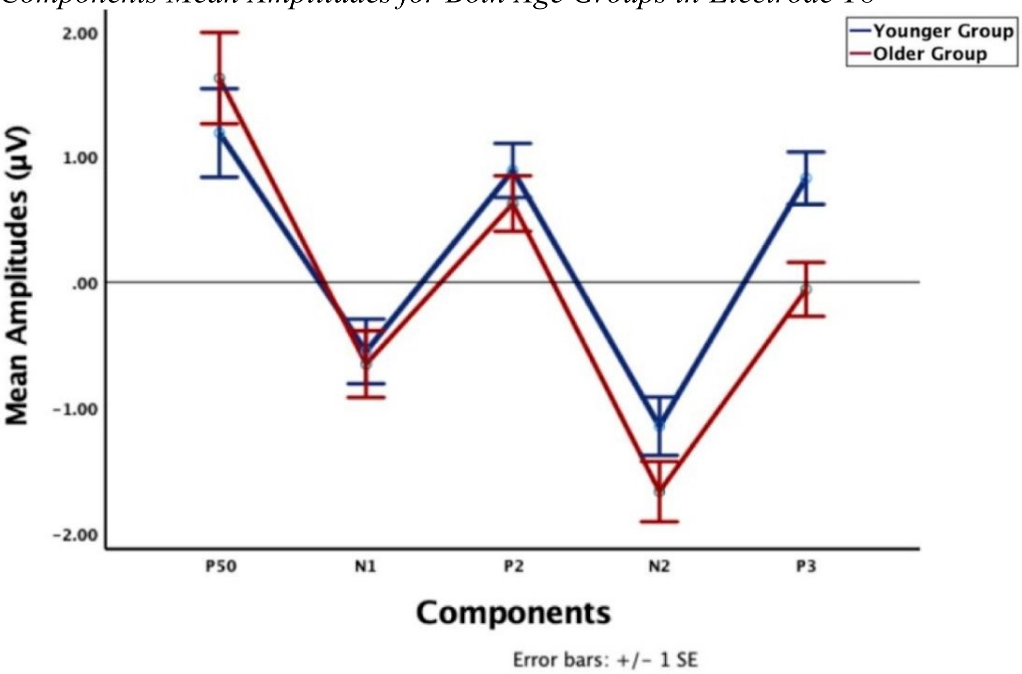
ERPs for Both Age Groups in Electrode T8



As shown in Figure 20, pairwise comparisons revealed, as predicted, that in electrode T8, there was no effect of age on the N1 component amplitudes as the difference between the younger (M = -0.55) and older (M = -0.65) participants' mean amplitudes did not meet the threshold for significance, $F(1, 31) = 0.07$, $p = 0.78$, $\eta_p^2 = 0.002$.

Figure 20

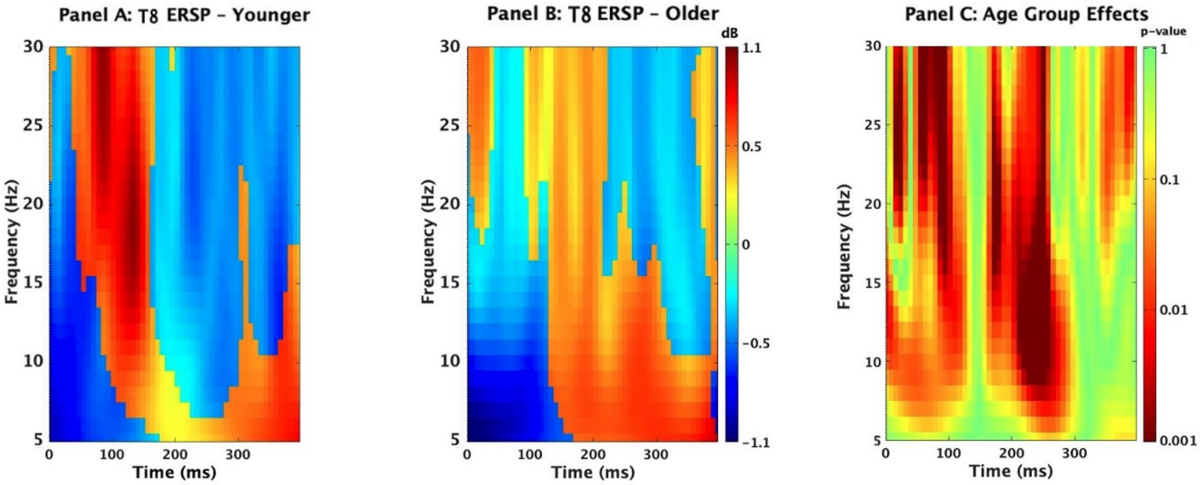
Components Mean Amplitudes for Both Age Groups in Electrode T8



4.2.1.2.2 ERSP Analysis of Electrode T8. Illustrated in Figure 21 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode T8.

Figure 21

ERSPs for Both Age Groups in Electrode T8



An age effect can be observed in Panel C of Figure 21, around 10 to 100 ms in the beta oscillatory bands post-stimulus, such that the power increase was significantly greater for the younger participants (see Panel A) in comparison to the older participants (see Panel B) from electrode T8.

4.2.1.3 Summary of the Findings of the Sound Detection Areas.

Table 6

Summary of the Sound Detection Findings Related to the Hypotheses

<table>
<tr><td colspan="4">Sound and feature detection of the tones were explored in auditory electrode locations, particularly associated with Brodmann’s areas 42 (BA42) and 27 (BA27) (Trans Cranial Technologies, 2012; Mirz et al., 1999).

The N1 component was of particular interest as it has been associated with the brain’s stimulus detection phase of processing (Näätänen et al., 1988; P et al., 2020; Hyde, 1997; Trainor, 2008).

The theta and beta oscillatory bands were of particular interest for their known associations with being activated during the stimulus detection phase of processing (Christov & Dushanova, 2016; Fujioka et al, 2015; Wisniewski et al., 2017).</td></tr>
<tr><th>Electrode</th><th>ERP Results</th><th>ERSP Results</th><th>Aviator Implications</th></tr>
<tr><td>T7</td><td>No significant effect of age was found on the N1 component amplitudes</td><td>No significant effect of age was found in the changes of the theta and beta oscillatory bands post-stimulus</td><td rowspan="2">Regarding the auditory processing of pilots during aviation, evidence from electrodes T7 and T8 suggests that aging may impact the pilots’ dedicated neural power towards detecting sounds.</td></tr>
<tr><td>T8</td><td>No significant effect of age was found on the N1 component amplitudes</td><td>Beta oscillatory power increases were found in the younger, but not in the older participants’ neural power around 10 to 100 ms post-stimulus</td></tr>
</table>

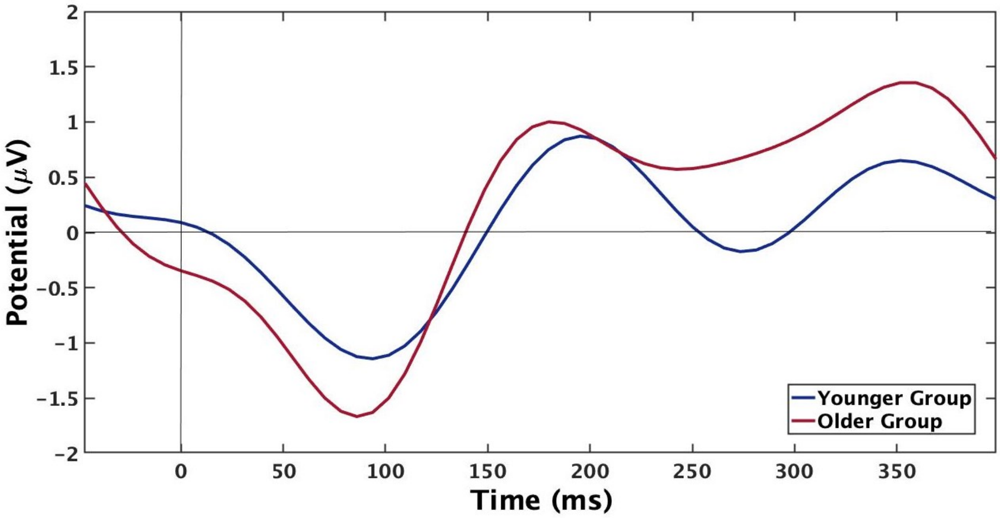
4.2.2 First phase of input representation - Language Processing Areas

4.2.2.1 Electrode F3.

4.2.2.1.1 ERP Analysis of Electrode F3. Illustrated in Figure 22 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode F3.

Figure 22

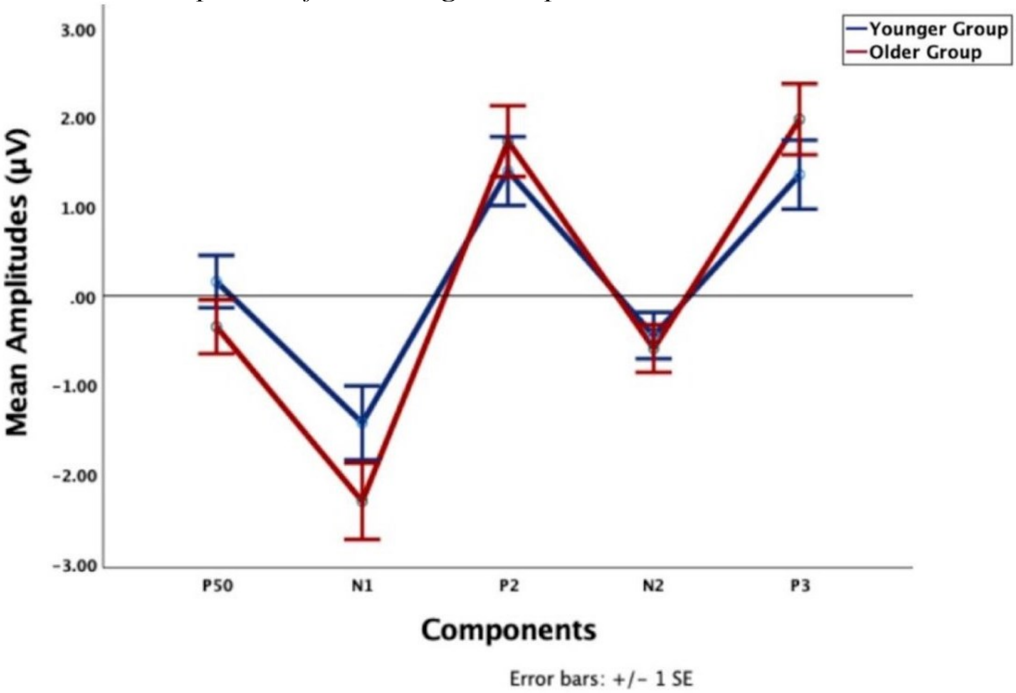
ERPs for Both Age Groups in Electrode F3



As shown in Figure 23, pairwise comparisons revealed, as predicted, that in electrode F3 there was no effect of age on the mean P2, N2 or P3 component amplitudes as the difference between the younger and older participants' mean amplitudes in each component did not meet the threshold for significance, $p > 0.1$.

Figure 23

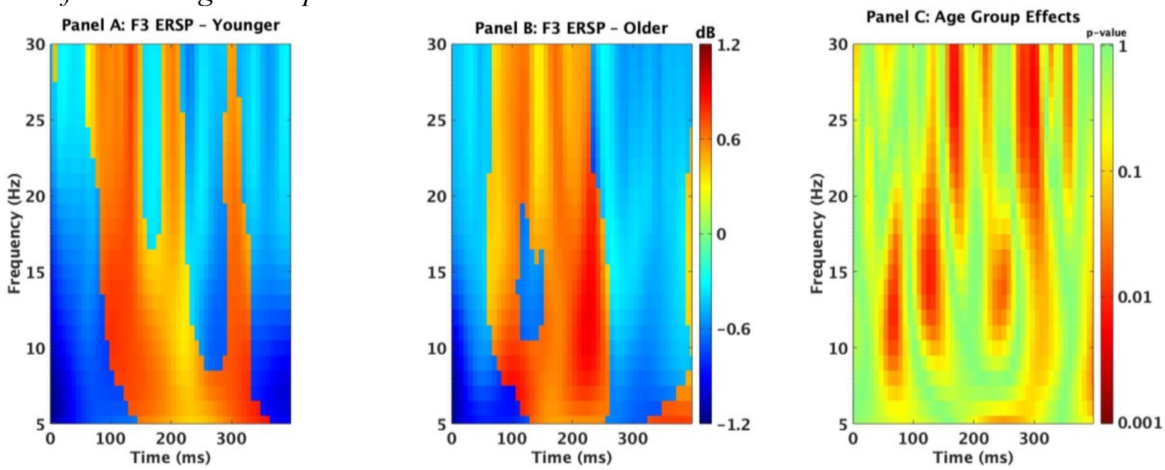
Components Mean Amplitudes for Both Age Groups in Electrode F3



4.2.2.1.2 ERSP Analysis of Electrode F3. Illustrated in Figure 24 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode F3.

Figure 24

ERSPs for Both Age Groups in Electrode F3



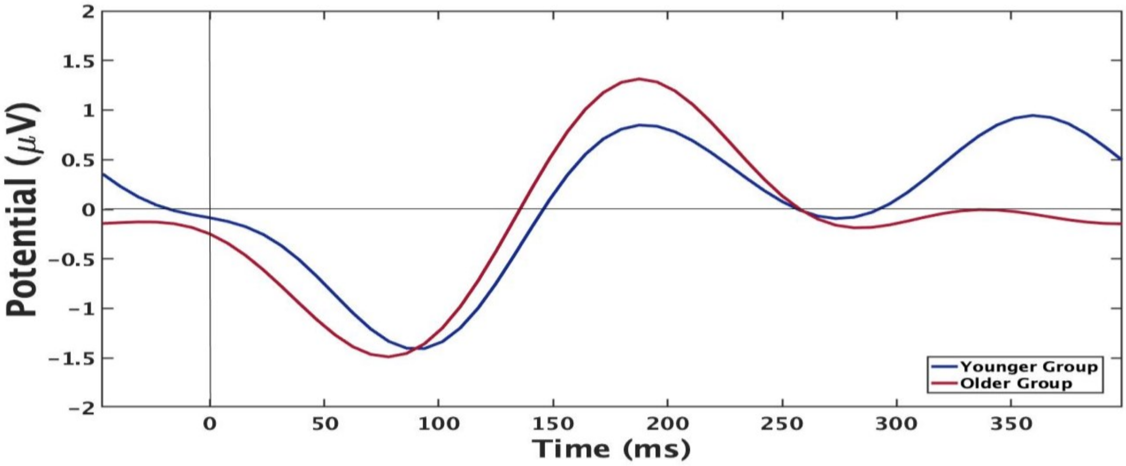
As can be observed in Panel C of Figure 24, in the later latencies of tonal processing, there were no significant effects of age ($p > 0.05$) on the change in energy of any of the oscillatory bands in electrode F3.

