Developing a Virtual Reality Cognitive Health Assessment for General Aviation

Ryan Lacroix, 100901696

Carleton University

April 2017

Abstract

Older age has been found to be associated with a decline in certain cognitive abilities (Salthouse, 2010), however the rate of decline varies between individuals. As the average age of general aviation pilots slowly increases (Christopher, 2012), there is a growing need for a cognitive health assessment tool to determine a pilot's suitability to continue flying. If such an assessment tool is to be widely adopted, then developing smaller and less expensive alternatives to the current range of flight simulators being used for evaluative purposes is crucial. This research explored the possibility of using Virtual Reality (VR) technology to conduct flight simulation tests in place of typical projector-based simulator setups. Results showed very little performance difference between VR and non-VR conditions, and no increase in ill-effects experienced by participants as a result of first exposure to the VR medium.

Introduction

Due to a steady rise in the average age of general aviation pilots (Christopher, 2012), flight authorities are becoming increasingly concerned with older pilots' abilities to safely operate aircraft. Older age has been shown to be associated with a decline in certain aspects of cognition, such as prospective memory (Van Benthem, Tolton, Lefevre, Herdman, 2015) and working memory and attention (Salthouse, 2010). These cognitive declines may affect a pilot's ability to fly, given that flying is a task that necessitates working memory and a strong sense of spatial awareness. Although older age has been found to diminish cognitive abilities, the rate at which these abilities decline varies between individuals. Thus, the key to screening an older pilot's fitness to fly is best served by establishing minimum requirements in cognitive ability and not by instantiating an arbitrary age limit. By developing a method to categorize the risk of a pilot based on their cognitive ability on flight-related tasks, at-risk pilots may be identified before they become hazardous to both passengers and themselves. By the same approach, older pilots who retain high cognitive ability, whom otherwise may have been forced to retire due to age, may continue to fly in confidence knowing that it is perfectly safe to do so.

A current solution to this problem is the use of cognitive health assessment tools for screening at-risk pilots. The CogScreen Aeromedical Edition (Kay, 1995) software package is a common standard for screening cognitive health in aviation. The test battery contains a variety of tasks used to determine the cognitive health of a pilot from which the user's fitness to remain flying is inferred. Because many of the derived outcome measures in the CogScreen-AE battery rely largely on reaction time (Kay, 1995), the results of this assessment are biased against older pilots, who tend to have slightly slower reaction times (Hultsch, MacDonald, & Dixon, 2002)

Another method for determining a pilot's flight-related cognitive abilities is to test them in simulated flight environments using a cognitive health assessment tool. Pilots can be placed in a wide variety of situations in which their skills can be examined, ranging from simple visual flight conditions to more challenging instrument flights, as are required at night or in bad weather. Simulated flight environments can also be used to determine a pilot's ability to respond to emergency situations such as engine failure or fire in a safe and controlled manner. When testing pilots that have experienced cognitive decline, carrying out these exercises in a simulated environment is less risky than performing them in a real aircraft. By studying a pilot's performance on simulated and real flight tasks information can be obtained regarding the pilot's safety while flying, allowing inferences to be made about the pilot's cognitive health as it relates to flying.

A flight simulator typically consists of a close re-creation of an aircraft's cockpit fitted with working instruments, enclosed in an environment where the outside world is represented on a screen viewable through the front of the cockpit. The visual display systems used in flight simulation can vary quite a bit, with some applications utilizing numerous small screens held close to the aircraft's windows while others use large, curved screens placed in front of the aircraft, creating a wide, seamless view of the simulated environment. Some more advanced simulators are even built on top of moving platforms in an attempt to recreate the motions of flight, providing physical feedback to the pilot's actions and also allowing the simulation of turbulence (Winter, Dodou, & Mulder, 2012). Although current flight simulators are more technologically advanced compared to the first digital simulators of the early 1960s in regards to processing power and graphics, surprisingly little has changed in their overall design. Authenticity to the real flying experience, ranging from a true-to-life cockpit to realistic aircraft responsiveness, is a major factor in the design of simulators and the current common layout accommodates for this very well. Simulators have been built for a wide variety of aircraft, ranging from high speed fighter jets to large cargo planes. Despite the vast differences between the various types of aircraft, the simulation medium remains largely similar with a physical recreation of the cockpit and a projected or mounted screen outside the cockpit displaying the virtual world.