4.2.2.2 Electrode F4.

4.2.2.2.1 ERP Analysis of Electrode F4. Illustrated in Figure 25 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode F4.

Figure 25

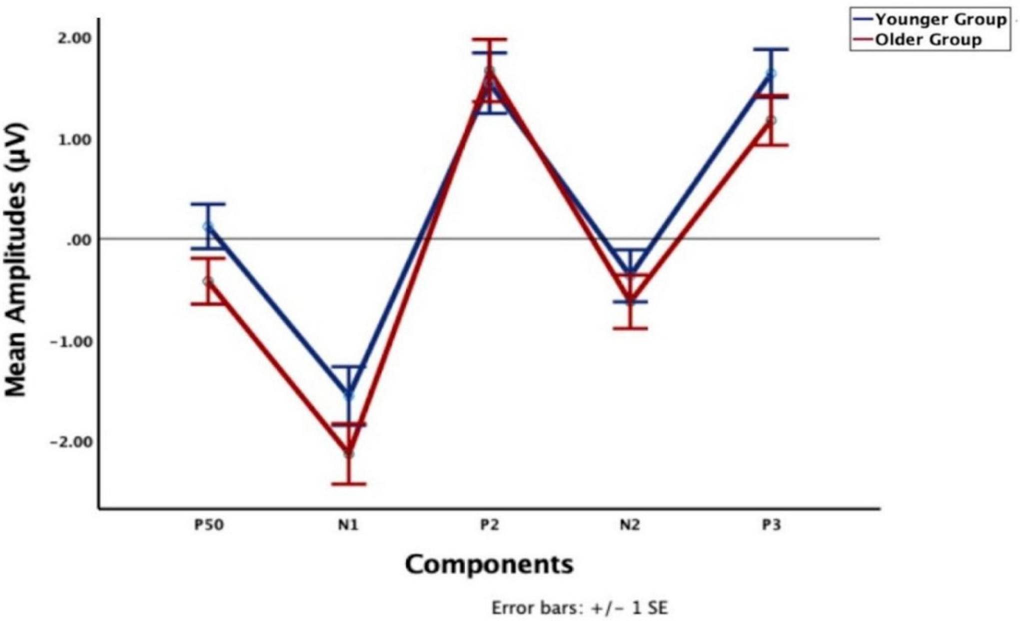
ERPs for Both Age Groups Electrode F4



As shown in Figure 26, pairwise comparisons revealed, as predicted, that in electrode F4 there was no effect of age on the mean P2, N2 or P3 component amplitudes as the difference between the younger and older participants' mean amplitudes in each component did not meet the threshold for significance, $p > 0.1$.

Figure 26

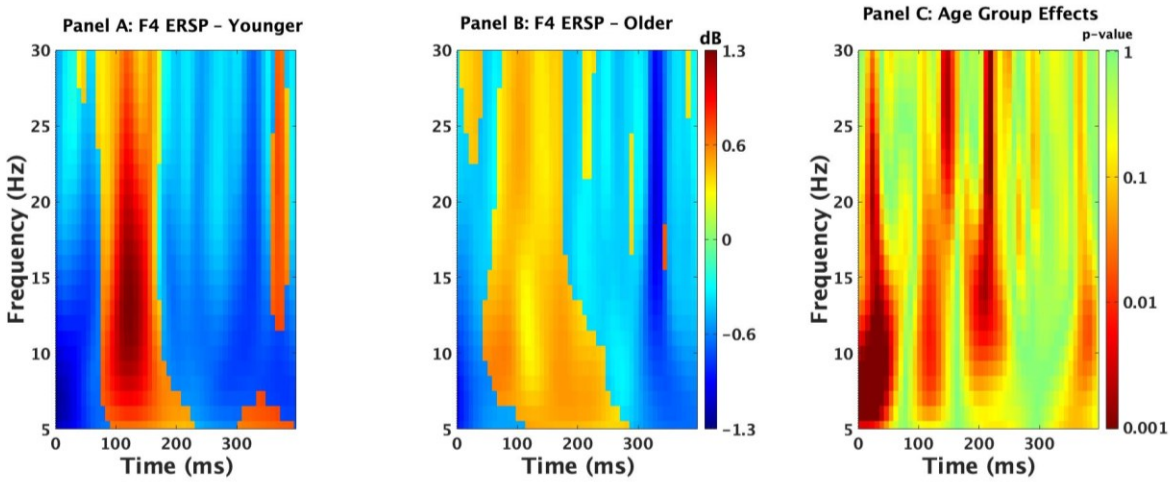
Components Mean Amplitudes for Both Age Groups in Electrode F4



4.2.2.2.2 ERSP Analysis of Electrode F4. Illustrated in Figure 27 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode F4.

Figure 27

ERSPs for Both Age Groups in Electrode F4



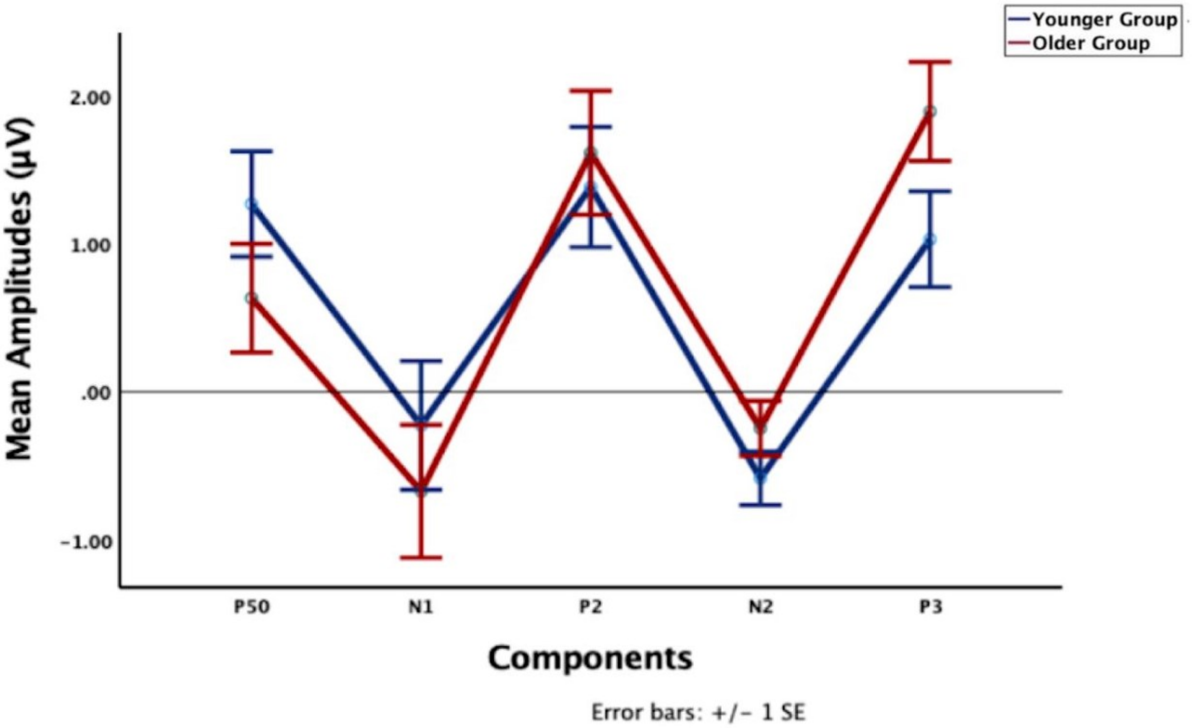
As can be observed in Panel C of Figure 27, in the later latencies of tonal processing, there were no significant effects of age ($p > 0.05$) on the change in energy of any of the oscillatory bands from the electrode F4.

4.2.2.3 Electrode FC5.

4.2.2.3.1 ERP Analysis of Electrode FC5. As shown in Figure 28, pairwise comparisons conducted on the component peak amplitudes revealed a medium effect of age in electrode FC5 at the P3 component amplitudes such that lower amplitudes were observed for the younger ($M = 1.02$) as compared to the older ($M = 1.89$) participants, $F(1, 31) = 3.44$, $p = 0.07$, $\eta_p^2 = 0.1$.

Figure 28

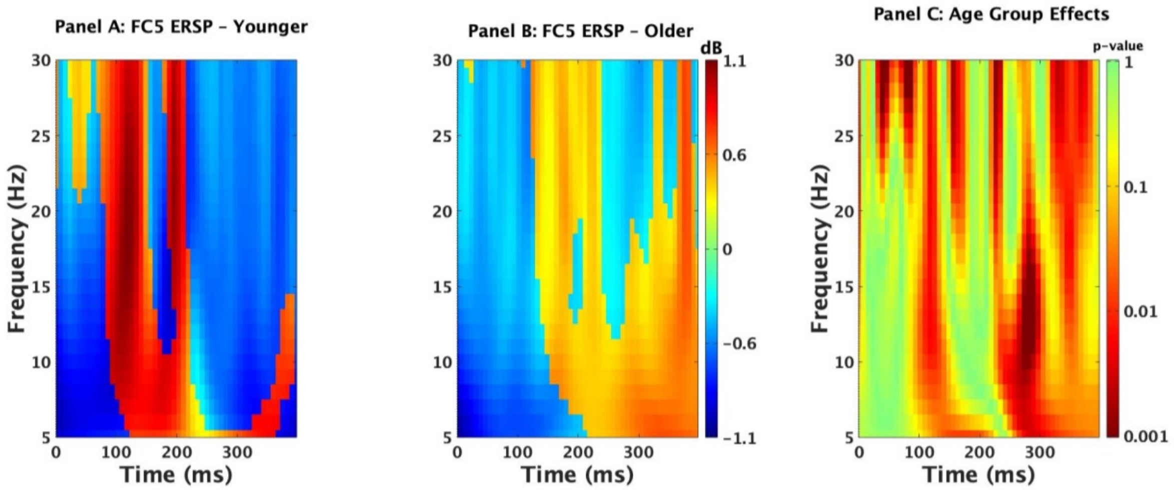
Components Mean Amplitudes for Both Age Groups in Electrode FC5



4.2.2.3.2 ERSP Analysis of Electrode FC5. Illustrated in Figure 29 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode FC5.

Figure 29

ERSPs for Both Age Groups in Electrode FC5



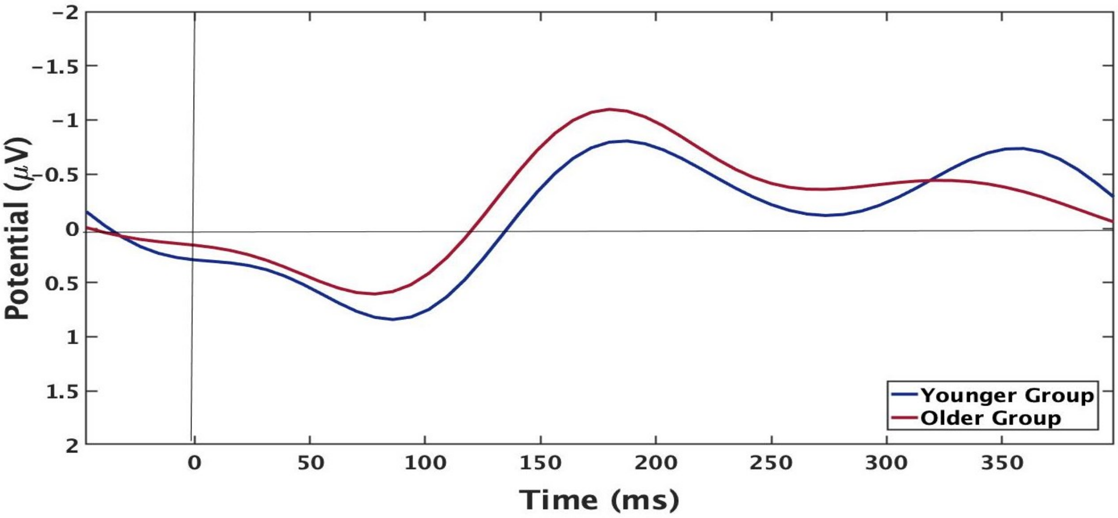
An age effect can be observed in Panel C of Figure 29, around 250 to 300 ms in the alpha and beta oscillatory bands post-stimulus, such that a power increase in the alpha and beta bands in the older groups (see Panel B) that was not observed in the younger participants (see Panel A) in electrode FC5.

4.2.2.4 Electrode F7.

4.2.2.4.1 ERP Analysis of Electrode F7. Illustrated in Figure 30 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode F7.

Figure 30

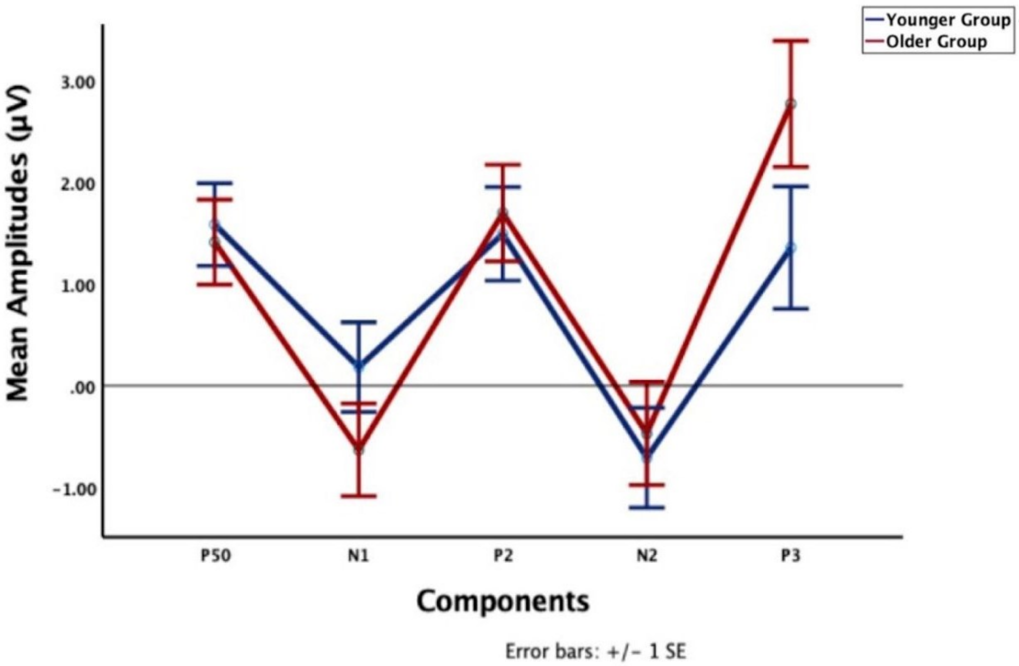
ERPs for Both Age Groups in Electrode F7



As shown in Figure 31, pairwise comparisons revealed that in electrode F7, there was no effect of age on the mean N2, P2 or P3 component amplitudes as the difference between the younger and older participants' mean amplitudes in each component did not meet the threshold for significance, $p > 0.1$.