This common design of flight simulators, although highly realistic, has some crucial drawbacks. The main criticisms are that they occupy a large footprint, are very difficult to move, and are often very expensive. A general aviation simulator for small aircraft, such as the Redbird FMX, costs upwards of $60,000 and requires around 3 square metres of dedicated space. A recent solution to this problem has been to use head-mounted Virtual Reality (VR) devices and a minimalistic computer setup to carry out the same variety of testing. This solution requires a small area for the test to occur, is highly portable and can be stored away when not in use. A VR setup is also considerably less expensive than a traditional simulator, making the widespread use of such tests much more financially viable.

There are, however, some factors to consider before moving flight-based cognitive assessments from a traditional flight simulator to a VR environment. Performance in traditional simulator setups has been widely studied (Hays, Jacobs, Prince, & Salas, 1992), with large amounts of research going into the design of simulators to make them as close to the real flying experience as possible. VR, on the other hand, is an emerging technology with a significantly smaller research base. In order to ensure that VR-based cognitive health assessment tools for pilots are appropriate, it must be determined whether or not a pilot’s performance is affected in some way by the VR environment itself, which could put the pilot at an advantage or disadvantage compared to when a traditional flight simulator is used.

A major concern in this area of research is the occurrence of VR sickness, a form of motion sickness induced by head-mounted VR devices. VR sickness shares many symptoms with traditional motion sickness, such as a heaviness in the stomach, eye strain, nausea and disorientation (Arns & Cerney, 2005) and can vary in strength from mild to debilitating. Certain users are more susceptible to VR sickness than others, and may begin to show symptoms anywhere from the moment they enter the VR environment to hours afterward (cite). Although the occurrence of debilitating VR sickness is relatively uncommon, milder symptoms such as eye strain and headaches are commonly reported when users are in a VR environment for a prolonged period of time (Treleaven et al., 2015). Recent advances in VR technology, such as relying on higher refresh rates to reduce the flicker effect, have been shown to reduce the severity of VR sickness (Paush, Crea, & Conway, 1995), however its occurrence is still widely reported. The impact of VR sickness on flight performance is not yet fully understood, but if it is substantial enough, it is not unreasonable to assume that it could bias in the results of cognitive health screenings. It is important to ensure that if a new cognitive health screening tool were developed, the biases of current tools are resolved and not replaced by biases introduced by VR technologies.

The aim of this study is to understand the differences, if any, in pilot performance between traditional and VR simulation environments. If no difference in performance is found, it can be taken as evidence supporting the viability of VR as a cost-effective alternative to traditional setups, and that a cognitive health assessment tool could be developed for widespread use in the general aviation community.

Literature Review

Head mounted VR devices may be a useful diagnostic tool for the cognitive screening of individuals. In developing a screening tool specifically for pilots, it is important to ensure that performance is unaffected by peculiarities of the simulation medium itself, notably the simulator sickness often attributed to the VR environment. Older adults may be at a disadvantage in VR simulation environments due to the possibility of an association between age and susceptibility to motion sickness. Park, Allen, Fiorentino, Rosenthal, and Cook (2006) reported that older individuals were more likely to drop out of a VR study prematurely due to the discomfort caused by simulator sickness. Interestingly, the study also found that of the participants who did not drop out, there was no significant difference in ill feelings across age groups. These findings suggest that individuals who are susceptible to VR sickness may be more likely to experience negative effects from the VR environment as they age. Other studies involving both older and younger participants have produced similar results, showing a higher occurrence of simulator sickness symptoms among older individuals (Kawano et al., 2012).