Figure 31

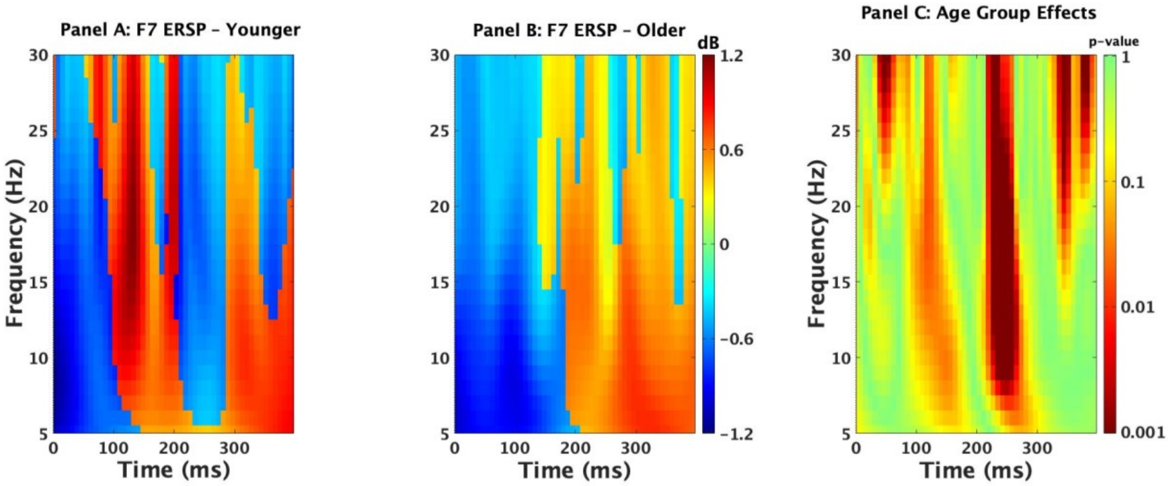
Components Mean Amplitudes for Electrode F7



4.2.2.4.2 ERSP Analysis Electrode F7. Illustrated in Figure 32 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode F7.

Figure 32

ERSPs for Both Age Groups in Electrode F7



An age effect can be observed in Panel C of Figure 32, around 215 to 260 ms in the alpha and beta oscillatory bands post-stimulus, such that the older pilots experienced a power increase (see Panel B) that was not observed in the younger participants’ response (see Panel A) in electrode F7.

4.2.2.5 Summary of the Sound Detection in Auditory Cortex Regions Findings.

Table 7

Summary of the First Phase of Input Representation (Language Processing Areas) Findings Related to the Hypotheses

<table>
<tr><td colspan="4">The first phase of input representation was explored using electrodes typically related to language processing areas; specifically in Brodmann's areas 8 (BA8), left 44 (left BA44) and 47 (BA47) (Anderson et al.1994; Trans Cranial Technologies, 2012; Crozier et al., 1999; Cutting et al., 2006; De Carli et al., 2007; Heim et al., 2008; Kübler et al., 2006; Rama et al., 2001; Sahin et al., 2006 Volz et al., 2003). The neural responses to the tones in these regions, which are not presumed to be directly related to the task associated with the tone, were analyzed as gauges of how much other ongoing brain activity is happening in language processing regions that should be associated with the processing of radio call messages throughout the flight.

The P2, N2 and P3 components were of particular interest as they have been associated with higher-order processing of auditory information (P et al., 2020; Trainor, 2008).

The alpha oscillatory band was of particular interest for its known association with cognitive inhibition and neural resource management in task-irrelevant regions (Christov & Dushanova, 2016; Fujioka et al, 2015; Wisniewski et al., 2017).</td></tr>
<tr><th>Electrode</th><th>ERP Results</th><th>ERSP Results</th><th>Aviator Implications</th></tr>
<tr><td>F3</td><td>No significant effect of age on the N2, P2 or P3 component amplitudes</td><td>No significant effect of age was found in the changes of the alpha oscillatory band post-stimulus</td><td rowspan="4">Regarding the auditory processing of pilots during aviation, evidence from electrodes FC5 left and F7 regions suggests that older pilots may allot mental resources in regions and latencies where neural activity may not be optimal and result in communication processing being compromised.</td></tr>
<tr><td>F4</td><td>No significant effect of age on the N2, P2 or P3 component amplitudes</td><td>No significant effects of age on the changes post-stimulus of any of the oscillatory bands in later processing of the tones</td></tr>
<tr><td>FC5</td><td>The P3 amplitudes showed greater amplitudes in the older as compared to the younger participants</td><td>Alpha and beta oscillatory power increases were found in the older, but not in the younger participants' neural power around 250 to 300 ms post-stimulus</td></tr>
<tr><td>F7</td><td>No significant effect of age on the N2, P2 or P3 component amplitudes</td><td>Alpha and beta oscillatory power increases were found in the older, but not in the younger participants' neural power around 215 to 260 ms post-stimulus</td></tr>
</table>

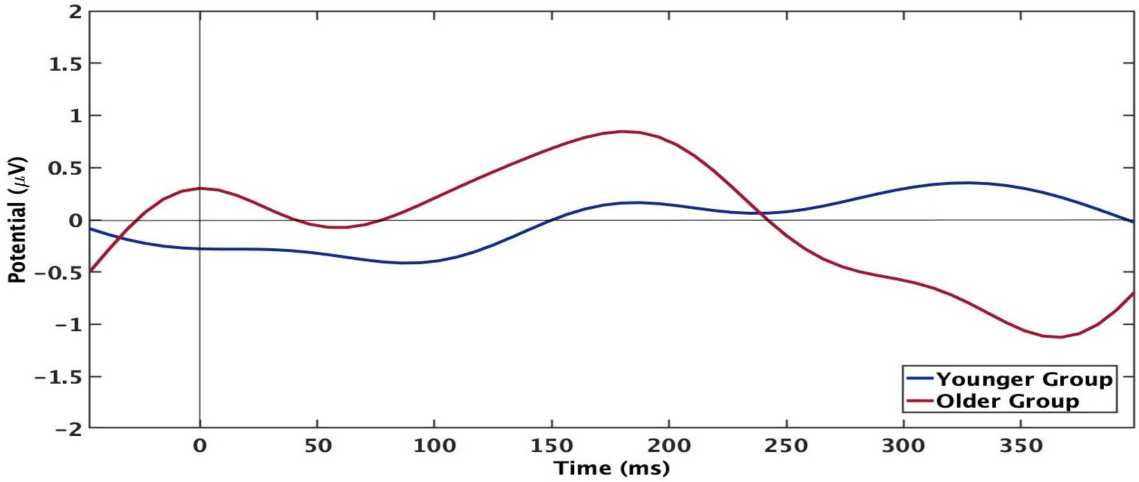
4.2.3 Second phase of input representation – Cognitive and Motor Inhibition Areas

4.2.3.1 Electrode FC6.

4.2.3.1.1 ERP Analysis of Electrode FC6. Illustrated in Figure 33 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode FC6.

Figure 33

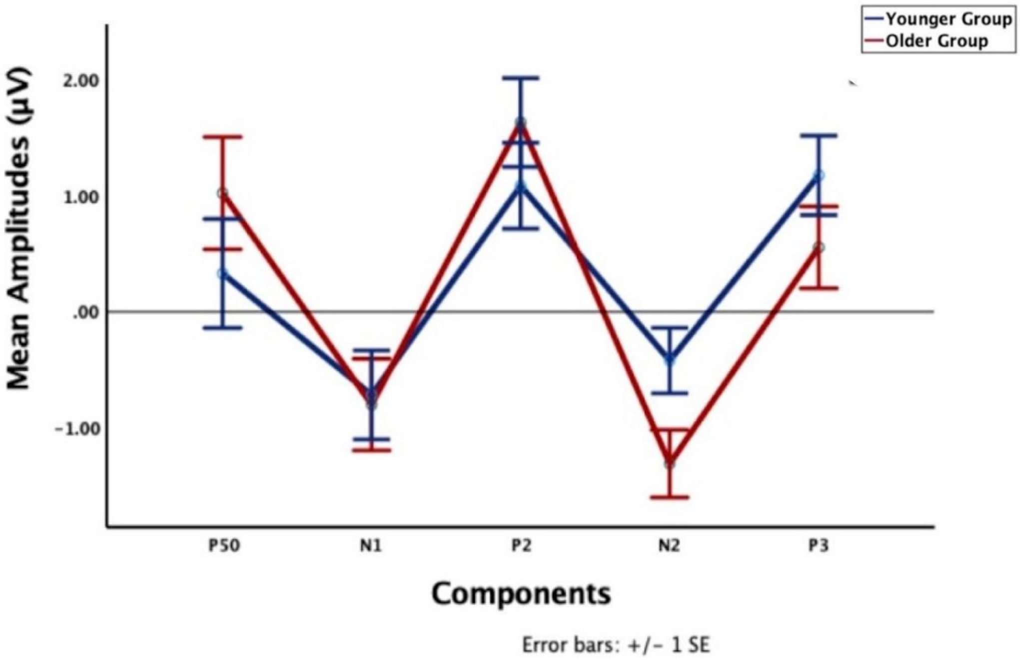
ERPs for Both Age Groups in Electrode FC6



As shown in Figure 34, pairwise comparisons revealed, that in electrode FC6, there was a medium effect of age at the N2 component such lower amplitudes were observed for the younger (M = -0.43) as compared to the older (M = -1.32) participants, $F(1, 31) = 4.8$, p = 0.03, $\eta_p^2 =$ 0.13.

Figure 34

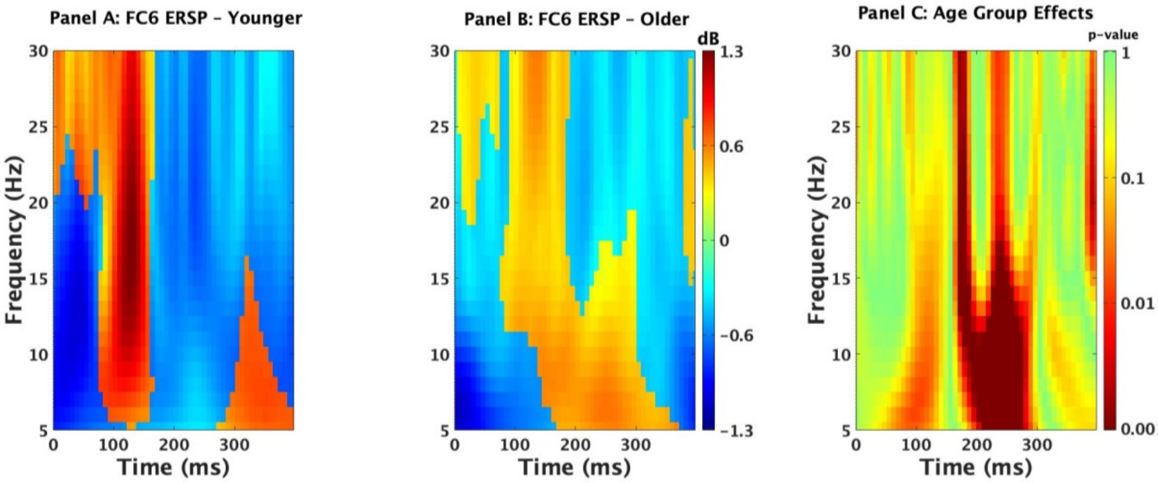
Components Mean Amplitudes for Both Age Groups in Electrode FC6



4.2.3.1.2 ERSP Analysis of Electrode FC6. Illustrated in Figure 35 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in electrode FC6.

Figure 35

ERSPs for Both Age Groups in Electrode FC6



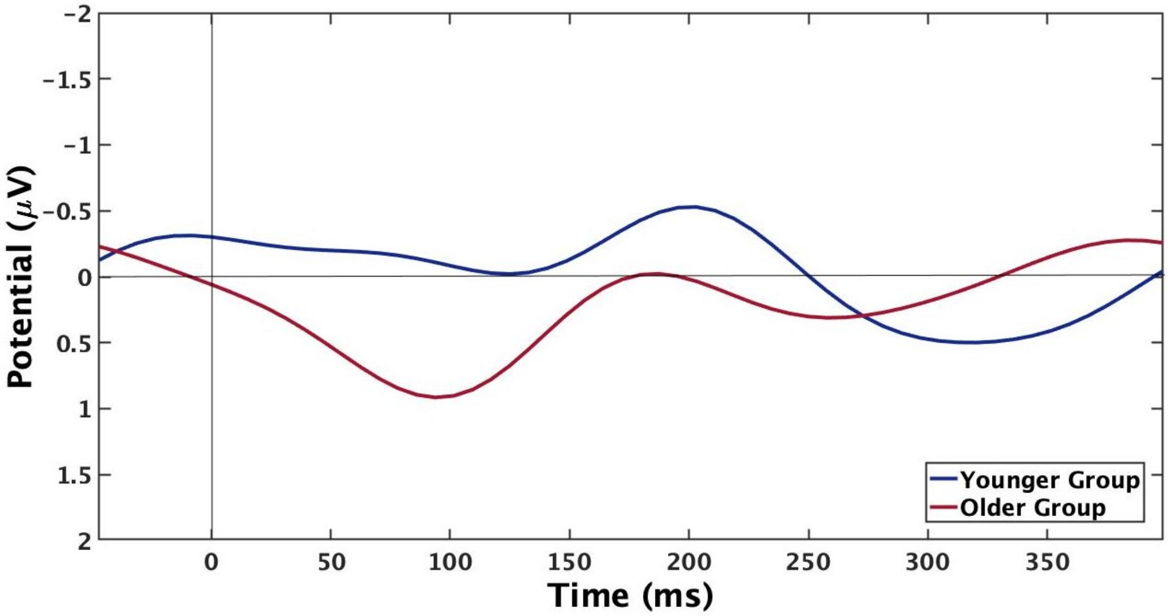
An age effect can be observed in Panel C of Figure 35, around 160 to 280 ms in the alpha and beta oscillatory bands post-stimulus, such that the power increase was significantly greater for the older participants (see Panel B) in comparison to the younger participants (see Panel A) from electrode FC6.

4.2.3.2 Electrode F8.

4.2.3.2.1 ERP Analysis of Electrode F8. Illustrated in Figure 36 is the average ERP linked to the onset of the tones for both the younger (blue) and the older (red) groups of pilots in electrode F8.

Figure 36

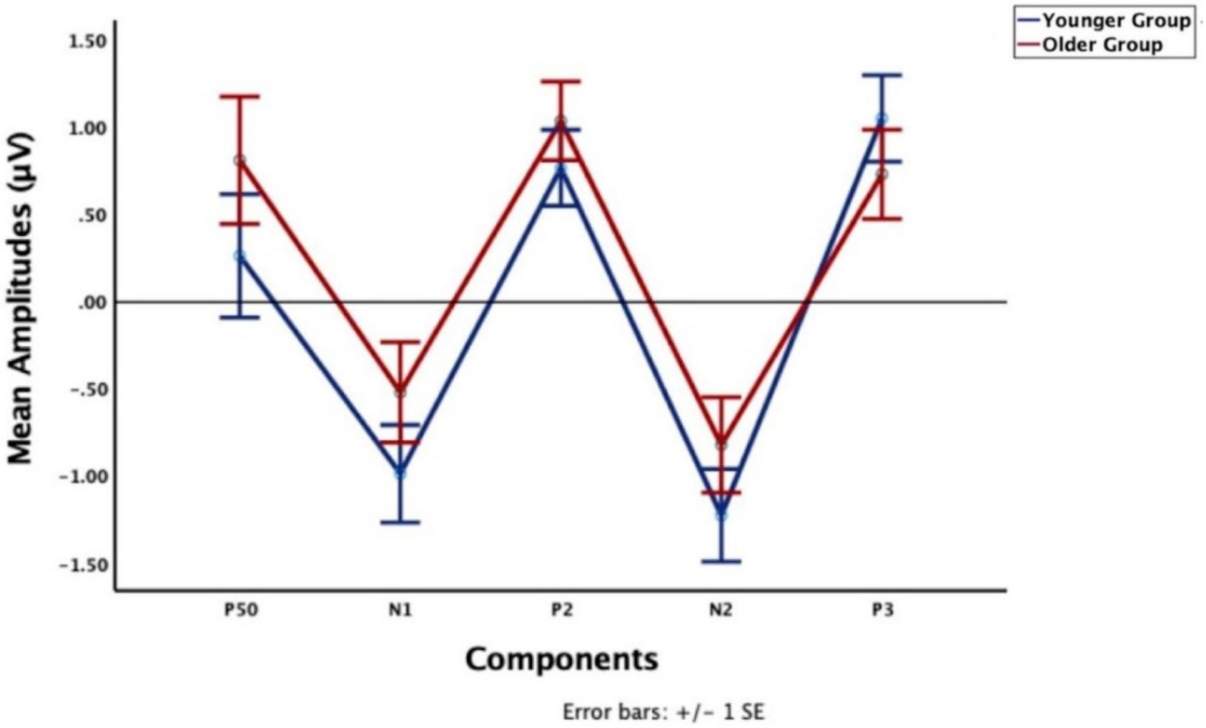
ERPs for Both Age Groups in Electrode F8



As shown in Figure 37, pairwise comparisons revealed that in electrode F8, there was no effect of age on the mean P2, N2 or P3 component amplitudes as the difference between the younger and older participants' mean amplitudes in each component did not meet the threshold for significance, $p > 0.1$.

Figure 37

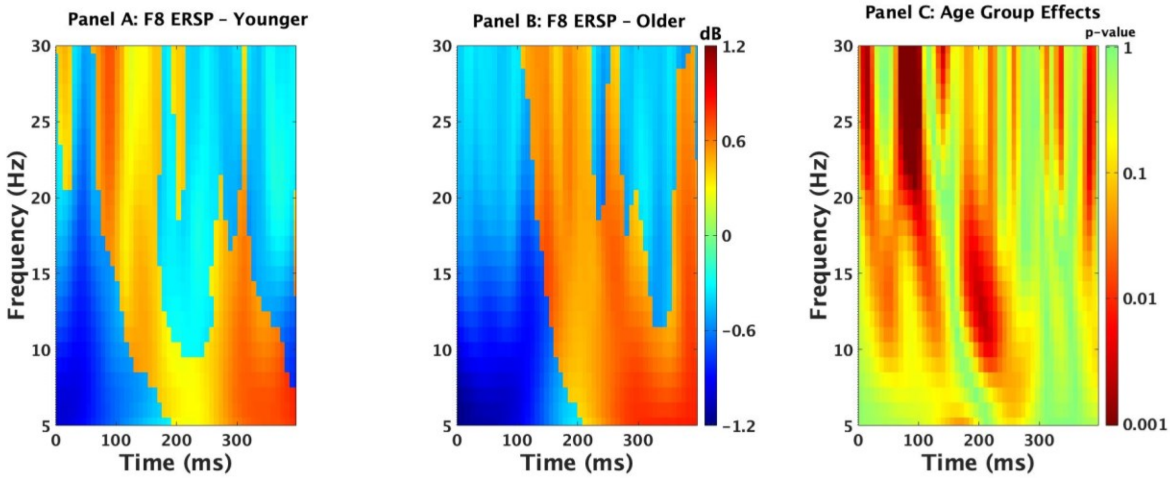
Components Mean Amplitudes for Both Age Groups in Electrode F8



4.2.3.2.2 ERSP Analysis of Electrode F8. Illustrated in Figure 38 are the changes in oscillatory power, from the pre-stimulus baseline, linked to the onset of the tones for both the younger (Panel A) and the older (Panel B) groups of pilots as well as the *p*-value statistical comparisons between both groups (Panel C) in the electrode F8.

Figure 38

ERSPs for Both Age Groups in Electrode F8



As can be observed in Panel C of Figure 38, in the later latencies of tonal processing, there were no significant effects of age ($p > 0.05$) on the change in energy of any of the oscillatory bands from electrode F8.

4.2.3.3 Summary of the Sound Detection in Auditory Cortex Regions Findings.

Table 8

Summary of the Second Phase of Input Representation (Cognitive and Motor Inhibition Areas) Findings Related to the Hypotheses

<table>
<tr><td colspan="4">In the second phase of input representation, where concepts and representations are created and utilized for cognitive tasks, cognitive and motor inhibition were explored in electrode locations typically associated to Brodmann’s areas 45 (BA45) and right 44 (right BA44) (Trans Cranial Technologies, 2012; Picton et al., 2007). These regions have been associated with decision making, monitoring of actions and inhibition processes (see Appendix E).

The P2, N2 and P3 components were of particular interest as they have been associated with higher-order processing of auditory information (P et al., 2020; Trainor, 2008).

The theta and beta oscillatory bands were of particular interest for their known associations with response inhibition deficits as well as the preparation and execution of motor responses (Barry, 2009; Schmiedt-Fehr et al., 2016).</td></tr>
<tr><th>Electrode</th><th>ERP Results</th><th>ERSP Results</th><th>Aviator Implications</th></tr>
<tr><td>FC6</td><td>The N2 amplitudes showed greater amplitudes in the older as compared to the younger participants</td><td>Theta, alpha and beta oscillatory power increases were found in the older, but not in the younger participants’ neural power around 200 to 300 ms post-stimulus</td><td rowspan="2">Regarding the auditory processing of pilots during aviation, evidence from electrodes FC6 and F8 suggests that the management of neural resources during task responses may be negatively impacted by age and in turn, can compromise the execution of actions that follow aurally communicated information during flight.</td></tr>
<tr><td>F8</td><td>No significant effect of age on the N2, P2 or P3 component amplitudes</td><td>No significant effects of age on the changes post-stimulus of any of the oscillatory bands in later processing of the tones</td></tr>
</table>

Chapter 5: Discussion

Understanding the cognitive-linguistic factors involved in radio call communication is crucial for investigating approaches and technologies that enhance pilot safety in aviation. The present thesis investigated the impact of age on how pilots integrate aurally presented information into SA models along the auditory processing pipeline. Data collected from licensed pilots during a simulated flight experiment was analyzed from a behavioural and neural perspective with a focus on auditory processing.

5.1 Behavioural Analyses

5.1.1 The effects of age and situation awareness on critical incidents

This study examined the effects of age and SA on the number of critical incidents pilots incurred during a simulated flight. Critical incidents measures were created based on the occurrence of the following types of issues: getting lost, crashing, flying contrary to circuit procedures, or landing poorly. Older participants in this study incurred more critical incidents than the younger participants in support of the first behavioural hypothesis. This trend has been observed in previous simulation studies (Taylor et al., 2007; Van Benthem & Herdman, 2020), as well as in the real world (Bazargan & Guzhva, 2011; Li et al., 2005). The greater risk of incurring critical incidents as observed in older pilots points to the importance of further investigating the human factors involved in pilot safety and what solutions or adaptations can be created to reduce the risks associated with flying.

This study also found that lower radio call-related SA performance scores predicted higher critical incident counts. This finding is in line with previous studies that observed an association between situation awareness and accidents in aviation. In another flight simulation study, Van Benthem and Herdman (2020) examined the human factors that can contribute to GA safety and identified SA as one of the key critical human functions involved in greater risk of critical incidents. Using both subjective (self-reports) and objective measures (responses to probe questions), SA measures were indexed throughout the course of a simulated flight. Critical incident outcomes were also measured based on the number of occurrences pilots experienced during the experiment. Correlations were found between all three levels of SA and critical incidents such that the likelihood of incurring a risky event was linked to poorer SA abilities. In a survey-based study, Shook et al. (2000) examined how SA contributes to issues in GA. Participant flight instructors rated the importance of certain cognitive systems and environmental factors involved in SA abilities and how they pertain to issues during flight. The findings showed the significance of all three levels of SA during critical events in aviation. Thus, further investigating the contribution of different factors involved in SA abilities and how to improve the integration of constantly flowing information in dynamic flight environments can significantly contribute to the field of aviation.

5.1.2 The effects of age on SA Level-1

The ability to perceive information within an environment, SA level-1, is a critical factor that can contribute to higher rates of critical incidents observed in older pilots. In the present research, the performance scores on recall tasks for static SA level-1 information presented in radio call messages were analyzed. Age had a marginally significant effect on the performance of SA level-1 scores, such that older pilots performed worse than younger pilots on recalling static bits of information presented during the simulated flight. Further investigation was conducted to examine if there were specific message segments that drove the age effect as observed on performance scores. Ad hoc tests showed that the strongest age effect was seen on recall for the Type segment, where older participants were significantly less accurate in recalling this message segment than younger participants.

This study's finding that older age was associated with lower performance on recall accuracy for communicated messages shows parallel results with Morrow et al. (2001) who found declines in read-back performance for older pilots. They investigated the effects of age on pilot communication by presenting both pilots and non-pilots with a series of ATC communications that described the legs of certain air-space routes with varying message conditions such as amounts of information presented or the order of message segments. Participants were asked to read-back the message instructions presented in the messages. With enhanced age, readback performance declined significantly and this was largely associated with domain general declines in sentence span tasks that they also performed, where for longer sentences, older participants had greater difficulty than the younger individuals. Taken together with the findings of older pilots' lower performance scores on the Type message segment in this study, one can assume that a potential factor involved in older pilots' lower performance scores on SA tasks involving read-back tasks may be working memory (WM) ability declines in the commonly observed aging population (for a review see Salthouse, 1990).

Working memory is a cognitive function that can be described as "the retention of a small amount of information in a readily accessible form" (Cowan, 2014). SA model building utilizes this ability as the constant flow of new information needs to be integrated into existing models while updating the picture of a situation (Endsley, 1995). Literature has shown associations between declines in WM and SA abilities (Catherwood et al., 2014). The study by Morrow et al. (2001) described above further hypothesized the attribution of WM effects on their findings of lower read-back performance as well as sentence span scores in older participants.

One assumption associated with aging and WM abilities is that older individuals struggle with retaining information in the mind while simultaneously processing relevant and irrelevant information (updating and inhibition). In one study, looking at the effects of age on updating WM, participants were tasked with listening to lists of words and one task was that they had to remember the smallest items in the lists. Older participants exhibited lower WM abilities pertaining to updating than did the younger participants. More specifically, high memory demands (e.g., more large items to repress) affected this group of individuals (De Beni & Palladino, 2004). Similar results were found in a study involving WM span tasks (such as reading and counting span) where participants were asked to remember certain key features of lists of words. The deficits in the inhibition process have also been associated with age-related variability in WM tasks in previous literature (Zuber et al., 2019).

The findings of this study that the message segment Type showed age-related effects in recall scores suggest that older pilots may struggle with both updating processes as well as inhibition processes. Retaining the Type information might have been a bigger challenge for older participants as perhaps they had to drop earlier presented information to remember subsequent information in the list presented in messages. That is, perhaps older pilots may have difficulty maintaining these pieces of information in their WM as they are still processing and retaining subsequent information.

Another possible contributing factor for the SA level-1 findings in relation to WM is that the Type segment was the message component that was the least broadcasted throughout the flight. In real scenarios, pilots do not always broadcast all of the information that they are trained to, and this was attempted to be replicated in the recordings for the simulated flight of this study. For that reason, some components appeared more often than others, the Type segment being the least frequent. Since it was the least consistent, older pilots may have had to work harder to retain this information in their WM as they were constantly receiving new information with which they had to update their models. Thus, perhaps when training pilots on communication, it should be emphasized, or a standard rule should be that all four bits of information (aircraft type, call sign, location, and intention) should be announced in every message. Future studies should test this proposed effect of message segment frequency in simulation studies with radio messages that contain all four bits of information versus ones that have differing frequencies in all of the broadcasted message segments.

5.1.2.1 Pitch and Intensity. Considering the results regarding the Type segment, an ad hoc analysis was conducted on the message segments to investigate whether there were differing linguistic features of message segments that could contribute to the recall lower performance scores as observed in the older pilots as compared to the younger pilots. The message segments were decomposed into two linguistic features - pitch and intensity. In speech, pitch is the perceptual correlate of the fundamental frequency of a sound. Fundamental frequency is the average number of sound waves or oscillations representing the frequency that sounds omit. Intensity is the perceived power or amplitude that sounds emit. Results showed that there was an overall effect of the message segment on the pitch and that this effect was driven by the Type segments being significantly higher in pitch than that of the Call Sign and Intention segments. Moreover, a marginally significant effect of the message segments of the ranked average intensity was found and this was driven by greater intensity in the Call Sign segment as compared to the Intention segment.

The higher pitch in the Type segment, combined with the fact that older age was associated with lower SA level-1 performance scores on recalling Type segments suggest that communications with higher pitch may disadvantage older pilots. As discussed, the participants of this study were considered to be audiometrically matched as firstly, they passed their medical screening testing, and both age groups in the study were able to detect the auditory tones presented in their simulated flight similarly.

Audiometric hearing abilities are normally measured using tests that provide individuals with certain thresholds of sound features, which in turn detect peripheral auditory system deficits. Regardless, age-related difficulties in processing speech features despite normal audiometric hearing thresholds have been found in previous literature (Füllgrabe, Moore & Stone, 2014; Strouse et al., 1998) For GA pilots flying within Canada, a whisper test is conducted in which individuals hear a soft-whispered voice in both ears and need to be able to hear what is said from two meters away (Transport Canada, 2019). Evidently, these types of tests do not necessarily account for potential central auditory system deficits. As a consequence, issues in cognitive processing of speech features that may disadvantage older individuals may not be appropriately identified.

Central Auditory Processing Disorder (CAPD) is a condition that affects changes in the cognitive neural network of speech processing. When a sound is transferred from the peripheral auditory system (the outer, middle, and inner ear) to the central auditory system (higher-order neural processing in the brain), different frequencies of sounds activate different aspects of the primary auditory cortex. If there are age-related deficits in the central auditory processing system, such as issues processing higher frequencies of sounds, speech intelligibility may arise. CAPD has been identified in older individuals who show good audiometric abilities (Sardone et al., 2019). Therefore, although older pilots may pass the whisper test, further testing should be conducted to account for potential central auditory processing deficits.

5.1.3 The effects of age on grouping of SA Level-2

Quantifying the effects of age on the accuracy of grouping auditory information was a novel and important method for investigating the source of the increased risk for accidents found for older pilots. Grouping static bits of information, such as other aircraft identification and intention, is necessary for accurate and robust awareness of the flight environment. There was an overall trend for older pilots to have lower grouping scores, as compared to the younger pilots. The ability to group information together relates to SA level-2, which involves the integration of bits of information into mental models. This cognitively demanding task allows pilots to build a greater understanding of the dynamics of the information they are perceiving. When bits of information are synthesized, critical decisions can be made during flight. It was predicted that SA level-2 would be negatively impacted by aging. This is due to the fact that SA level-2 is based on SA level-1 and that age effects on SA have been found on both the general population as well as the pilot population.

Simulated vehicle driving and aviation experiments for instance, have found that older individuals perform worse on recall tasks that involve describing certain environmental features or events that occurred during the course of a driven route (Bolstad, 2001; Ou & Liu, 2017). The study by Morrow et al. (2000), described in section 5.1.2, found that when participants were tasked with drawing on a chart the route that was described in each leg, older participants performed worse than younger pilots. Recalling an entire route of a flight involves SA level-2 abilities as the individuals must group particular information together and maintain those concepts as the flight progresses.

5.1.4 The effects of age on Location SA Level-2

Another cognitively demanding function involved in SA level-2 abilities is the updating of mental models with dynamically changing information. Behavioural measures were created to analyze how pilots updated their mental models with dynamic types of information as they play a critical role in decision making during flight. In the first leg of the flight, where other aircraft positions varied widely over time, older pilots performed worse than younger pilots when asked to identify the position of all other aircraft. The present findings support the hypothesis that older age would negatively affect dynamic information SA. The greater difficulty for older pilots in identifying the position of other aircraft can be due to age-related issues in regard to updating spatial information, as found in the previous literature. One study, aimed at addressing the effects of age on the ability to update spatial memories in younger and older participants, found that when trying to identify relocated items, older individuals had a more difficult time identifying items that had appeared in changed locations (Merhav, Riemer & Wolbers, 2019). Using simple virtual navigation tasks (triangle completion tasks, distance and turn reproduction tasks), another study explored age differences in path integration, with and without landmark information, in both older and younger participants (Harris & Thomas Wolbers, 2012). Participants had to provide input in a virtual environment using a joystick while asked to reproduce certain turns and distances. They found that older age affected distance and turn reproduction tasks such that older pilots reproduced distances observed on a screen, as well as turns, less accurately than younger participants.

A deeper investigation on age-related effects on recalling dynamic information is needed in order to get a better understanding of the cognitive factors that play a role in high-risk events related to SA. Issues with monitoring dynamic information can play a significant role in the greater critical incident rates as seen in the older population. Not only do pilots need to be aware of constantly changing information, but they need to use their knowledge of them to make decisions to avoid risky situations. Although an older individual can show appropriate memory abilities in basic memory-related tasks or tests, pilot cognitive testing must integrate spatial memory tasks that can act as indicators for higher risk of critical incidents.

5.2 Neural Analyses

5.2.1 Neural Analyses - Event Related Potential (ERP)

5.2.1.1 Sound Detection. The ability to detect sounds and their features play a crucial role in a listener's ability to further create mental representations of concepts. In neural studies using auditory ERP measures, the N1 component has been associated with the brain's stimulus detection phase of processing (Hyde, 1997; Näätänen et al., 1988; P et al., 2020; Trainor, 2008). This component was analyzed in this study in electrodes T7 and T8. These regions are commonly associated with auditory processing and are therefore important when investigating sound detection (Trans Cranial Technologies, 2012; Mirz et al., 1999). Results showed that in both of these regions, there was no effect of age on the amplitude response at the N1 component. These findings support the first ERP hypothesis stating that in the sound detection phase of auditory processing, there would be no effect of age on the brain's neural response to the tones.

The first ERP hypothesis related to sound detection was theorized based on the assumption that both age groups should be matched audiometrically. All participants in the study had up-to-date medical clearance to maintain their licenses. Since pilots should be matched audiometrically, there is no reason to suspect any age-related effects on the neural detection of sound and its features in the auditory cortex regions. Moreover, pilots performed a PDT task involving them having to press on a thumb switch on the left yoke column when they heard the auditory tones that were frequently presented. Response times and timeouts were recorded, and statistical analyses found that there was no significant difference in the response rate between both groups in either of the legs of the flight. Thus, the results regarding the N1 component were expected.

5.2.1.2 First Phase of Input Representation – Language Processing. The first phase of input representation was analyzed in electrodes F3, F4, FC5 and F7. In relation to radio call communication, this phase represents the language processing stage in the auditory processing pipeline. Since these parts of the brain should not be extremely busy doing tone-related tasks, the neural responses to the tones can be used as a measure of how many neural resources the brain is using towards ongoing flight task-related neural activity, such as language processing. The findings in this study showed that in electrodes F3 and F4, there were no significant age effects on the mean P2, N2 and P3 component amplitudes in response to the tones. Unexpectedly, in the FC5 electrode, older participants had higher amplitudes as compared to the younger participants at the P3 component.

In previous auditory ERP studies, the P3 component has been associated with the preparation of an action that follows a presented stimulus (Hyde, 1997; Näätänen et al., 1988; P et al., 2020; Trainor, 2008). In Go/NoGo studies, this component has been associated with frontal motor response inhibition in NoGo tasks, whereby an individual is required to not respond to a specific stimulus (Harper, Malone & Bernat, 2014; Hong et al., 2014; Kropotov et al., 2016). Moreover, age related effects have been found on the P3 component amplitudes in NoGo tasks such that older individuals show higher amplitudes in this component than do younger individuals in frontal task-related areas (Hong et al., 2014; Kropotov et al., 2016).

For the task related to the auditory tone, pilots were required to press on a thumb switch on the left yoke column when they heard the auditory tones, and there were no to-be-ignored tones. Based on the tone task, it was likely that between thumb switch presses, there was left hemisphere motor inhibition occurring (at the sensorimotor cortex associated with thumb motor responses) related to priming the thumb for the next tone press. As such, perhaps the greater P3 amplitudes in this brain region that are not associated with the task as observed in the older pilots reflects a compensation phenomenon.

The compensation-related utilization of neural circuits hypothesis (CRUNCH) describes an aging phenomenon wherein certain brain regions that are not associated with certain tasks display neural activation in older adults (Reuter-Lorenz & Cappell, 2008). This overactivation has mostly been observed in prefrontal sites, commonly associated with executive control functions like attentional selection or inhibition. This additional activity may serve as a beneficial compensatory function for older individuals in order to complete tasks as efficiently as younger individuals. The greater P3 amplitudes in the FC5 electrode, as seen in older adults, may be a compensation phenomenon wherein the parts of the brain responsible for the motor inhibition are not acting efficiently and therefore, the frontal region is compensating for that.

As discussed, the FC5 electrode is highly associated with language processing abilities (Trans Cranial Technologies, 2012; Heim et al., 2008; Sahin et al., 2006). During flight, this area should be highly involved in processing radio call communication. In realistic flying scenarios, pilots certainly do not need to respond to frequently presented tones. However, they do have to attend to other motor tasks. If this area of the brain is indeed compensating for flight-related motor inhibition tasks, then perhaps the communication processing is being compromised, thereby potentially contributing to greater issues in SA abilities and critical incident rates.

5.2.1.3 Second Phase of Input Representation – Cognitive and Motor Inhibition. The second phase of input representation was analyzed in electrodes F3, F4, FC5 and F7. In relation to radio call communication, this phase represents the cognitive inhibition and decision-making in the auditory processing pipeline and will be used to directly evaluate the pilots' response to the auditory tones. Contrary to what was hypothesized, the findings in this study showed that in the F8, there was no effect of age on the neural response of any of the later components (P2, N2 and P3). However, in the FC6 electrode, the N2 component showed a medium effect of age which revealed lower amplitudes for the younger as compared to the older participants. This may reflect cognitive inhibition deficits in older pilots.

Response inhibition studies using the Go/NoGo paradigm have linked the right BA44 area to be activated during NoGo tasks reflecting when to withhold a response to certain stimuli (Garavan et al., 2006; Picton et al., 2007). Moreover, previous literature has associated the N2 component with cognitive control, triggering the inhibitory process (Folstein & Van Petten, 2008; Kopp et al., 1996; Schmajuk et al., 2005). The greater amplitudes at the N2 component in the FC6 electrode, associated with the right BA44 area, as seen in the older pilots, contradicts studies that have found smaller N2 amplitudes with increased age (Anderer, 1996; Cheng et al., 2019). One possible explanation for the contrasting result can be related to the nature of the task. In this study, there were no to-be-ignored tones in the PDT task, therefore, there was no specific target that the pilots were instructed to ignore. However, between thumb switch presses, there may have been inhibitory activity associated with priming the thumb for the next tone press. The older pilots' greater amplitude in the negative N2 deflection can therefore be attributed to the lateralized readiness potential (LRP).

The LRP is a generalized negativity that is associated with the contralateral side of a motor task preceding a response associated with an impending readiness to perform a motor task (Masaki et al., 2004; Roggeveen, Prime & Ward, 2007). This increase in negativity elicited before a motor response provides information related to the process of initiating or inhibiting a motor response. In this study, the tones were played every 7 seconds and therefore, the pilots were ready all the time as they were either pushing the button or not. As a result, negativity can occur around certain electrodes contralateral to the motor area associated with the press task. Since the pilots had to press the button with their left thumb, the FC6 electrode could be exhibiting some sort of spillover effect of the readiness potential.

In more controlled environments it is easier to identify the source of the N2 component as well as the LRP since they are specific responses to certain targets. However, since pilots were performing a multitude of tasks simultaneously when they heard the tones, there may be lingering negativity associated with inhibition until it is completely overcome so they can press the button. That is, perhaps the greater N2 amplitudes, that are in fact negative, reflect potential deficits associated with older pilots' constant inhibition process. Larger LRP amplitudes in older individuals have been found in previous literature associated with inhibition deficiencies (Falkenstein, Yordanova & Kolev, 2006; Roggeveen et al., 2007). Thus, inhibition deficits in older pilots may be occurring during flight tasks. In real-time flying scenarios, pilots are in a constant decision-making headspace and are constantly inhibiting actions consequently. If older pilots are allocating more neural resources to motor inhibition, as a result of the LRP, it can be a factor that plays a role in the greater critical incidents observed in these demographics. That is, perhaps older pilots' brains cannot perform other cognitive tasks as efficiently as younger pilots as their brains are allocating more resources to inhibition processes.

5.2.2 Neural Analyses - Event-Related Spectral Perturbation (ERSP)

5.2.2.1 Sound Detection. As predicted, in the earlier latencies of tonal processing related to sound detection, there was no significant effect of age on the spectral perturbation of the theta or beta bands in the electrode T7. In contrast, in the electrode T8, clusters of increased beta activity between 10 to 100 ms post-stimulus were found in the younger participants that were greater than the activity observed for the older participants. Previous literature discusses the beta band being elicited during earlier and later stages of processing auditory information in temporal regions of the brain (Christov & Dushanova, 2016; Fujioka et al., 2015). Since the older individuals of the current study are not eliciting much of the beta response, they may be experiencing deficits in fully processing sounds at a neural level.

A large amount of the research that has been conducted using time-frequency analyses in auditory paradigms involve some form of target detection, which involves participants pressing on a button when they have heard certain sounds (Christov & Dushanova, 2016; Schmiedt-Fehr et al., 2016). The observation that older pilots exhibited lower changes in beta power may be related to the beta activity linked to movement and motor or sensorimotor functions in the literature (Baker, 2007; Pogosyan et al., 2009). That is, perhaps the tone is being detected by both groups, but the response to the tone is being attended to earlier in the older group than in the younger group and may be reflected in the auditory cortices regions as a compensation mechanism for neural deficits in motor processing areas. This age-related compensation notion can be further supported by the observation that older pilots had similar auditory PDT response rates, suggesting that although there may be age-related differences in early beta band oscillations, the difference may not be associated with sound detection, but rather with the complex cognitive processing of the motor responses.

5.2.2.2 First Phase of Input Representation – Language Processing. In the later latencies of tonal processing, no significant effects of age on spectral perturbation of any of the oscillatory bands in electrodes F3 and F4 were found. In contrast, in the electrode F7, clusters of increased alpha and beta oscillatory activity around 215 to 260 ms from the baseline post-stimulus were elicited in the older participants and not in the younger participants. Additionally, similar findings were observed in electrode FC5. One possibility for this age difference may be related to the function of alpha oscillations, namely the management of neural resources. Previous studies have associated the frontal alpha band with inhibiting neural resources in task-irrelevant regions (Jensen & Mazaheri, 2010; Klimesch et al., 2007; Wisniewski et al., 2017). This management of resources is conducted to maintain neural efficiency during tasks.

Considering that these two brain regions are associated with language processing, the tones should not affect the oscillatory bands to a great extent in later processing, as the tone is not related to sentence processing. Perhaps the brain still detects some sound in this area at the beginning of the neural pipeline, but when there is no association to sentence processing, the sound becomes suppressed in this brain region. Meanwhile, for pilots, there is still constant processing in this brain region as a result of frequent communication demands, where there is syntactic, semantic, and phonological processing occurring. Thus, if the alpha band is associated with functional inhibition, and there is activity going on at this frequency band in task-irrelevant regions, it may be the case that the tone in the older pilots is still being processed in later stages of these tone-irrelevant brain regions. That is, the alpha activity observed in older pilot participants may reflect greater power being allocated to suppressing the tone in order to be able to more efficiently process the tone in the regions related to the tone task.

At the same time, beta oscillations are also observed in the older group in these task-irrelevant brain regions. As previously discussed, the beta band has been linked to motor abilities and decision-making during motor tasks (Schmiedt-Fehr et al., 2016). The latencies where the increased beta activity is observed in the older group align with the point at which pilots should be making the decision to press on the button on the yoke. Therefore, perhaps other regions of the brain directly involved in the decision of the motor response are recruiting resources from these regions. That is, there may be a compensation mechanism occurring once more, causing this activity in the task-irrelevant brain regions.

The right homologous electrodes to these F7 and FC5 electrodes should be related to the decision making of the tone-press task (e.g., the right electrodes are the F8 and FC6). The hemispheric asymmetry reduction in older adults (HAROLD) hypothesis theorizes that in certain situations, the neural resources allocated to a cognitive task tends to be less lateralized in older adults (Cabeza, 2002). That is, the older brain may utilize both hemispheres of a certain area to compensate for a lack of prefrontal neural processing abilities. In the case of the observation that only older pilots have increased beta activity in task-irrelevant brain regions, there may be compensation occurring related to the decision and initiation of the motor task associated with pressing the button.

5.2.2.3 Second Phase of Input Representation – Cognitive and Motor Inhibition. The third ERSP hypothesis was related to the second phase of input representation, in electrodes F8 and FC6, both associated with monitoring of actions and inhibition (Picton et al., 2007). Contrary to what was hypothesized, the findings in this study showed that in electrode F8, there was no effect of age on the theta and beta oscillatory power. Also contradictory to the hypothesis was that in the FC6 electrode an increase in theta, alpha and beta power around 160 to 280 ms post-stimulus in the older pilots was observed that was greater than those of the younger pilots. The hypotheses were based on findings from previous auditory detection and response task studies that showed a negative impact of age on motor inhibition and motor response on older individuals (Barry, 2009; Schmiedt-Fehr et al., 2016). These studies had the motor responses as a primary task in their studies. However, contradictory results in this study can possibly be explained by the instructions given to the pilots before the experimental flight. Pilots were specifically instructed to maintain their focus on the aviation-related tasks and activities, and to attend to the tones as a secondary task. What may be explaining the greater increase in theta, alpha and beta power in the older pilots is a potential deficit in the neural management of resources when there are multiple tasks involved with various degrees of priority.

In previous studies, greater theta and alpha band power have been associated with mind wandering. For instance, in a simulated driving study, increased frontal theta was observed during high cognitive workload tasks (Savage, Potter, & Tatler, 2013). The high workload condition consisted of participants hearing audio clips of a thought puzzle, followed by a hazardous event to which they should have responded. They found that after hearing puzzles that participants could not solve before the onset of the hazardous clip, events were responded to more slowly. It was concluded that since participants could not respond as fast to the hazardous situations, the theta increase may represent preoccupation in relation to solving the puzzle. In another driving study aimed at examining mind wandering, higher periods of mind wandering were associated with an increase in alpha power during on-task scenarios (Baldwin et al., 2017).

The increase in theta and alpha oscillatory power as observed in older pilots during the tonal processing periods in this study may result from them maintaining the flight-related task as their priority tasks, thereby shifting their attentional resources to other tasks, not associated with the tone. There were no subjective measures to indicate mind wandering, however, the tones that pilots had to respond to were played quite frequently, and participants were advised to always keep their primary focus on flying tasks, and to especially attend to the radio messages. As such, older pilots may be experiencing depletion of neural resources due to the multiple tasks that required engagement, leading to overall neural inattentiveness to the tones.

GA pilots are trained to follow a crucial set of priorities, namely “aviate, navigate, and communicate”. In this mindset, the most important tasks for pilots should be to attend to flying the aircraft with regard to maintaining altitude and airspeed. If this task is not jeopardised, their next priority would be to navigate the airspace and get from one point to the next safely. Communication between aircraft and with ground services or air traffic controllers is certainly important, but pilots must take precedence for aviating and navigating. Thus, the finding that there was an increase in theta and alpha oscillatory power in older pilots is vital as it suggests that when the older pilots are met with a set of responsibilities, their higher-order processing of lower priority tasks may be negatively impacted. In turn, communication deficits may result from older pilots not prioritizing this function consciously (similarly to the tone task) in comparison to other aviation tasks, causing a potential depletion of neural resources where this lower priority task then is jeopardized.

Chapter 6: Conclusion

The findings outlined in this research contribute to the aviation psychology literature, particularly as it pertains to human factors and GA safety. Results from this study indicate that greater critical incidents, as observed in the older pilot population, may be driven by situation awareness deficits, specifically related to the processing of aurally presented information. Behavioural results revealed that the participants' critical incident rates in the simulated flight were higher in the older individuals, supporting previous literature and real-world findings (Bazargah & Guzhva, 2011; Li et al., 2005; Taylor et al., 2007; Van Benthem & Herdman, 2020). The analysis of the effects of age on SA based on radio call communication showed that pilots' SA level-1 and level-2 abilities are impacted by age. What's more, the effects of age on communication are likely related to individual bits of information rather than messages in their entirety. Further linguistic analysis of pitch and intensity of message segments revealed that higher pitch might disadvantage older pilots. Behavioural observations also indicated that SA related to auditory information was associated with greater risk of critical incidents.

Neural results revealed that higher-order cognitive processing of auditory information during flight was affected by older age, specifically as a result of inefficient inhibition and poorer neural resource allocation. Findings showed that overall, in the sound detection phase of auditory processing, both the younger and older pilots' neural resources operate similarly in the auditory cortex regions. This aligns with the methodological findings regarding the PDT task wherein across both age groups, participants displayed similar button press rates, indicating successful detection of auditory tones. However, in both the first and the second phase of input representation, EEG results showed differences in the way both age groups process the auditory information.

The first phase of input representation was analyzed in frontal regions of the brain, whose function involves complex speech processing. Thus, no age-related differences in processing were expected. Results in these regions revealed that for older adults, the P3 component amplitude in the FC5 electrode (associated with language processing), was greater than what was seen in the younger group. Moreover, results of later processing in electrodes F7 and FC6 revealed clusters of increased alpha and beta activity for the older group not observed in the younger group.

Effects of age on tonal processing were observed in the ERP P3 component, involved in response inhibition suggests that a compensation mechanism occurs in older pilots' brains for processing to-be-ignored stimuli. Response inhibition tasks may be more cognitively taxing, resulting in the older brain recruiting neural resources from other locations to enhance the efficiency of task completion. Moreover, the greater beta-band oscillatory power increase from the baseline in older pilots at later stages in these regions suggests that when processing motor decisions for response tasks, the older brain may utilize both hemispheres to compensate for neural difficulties in the homologous right brain regions. The greater alpha-band oscillatory power increase from the baseline in older pilots at later stages further supports differences in managing neural resources in both age groups. This band is associated with managing neural resources so that they are appropriately distributed to task-specific brain regions. Greater alpha power in task-irrelevant regions might suggest that older pilots have greater difficulty efficiently suppressing activity in these brain regions.

The present findings indicate that the processing of non-speech sounds or the inhibition of responses associated with these sounds may be using neural resources from language processing brain areas, thereby causing competition of resources during language-related tasks. Although the stimuli used in this study were experimental and not a part of regular GA, there is constant background noise occurring while pilots are flying due to the engine, the landing gear, weather conditions, and more. Moreover, there are motor tasks that the pilots need to perform in concurrence with comprehending radio calls. If response inhibition is competing for neural resources, it can cause higher-order communication processing issues in these brain regions and therefore, can potentially be a factor in the lower SA abilities and higher risk of critical incidents reported in older pilots.

The second phase of input representation was analyzed in frontal regions (electrodes FC6 and F8) that are generally involved in the processing of the tones as they relate to the monitoring of actions and inhibition. Results in these areas revealed that in the electrode FC6, the N2 component amplitudes were greater in the older group as compared to the younger group, suggesting that the older group required more neural resource allocation to inhibit responses to the tones as a reflection of their readiness related to the motor response to the tones. In similar latencies, there was an effect of age on the power of the theta, alpha and beta bands post-stimulus, potentially associated with the neural management of the readiness to press on the button.

The neural results discussed in this thesis suggest that managing neural resources and inhibiting both response and cognitive activities in the later, higher-order processing of auditory information are negatively impacted by older age. These issues, taken together with the behavioural results, suggest that language processing of radio call communication may be impacted not by audiometric threshold differences between older and younger pilots, but by complex processing of auditory information and motor tasks. The study showed that measures related to audiometry (e.g., PDT response and early sound detection in EEG) indicate that both age groups can detect auditory information and similarly provide motor responses. Therefore, the issues with communication must be related to higher-order speech processing abilities.

Findings from this study are important for the aviation industry as they provide evidence for the importance of examining age as it relates to aviation safety. Aviation communication is more difficult for older pilots, and this contributes to SA issues. This study points to the importance of breaking apart radio call communication and investigating the age effects on processing its component features. Moreover, when comprehending messages, it was found that older participants are inclined to present issues with higher-order cognitive processing, which suggests that hearing examinations based on the whisper test are not sufficient to identify potential deficits in auditory processing.

6.1 Limitations

Three notable limitations are worth highlighting regarding the present research. Firstly, of the 51 participants recruited, four participants were female. Sociological and biological factors like participants' sex or gender play a significant role in communication and the various cognitive factors involved in processing speech. Thus, although the sample size of this study was not a confounding factor, studying gender effects on communication during flight could provide a more complete analysis of the situation. Secondly, given the more naturalistic nature of the study, a portable, Bluetooth 14-channel EEG headset was utilized as a practical method of collecting neural responses to the auditory tone stimuli. Much of the literature reported use more extensive headsets that utilize and discuss central electrodes. Having more electrodes, including the central and motor regions, would have allowed for a better comparison with previous auditory processing findings. Lastly, the EEG design used active (with a motor response) rather than passive (no response) auditory stimuli. Using an EEG design where triggers are time-locked to ignored tones would increase our understanding of the neural management and inhibition processes used by pilots and clarify how age might affect these mechanisms.

6.2 Future Work

This research points to two areas of future work to be considered - aviation psychology research of radio call communication and adaptive communicative technologies. Although behavioural studies have been conducted to investigate age effects on communication, this area of study needs to be further investigated from a cognitive linguistics perspective. Breaking apart the process of communication from the features of the messages to the cognitive systems processing these messages, and finally, how pilots respond to these messages as a consequence should be a more established area of investigation in this field. Based on audiometric testing, all pilots should be able to hear at a certain threshold. After an acoustic signal is detected, it needs to be distinguished as either a linguistic feature or a speech-irrelevant sound. This study showed that distinguishing acoustic signals may be affected by age and therefore, should be more thoroughly examined. One method in which this can be achieved is to conduct a more controlled EEG experiment, one where pilots are not necessarily engaged in a flying task but instead are occupied by an online visualization of a flight involving communication. Additionally, by introducing non-speech-related sounds and controlling for muscular movements, we can obtain a more representative neural understanding of the effect of age in the first phase of input representation during radio call communication.

Further investigation into how older and younger pilots' brains manage their neural resources while auditory information is being processed is another area where future research is necessary. Variables that play a role in taking auditory input and transforming them into concepts, such as potential speech features of messages also need to be identified and studied in the aging process. Linguistic features of radio communication that might affect processing at a suprasegmental level need to be examined and controlled for in future studies, such as the pitch and intensity of message signals. Other cognitive processes involved in processing linguistic features, such as auditory WM or inhibition need to be investigated in the context of communication as well as the aspects of radio messages, such as speech rate or the content, to understand why certain elements of messages are better understood than others.

Once a more thorough understanding of the facets of sounds that are easier to process for older pilots is reached, AI headphones can be created that modulate sound features of incoming calls. This would allow older pilots an adaptive means of avoiding critical incidents related to not being able to efficiently process certain features, such as higher pitch message segments. Currently, accessible FM hearing devices exist that transmit sounds directly from a speaker recorder to an earpiece. These devices reduce background noise for people who struggle to hear in noisy environments. Additional modifications to these types of systems that modulate the frequency or pitch of communicated messages can be created that allow for a clearer communication method for older pilots. Other adaptive technologies that can allow for more inclusive communication during flying for older individuals can be in the form of visual technologies to augment the auditory information available to pilots. Perhaps if visual cues are presented simultaneously, there can be a decrease in the abundance of auditory information pilots need to store while integrating information into their mental models.

This study revealed the importance of flight training that stresses the necessity of efficient communication between traffic and between aircraft and ground services. Once identifying the factors involved in pilot communication deficits, the protocols and training plans for pilots will need to be adjusted accordingly. For example, a more thorough examination into auditory processing should be conducted during medical examinations. Additionally, cognitive tests of acoustic processing can be implemented into the medical certification procedure. This study also highlighted the importance of neural management of resources during flight. Thus, strategies that help pilots reduce the number of tasks occurring simultaneously while messages are being presented should be introduced in the hope that they will reduce non-optimal inhibition and improve neural management at the subconscious level for pilots across the lifespan.

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Appendices

Appendix A. Original Gilligan Phonology Model by Hale & Reiss (2008)

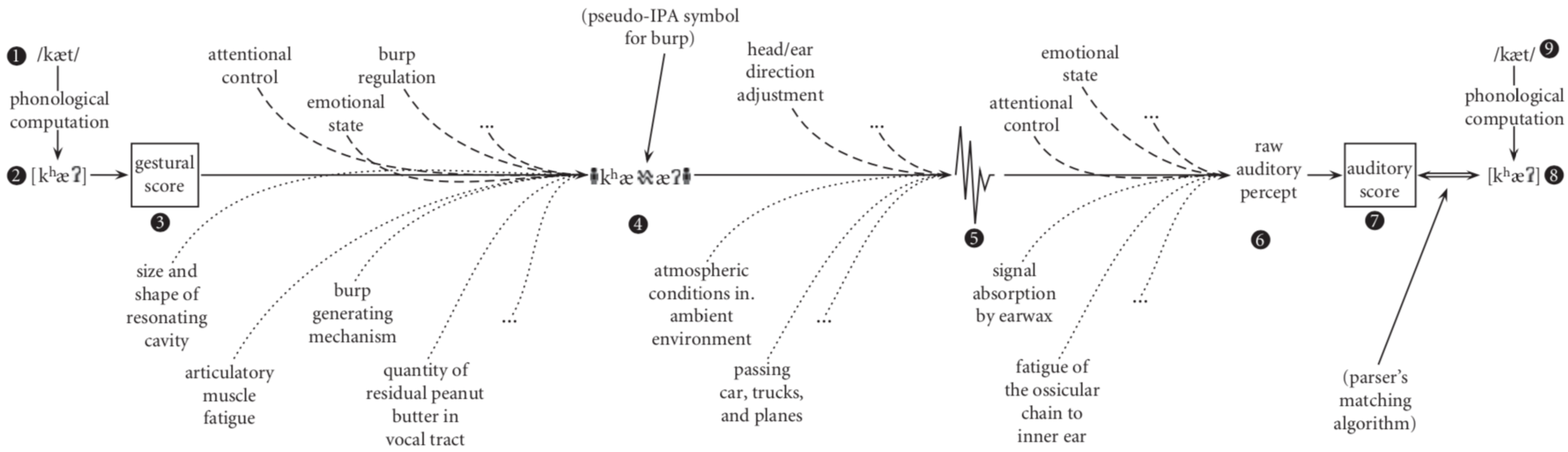


FIGURE 5.1 Saying *cat*

Appendix B. Ethics Clearance

Office of Research Ethics
4500 ARISE Building | 1125 Colonel By Drive
Ottawa, Ontario K1S 5B6
613-520-2600 Ext: 4085
ethics@carleton.ca

CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-B (CUREB-B) has granted ethics clearance for the changes to protocol to research project described below and research may now proceed. CUREB-B is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics Clearance ID: Project # 108569

Principal Investigator: Dr. Kathleen Van Benthem

Co-Investigator(s) (If applicable): **Dr. Kathleen Van Benthem (Primary Investigator)**
Alexia Ziccardi (Student Researcher)
Dr. Chris Herdman (Research Supervisor)

Project Title: **The Usefulness of Cognitive Health Screening for Predicting Risk in General Aviation [Kathleen Van Benthem]**

Funding Source:

Effective: **April 16, 2021** Expires: **February 28, 2022**.

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to CUREB-B via a Change to Protocol Form. All changes must be cleared prior to the continuance of the research.
3. An Annual Status Report for the renewal or closure of ethics clearance must be submitted and cleared by the renewal date listed above. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.
4. During the course of the study, if you encounter an adverse event, material incidental finding, protocol deviation or other unanticipated problem, you must complete and submit a Report of Adverse Events and Unanticipated Problems Form.
5. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

Appendix C. Participant Recruitment Poster

Appendix D. Informed Consent

Appendix 1: Informed Consent Form

Study: The Usefulness of Cognitive Health Screening for Predicting Risk in General Aviation
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 can determine whether you wish to participate in the study. This research was cleared by the Carleton University Research Ethics Board – B February 2018. Please ask the researcher to clarify any concerns that you may have after reading this form.

***Project Protocol Clearance #**:*
***Expiry**: December 31, 2019.*

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.

Name	Title	Email	Phone
Kathy Van Benthem	Postdoctoral Fellow	kathy.vanbenthem@carleton.ca	520-2600 x.2487
Caidence Paleske	Masters Student	caidencepaleske@cmail.carleton.ca	520-2600 x.2487
Connor Branch	Honours Student	connorbranch@cmail.carleton.ca	520-2600 x.2487
Alicia Fu	Honours Student	AliciaFu@cmail.carleton.ca	520-2600 x.2487
Alicia Krolak	Independent Study	aliciaKrolak@cmail.carleton.ca	520-2600 x.2487

Other Contacts: Should you have any ethical concerns regarding this study, please contact:

Name	Contact Info.
Carleton University Research Office	ethics@carleton.ca
Dr. Andy Adler, Chair, Carleton University Research Ethics Board - B	ethics@carleton.ca

If you have any ethical concerns with the study, please contact Dr. Andy Adler, Chair, Carleton University Research Ethics Board-B and the Carleton University Research Compliance Office (by phone at 613-520-2600 ext. 4085 or via email at ethics@carleton.ca)

Purpose: The purpose of this study is to determine the usefulness of cognitive health screening in predicting risk in general aviation. Measures collected during a simulated search and rescue (SAR) training exercise will be compared with performance on two cognitive screening tests (see page 4:A-C for an illustration of these tests). The general aviation performance measures include critical incidents, flight path deviations, memory for tasks, and situation awareness. We also track pilot mental workload using self-report, and biometrics, such as heart rate--using a wristband, and electroencephalographic (EEG) response--using a non-invasive EEG device (see page 5:D & E for a picture of these devices). Part of the time you will fly the SAR training exercise with an electronic navigational aid (see page 5:F), as we are interested in the impact of electronic navigational flight aids in general aviation.

Participants Eligibility
You are eligible to participate if you are a licensed aeroplane pilot with a valid medical certification, and you are at least 18 years of age. You should also have flown as pilot-in-command in the past 24-months. If you have a student permit you may be eligible to participate if you have “solo” and cross-country flight experience.

Study Tasks:

Session 1 Tasks: After signing the consent form we will ask you to complete a demographic questionnaire e.g., age, experience as a pilot. If you are not familiar with the ForeFlight navigational aid, you will then be asked to watch a brief instructional video like the online training video we suggested you watch before coming in for session one. You will have the opportunity to become familiar flying the Cessna 172 simulator and will fly basic maneuvers around the Ottawa airspace (while using the electronic navigational flight aid). We will review the use of the ForeFlight electronic navigational aid with you before you fly a custom-designed SAR training exercise in local airspace. In the SAR training exercise, you will fly circuits and a cross-country route that includes taking-off, flying at a pre-determined altitude, and executing turns and landings. There will be other "virtual" aircraft flying in the airspace that communicate air-to-air. You will be briefed on the search and rescue training exercise. We will ask you to wear a wireless EEG headset and a biometric wristband during the 60-minute search and rescue flight (see page 5).

Situation Awareness: At two points during the SAR training exercise we will pause the scenario and ask you questions pertaining to situation awareness. These questions are related to the location and details of other aircraft and the location and flight details of your own aircraft. You will also be asked to rate yourself on a situation awareness self-rating scale.

Prospective Memory Task: During the search and rescue training exercise you will monitor a small screen in the cockpit where arrows will be periodically displayed. You will be asked to make a short radio call when you observe a right-facing arrow.

Mental Workload Measures: Mental workload will be measured during the search and rescue training exercise. The first method uses a peripheral detection task (PDT), where you will depress a small switch on the Cessna yoke whenever you hear a "tone" played via a speaker. Workload will also be measured via two biometric devices: the Empatica E4 wristband and the EPOC+ electroencephalography (EEG) headset by EMOTIV (see page 5). The Empatica E4 wristband is a wearable wireless device designed for continuous, real-time data collection. It has a light sensor that measures blood volume pulse from which heart rate and heart rate variability may be derived. It also measures electrodermal activity (sweat) via a galvanic skin response sensor. This band also uses a sensor to read your skin temperature. The EPOC+ EEG headset detects electrical potentials at the scalp from 14 felt sensors, it is harmless and non-invasive (see page 5). Finally, you will be asked to report on your perception of the mental demands of the flight during the two pauses in the scenario.

Session 2 Tasks: On your second visit to the ACE Lab we will ask you to complete a questionnaire about your experience with electronic navigational flight aids. You will then complete two 20-minute cognitive screening tests (see page 4). The first test is the CanFly (our custom virtual reality test for pilots. The CanFly requires you to fly a short flight plan where you maintain situation awareness and respond to questions about other aircraft in the airspace. The CanFly collects data on basic aviator skills such as maintaining a prescribed altitude and remembering details of the flight environment. The CanFly test uses the Oculus Rift to deliver the graphics for the flight. The flight controls are managed through a simple custom Cessna 172 simulator. Before and after the CanFly virtual reality flight test, you will answer a few questions pertaining to how you are feeling. The second test is the MATB-II (a 20-minute computerized designed by NASA). The MATB-II test requires you to monitor gauges, track a shape, and change radio frequencies in response to messages you will hear via a headset. You will be asked to complete three five-minute sessions of the MATB-II that represent easy, medium, and difficult conditions (but not necessarily presented in that order)

Locale, Duration, and Affiliation: Testing will be completed in two phases: both will take place in VSIM 1214 at Carleton University. The total time to complete this study is four-hours and is spread over two sessions. This research is not affiliated with any device, flying club, flight school or aviation program.

Compensation: You will not be compensated monetarily. We compensate you for your time by paying for your parking on the Carleton Campus and by providing you with refreshments each session you attend.

Potential Risks/Discomfort: There are no potential psychological risks associated with participation in this experiment. Please note that your performance in the full-scale Cessna simulator 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 Cessna 172 or VR simulation, please bring your concerns to the researcher's attention and we will remove the device right away. After five minutes you can decide if you would like to continue the study. Any risk to well-being caused by the virtual reality device is considered minimal and usually disappears after a minute or two. Previous research using VR and a Cessna simulator in our lab with 40 participants did not result in any participants feeling ill after the simulated flight.

Anonymity/Confidentiality: All data collected in this experiment will be kept anonymized through the assignment of a coded number to the data. This data is securely stored on a local computer for a maximum of ten years. Similarly, this Informed Consent form will be kept for a maximum of ten years before being destroyed. The information provided will be used for research purposes and may therefore be presented and/or published. You can not be identified in any reports produced from this study.

Right to Withdraw/Omit: You have the right to withdraw at any time during session one or two without penalty. Before you leave on session two, you have the right and ability to withdraw from this experiment without penalty, and all your data will be deleted. However, because the data collected is anonymized, after you leave session two you will not be able to withdraw from the study. 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: _______________________________

Cognitive Screening Test Equipment Used in this Experiment

A: CanFly Cessna simulator components (Session Two, Clockwise: yoke, throttle, mixture, and flaps, and rudder pedals)

B: Oculus Rift C1 (Session Two, CanFly graphics presentation device, worn 20-minutes)

C: Multi-Attribute Test Battery-II Task Screen (Session Two, 20-minutes, On Left, Clockwise: system monitoring, visual-motor tracking, time management, resource management, communication. On right, mouse and joystick controls)

4

Devices worn in this experiment

D: EMOTIV EPOC+ EEG Headset (Session One, simulated search and rescue exercise, worn 60-minutes)

E: Empatica E4 Biometric Wristband (Session One, simulated search and rescue mission, worn 60-minutes)

F: iPad with “ForeFlight” electronic navigational aid (Session One, simulated search and rescue mission)

Appendix 2: Full-Scale Cessna 172 Simulator

F: Cessna 172 Simulator Fuselage and Cockpit. Located in front of a large curved screen for immersive graphical display.

Appendix 3: Debrief Form

The Usefulness of Cognitive Health Screening for Predicting Risk in General Aviation

Thank you for your participation in this study. The primary purpose of this study is to determine the usefulness of cognitive health screening for predicting risk in general aviation. In this experiment, general aviation performance, specifically situation awareness and decision-making, was assessed in four main 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 along a “perfect” trajectory. Third, information was collected with respect to touch and goes, critical incidents, and airspace infringements. Finally, prospective memory (remembering to complete radio calls for right-facing arrows) was assessed throughout the simulated flight.

Being able to predict general aviation performance using a standardized and objective assessment tool (such as the virtual reality screening test used in this experiment) is 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.

We will use the information we collect about mental workload to develop methods for predicting pilot mental workload in real time. This may have applications to other domains where complex cognitive tasks may be affected by operator workload.

This study was also an excellent opportunity to learn about the effects of using a well-known electronic navigational aid for GA flight in a complex airspace.

If you are interested in learning more about cognition and general aviation flight performance, then please see the following:

Van Benthem, K. & Herdman, C.M. (2016). Cognitive factors mediate the relation between age and flight path maintenance in general aviation pilots. *Aviation Psychology and Applied Human Factors, 6*(2), 81-90.

Van Benthem, K., Herdman, C.M., Tolton, R. & LeFevre, J. (2015). Prospective memory failures: effects of cue salience, workload, and pilot individual differences. *Aerospace Medicine and Human Performance, 86*(4), 366-373.

This research was cleared by the Carleton University Research Ethics Board – B February 2018 (Project Protocol Clearance #). If you have any ethical concerns with the study, please contact Dr. Andy Adler, Chair, Carleton University Research Ethics Board-B and the Carleton University Research Compliance Office (by phone at 613-520-2600 ext. 4085 or via email at ethics@carleton.ca). The study expires December 31, 2019.

Should you have any other concerns about this study, please contact any of the following individuals:

Name	Title	Department	Study Role	Contact Info.
Kathleen Van Benthem	Postdoctoral Fellow	ICS, ACE Lab	Principal Researcher	520-2600 x.2487
Dr. Chris Herdman	Professor	Psychology	Faculty Advisor	520-2600 x.8122

Thank-you again for your participation!

Appendix 4: Recruitment Poster Details

Full-Scale Cessna Simulator Study: 2018

The Usefulness of Cognitive Health Screening for Predicting Risk in General Aviation

The ACE Lab at Carleton University is looking for participants!
This study will explore cognition and general aviation flight.

You may participate if you:

- are 18 years or older, and
- have a current permit* or licence (aeroplane), and
- have a current medical certification; and
- have flown as pilot-in-command within the last 24-months.

*students who have solo and cross-country experience may qualify.

The study takes place *over two sessions* at the ACE Lab at Carleton University.

Participants will:

- Fly a full-scale Cessna simulator for a custom-designed search and rescue training exercise;
- Wear two bio-sensors while in the full-scale simulator (a wristband and a lightweight wireless EEG headset).
- Complete two brief cognitive screening tests (one using a head-mounted virtual reality device); and

You will not be compensated monetarily for participating but parking costs will be paid for by the study, and we provide you with refreshments.
During the simulated flight you will have the opportunity to use an electronic navigational flight aid (we provide).
Participation is completely voluntary.

We look forward to hearing from you!

Kathleen Van Benthem, Ph.D. and Chris M. Herdman Ph.D, Director, ACE Lab
Please reply at CessnaStudy@gmail.com

This poster expires December 2018.

This research was cleared by the Carleton University Research Ethics Board – B (Project Protocol Clearance # TBD)

G: Poster to be posted at local flight schools and flying clubs. Poster is sent to the Director of Flight Operations (or other appropriate authority). Permission is obtained by the authority agreeing to print the poster and place it on the school/club bulletin board. The poster may also be distributed to pilot members via the club e-newsletter.

Appendix 5: Initial Contact Email Script

Subject Line: Carleton U General Aviation Study
Hello Mr. (or Ms.) _______
Thank-you for your interest in the General Aviation Study at Carleton University, ACE Lab!

Who can participate: You are eligible to participate if you have an aeroplane license (or are a pilot in training who has solo and some cross country experience), you are medically certified to fly, and you have flown as pilot-in-command in the past 24 months.

How long does the study take: The study requires that you attend *two sessions* that take place at the ACE lab at Carleton University (a total of about 4 hours).

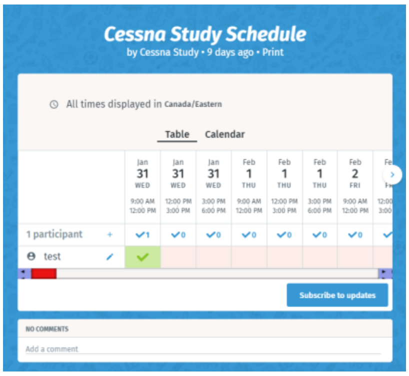
What will you be doing at the study: During the first study session most of the time will be flying a full-scale Cessna 172 simulator and answering a short questionnaire about your flying experience. The second session will include a cognitive test designed by NASA, and you will fly our new virtual reality CanFly test (using simple Cessna 172 simulator flight controls).

Preparation for the study: During the simulated flight you will use an electronic navigational aid. We recommend that you watch this tutorial online and maybe even check out a friend's Garmin or ForeFlight EFB before your appointment. We will give you plenty of time to practice with a similar device here at the ACE Lab.

ForeFlight 101 Beginner Presentation https://www.youtube.com/watch?v=9aSvi70M7-A

How to schedule your appointment: The link to an anonymous online scheduler is found below. We created this online scheduler so that you can easily choose one of the available time slots. *Please only enter your last name and first initial.* You only need to sign up for the first half, we will book your second session when you are here. Only the researchers (not other participants) can see who has signed up.

The link to the anonymous study session scheduler can be found here:
https://doodle.com/poll/54ww8xuvvbkcm8hh



Click the + where it says 1 participant. Please be sure to enter your name (or we will not know who selected that time slot) and move the scroll bar at the bottom to find a date convenient for you. As you will see, some timeslots have already been booked. **Be sure to click "Done" once you select one time.**

If none of the available times suit your schedule, please let us know and we can make other arrangements.

Where to meet us: On the day of your appointment we will meet you at your scheduled time at the Visualization and Simulation (VSIM) building door with a parking pass if you require one (at the back of Carleton Parking lot #1).

See http://carleton.ca/parking/wp-content/uploads/parking-map-2015.pdf for the location of parking lot #1 on Library Road.

We will contact you a day or so before your scheduled time as a reminder and to see if you have any additional questions.

In the meantime, I would be happy to answer any other questions you may have regarding this study!

Kathleen Van Benthem Ph.D., Research Fellow
Advanced Cognitive Engineering Laboratory
Institute of Cognitive Science, Carleton University
kathy.vanbenthem@carleton.ca
Phone: (613) 520-2600 Ext:2487

AGEWELL MEMBER

Appendix 6: Demographic Questionnaire

Cessna ForeFlight Q.1

* Required

1. 1. Gender. *
   Mark only one oval.
   - Female
   - Male
   - Other
   - Prefer not to say

2. 2. Handedness. *
   Mark only one oval.
   - Right-handed
   - Left-handed
   - Ambidextrous

3. 3. Highest level of completed education. *
   Mark only one oval.
   - Grade School
   - High School
   - College or University
   - Higher

4. 4. First language. *
   Mark only one oval.
   - English
   - French
   - Other: ______________________

5. 5. Do you wear corrective eyewear while flying? *
   Mark only one oval.
   - Yes
   - No

6. 6. Have you participated in another aviation study in this lab? *
   Mark only one oval.
   - No
   - Yes, between 2010 - 2012
   - Yes, in 2015

7. 7. State your current level of medical certification. *
   Mark only one oval.
   - I
   - II
   - III
   - IV

8. 8. Does your medical license have any limitations? (e.g. monocular vision) *

9. 9. Current highest pilot license. *
   Mark only one oval.
   - Student Permit
   - Recreational Permit
   - Ultra-Light Permit
   - Private VFR
   - Private IFR
   - Instructor/Examiner
   - Commercial
   - Airline Transport
   - Military
   - Other

10. 10. What other licenses do you hold? *

    ____

11. 11. Indicate all current ratings. *
    Check all that apply.
    - [ ] Float
    - [ ] Night
    - [ ] VFR - OTT
    - [ ] Instrument
    - [ ] Aerobatic
    - [ ] Flight Instructor

12. 12. Indicate you aeroplane class rating(s). *
    Mark only one oval.
    - Seaplane
    - Landplane
    - Multi-engine

13. 13. Total number of years with a valid pilot's license/permit (minus years you did not fly at all). *

    ____

14. 14. List years for each valid pilot's license/permit. (e.g., Commercial 5 years, Private VFR 3 years) *

    ____

15. 15. What is your approximate total number of flight hours? *

    ____

16. 16. What is your approximate total number of flight hours in a Cessna? *

    ____

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

    ____

18. 18. How frequently do you fly? *
    Mark only one oval.
    - Less than 2 times per year
    - 3 - 4 times per year
    - 6 times per year
    - Monthly
    - Weekly
    - Daily

19. **19. When was the last time you flew (even a practice circuit)?** *

20. **20. How familiar are you with flying in Eastern Ontario and Quebec?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not familiar	◯	◯	◯	◯	◯	◯	◯	Very familiar

21. **21. How comfortable are you with ATC communication?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not comfortable	◯	◯	◯	◯	◯	◯	◯	Very comfortable

22. **22. How experienced are you with Cross Country flight?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not experienced	◯	◯	◯	◯	◯	◯	◯	Highly experienced

23. **23. Do you have Search and Rescue flight experience?** *
Mark only one oval.

◯ None
◯ Some experience, I am a beginner
◯ Moderate
◯ I am highly experienced in search and rescue flight operations

24. **24. Are you comfortable flying in a Cessna 172?** *
Mark only one oval.

◯ Yes
◯ No

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

26. **26. How many hours have you flown using (any) flight simulation program/device ? (estimated).** *

27. **27. Describe the simulator system(s) you have used in the past. (e.g., Redbird)** *

Appendix 7: Self-Ratings for Situation Awareness and Mental Effort

Self-Ratings for SA and Mental Effort

Please enter a response to each question below

* Required

1. Please enter the code you are provided *

2. 1.1 Please rate your awareness of the navigation environment *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

3. 1.2 Awareness of your location during the mission *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

4. 1.3 Awareness of other aircraft locations during the mission *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

5. 1.4 Awareness of the piloting tasks to be performed *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

6. 1.5 Awareness of time needed to complete mission tasks *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

7. 1.6 Awareness of task priorities *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

8. 1.7 Awareness of the impact of other aircraft on your mission activities. *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

9. 1.8 Awareness of other aircraft intentions *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

10. 1.9 Ability to predict future events during the mission *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

11. 1.10 Your overall level of situation awareness *
Mark only one oval.

	1	2	3	4	5	6	
Very Poor	◯	◯	◯	◯	◯	◯	Very Good

12. 1.11 Rate your level of mental effort for the mission overall e.g., "Very Low" means that this was not at all a mentally demanding mission for you *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

13. 1.12 Rate your level of mental effort for the mission tasks *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

14. 1.13 Rate the level of physical demands of the mission *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

15. 1.14 Rate your level of mental effort for staying on your planned route *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

16. 1.15 Rate your level of mental effort for tracking the locations of other relevant aircraft *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

17. 1.16 Rate your level of mental effort for avoiding restricted airspace *
Mark only one oval.

	1	2	3	4	5	6	
Very Low	◯	◯	◯	◯	◯	◯	Very High

Note: Presented twice at Session One, at the two pauses during the SAR training exercise.

Appendix 8: Pre-Post Questionnaire

Cessna ForeFlight Q.2: 2018 (CanFly)

Please complete each question below.

* Required

1. Please enter your code *

2. 2.1 On a scale of 1 to 7 how alert are you right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all alert	◯	◯	◯	◯	◯	◯	◯	Very alert.

3. 2.2 On a scale of 1 to 7 how fatigued are you right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Very fatigued	◯	◯	◯	◯	◯	◯	◯	Not at all fatigued

4. 2.3 When did you last eat? *
Mark only one oval.
   - ◯ Within the last hour
   - ◯ Within the last 2 to 5 hours
   - ◯ More than 5 hours ago

5. 2.4 On a scale of 1 to 7 how queasy are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all queasy	◯	◯	◯	◯	◯	◯	◯	Very queasy

6. 2.5 On a scale of 1 to 7 how dizzy are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not dizzy at all.	◯	◯	◯	◯	◯	◯	◯	Very dizzy.

7. 2.6 On a scale of 1 to 7 how disoriented are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all disoriented.	◯	◯	◯	◯	◯	◯	◯	Very disoriented

8. 2.7 Are you prone to motion sickness? *
Mark only one oval.
   - ◯ Yes
   - ◯ No

9. 2.8 Have video games ever made you feel sick or queasy in the past? *
Mark only one oval.
   - ◯ Never.
   - ◯ Sometimes I feel a little queasy.
   - ◯ I always feel queasy when playing video games.
   - ◯ No- I don't play video games

10. 2.9 Have you ever used Virtual Reality products before? E.g. Oculus Rift goggles *
Mark only one oval.
   - ◯ Never
   - ◯ Maybe once or twice
   - ◯ I am a regular user of virtual reality products

11. 2.10 Have Virtual Reality products ever made you feel sick or queasy in the past? *
Mark only one oval.
   - ◯ I use them and I have never felt sick or queasy from them
   - ◯ Sometimes I feel a little queasy
   - ◯ I always feel queasy when using virtual reality products
   - ◯ I have never used virtual reality products

12. 2.11 What best describes the navigational aids you typically use while flying VFR? *
Mark only one oval.
   - ◯ Hard copy maps (e.g. VTA, VNC) and books (e.g. CFS), protractor, scale- NO ELECTRONIC NAV AIDS
   - ◯ I equally use both hard copy books and maps AND electronic nan aids
   - ◯ I mostly rely on my electronic nav aid.

13. 2.12 If you use one, what brand of electronic nav system do you use while flying VFR? *

14. 2.13 How often do you use ForeFlight? *
Mark only one oval.
   - ◯ Never
   - ◯ Sometimes
   - ◯ Often

15. 2.14 Rate your level of experience with ForeFlight *
Mark only one oval.
   - ◯ Never use
   - ◯ A beginner
   - ◯ Fairly knowledgeable
   - ◯ Expert Knowledge

16. 2.15 How many years have you been using electronic navigational aids? *
Mark only one oval.
   - ◯ Never use
   - ◯ Less than one year
   - ◯ One to three years
   - ◯ More than three years

17. STOP *
Mark only one oval.
   - ◯ ok

18. 3.1 On a scale of 1 to 7 how queasy are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all queasy	◯	◯	◯	◯	◯	◯	◯	Very queasy

19. 3.2 On a scale of 1 to 7 how dizzy are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not dizzy at all.	◯	◯	◯	◯	◯	◯	◯	Very dizzy.

20. 3.3 On a scale of 1 to 7 how disoriented are you feeling right now? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not dizzy at all.	◯	◯	◯	◯	◯	◯	◯	Very dizzy.

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Appendix E. Summary of the Associations Between the Brodmann's Areas and EEG Electrode Locations

Electrode	Brain Area	Cognitive Association	Phase	References
T7	Brodmann's Area 42 (BA42)	Highly associated with auditory processing	Sound detection	(Trans Cranial Technologies, 2012; Mirz et al., 1999)
T8	Brodmann's Area 27 (BA27)	Highly associated with auditory processing	Sound detection	(Trans Cranial Technologies, 2012; Mirz et al., 1999)
F3	Brodmann's Area 8 (BA8)	Managing uncertainty, executive control, working memory, visuospatial and visuomotor attention as well as sentence comprehension	First phase of input representation	(Trans Cranial Technologies, 2012; Kübler et al., 2006; Volz et al., 2003; Rama et al., 2001; Anderson et al., 1994; Crozier et al., 1999)
F4	Brodmann's Area 8 (BA8)	Managing uncertainty, executive control, working memory, visuospatial and visuomotor attention as well as sentence comprehension	First phase of input representation	(Trans Cranial Technologies, 2012; Kübler et al., 2006; Volz et al., 2003; Rama et al., 2001; Anderson et al.1994; Crozier et al., 1999)
FC5	Left side of Brodmann's Area 44 (left BA44)	Language Processing (BROCA's Area)	First phase of input representation	(Trans Cranial Technologies, 2012; Heim et al., 2008; Sahin et al., 2006).
FC6	Right side of Brodmann's Area 44 (right BA44)	Monitoring of actions and inhibition	Second phase of input representation	(Trans Cranial Technologies, 2012; Picton et al., 2007)
F7	Brodmann's Area 47 (BA47)	Language Processing Abilities	First phase of input representation	(Trans Cranial Technologies, 2012; De Carli et al., 2007; Cutting et al., 2006).
F8	Brodmann's Area 45 (BA45)	Monitoring of actions and inhibition	Second phase of input representation	(Trans Cranial Technologies, 2012; Picton et al., 2007)