In traditional simulator setups, older pilots have been found to produce significantly lower flight performance scores than younger pilots (Yesavage, Taylor, Mumenthaler, Noda, & O’Hara, 1999). In a study by Hardy, Satz, D’Elia, and Uchiyama (2007), age was found to be negatively correlated with numerous aspects of cognitive abilities related to flying on a variety of neurophysiological tests, including attention, information processing speed, and memory, as well as with direct measures of flight performance such as flight path deviation (Van Benthem & Herdman, 2016). Older pilots have also been found to be more likely to be involved in accidents in real world flight, a risk which becomes significantly higher after the age of 60 (Bazargan & Guzhva, 2011). It is important to note, however, that age is not the only factor in likelihood of accidents. Bazargan and Guzhva (2011) also found that accident rate and hours of flight experience were negatively correlated, and that pilots with more flight hours and a higher rating were less likely to be involved in an accident. Similarly, a study by Van Benthem and Herdman (2016) showed that pilot expertise was found to be negatively correlated with deviations in flight path, a result that was not mediated by any other factors including age. Taken together, these results show that although age is an important factor in flight performance, the effects of older age can be mitigated by pilot expertise. When considering the decline of certain cognitive abilities associated with older age (Hardy et al. 2007), it is important to put consider the contribution of pilot expertise when reviewing results of traditional cognitive assessment test batteries, as the results of these batteries may not fully represent the pilot's actual abilities. When designing a cognitive health assessment tool for pilots, fairness for all pilots should be a primary concern. A more experienced older pilot is likely to perform better in a simulator-based flight test (Van Benthem & Herdman, 2016), compared with traditional cognitive test battery, where tasks are based largely on reaction time (Kay, 1995), and a move from traditional tests to fully simulated flight tests may prove to be beneficial for this demographic of pilots. It must first be established, however, that the possibility of increased susceptibility to VR sickness in older individuals will not disadvantage them more than the known biases associated with current cognitive test batteries.

The existence of ill-effects as a result of exposure to VR environments may cause a number of issues in regards to simulator performance. Foremost, users experiencing negative side effects of VR exposure may perform worse than those who do not experience such effects, as the motion sickness may distract them from the task at hand (McCauley, 1984). Users who experience simulator sickness may also deviate their behaviors within the simulated environment in order to find methods to reduce the sickness. These intentional changes in behavior, which may range from reducing head movements to avoiding certain actions within the simulated environment, can have an effect on the outcome of an experiment and may make the results less representative of the user's true performance capabilities (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989).

Previous studies have shown that individuals are less likely to feel the effects of traditional motion sickness as they age, with very few people showing any signs of ill-effect after the age of 50 (Reason & Brand, 1975). Until recently, it was widely believed that the occurrence of VR sickness would follow a similar pattern whereby older individuals would be less susceptible. This assumption could be based on the observation that the symptoms associated with motion sickness and VR sickness are nearly identical. However, it is important to note that the sensory causes of motion sickness and VR sickness are not identical – the two phenomena are triggered by distinct combinations of visual and vestibular stimuli. In the case of traditional motion sickness, discomfort is experienced when the individual is subjected to an environment where changes in position and orientation are detected by the vestibular system, but there is no matching visual stimulation to corroborate the vestibular information. Conversely, VR sickness is triggered by the presence of optic flow in combination with the individual being physically stationary. This causes conflicting signals to emerge from the two sensory systems, which in turn creates feelings of discomfort.

Multiple theories (see LaViola, 2000) have been put forward in an attempt to explain the underlying mechanism of the relationship between the visual and vestibular system when exposed to conflicting information. One theory is that sensory dissonance causes the brain's neural circuitry to become confused, eliciting a reaction which gives negative body feelings. This explanation, aptly referred to as sensory-conflict theory (Oman, 1988), provides a high-level description of the cause and effect of motion sickness but fails to provide any explanation as to why there is a relationship between the two.

A possible explanation for why the body would create feelings of uneasiness in the presence of conflicting stimuli is as a survival mechanism. The outside world typically presents an individual with consistent, non-conflicting stimuli. When there is a prolonged absence of this expected consistency in our experience of the world, the body assumes that something internal is not working correctly and may attribute this to the effects of being poisoned. In an effort to rid itself of the assumed poison, the body creates feelings of sickness in order to elicit vomiting (Treisman, 1977). Although the ingestion of poisonous substances is only one possible cause of sensory conflict, the severity or just the possibility of being poisoned is great enough that the body must do what it can in an effort of self-preservation.

The duration and intensity of motion/VR sickness can vary drastically between individuals, with some people experiencing immediate discomfort upon entering the VR environment while others are seemingly unaffected. (Nichols, 2000). A study for the Swedish Defense Research Association found that after testing 32 participants on a high-speed fighter jet simulator, no participants felt any form of sickness aside from minor headaches (Oskarsson, Nählinder, 2006). Due to the high rate of vection in Oskarsson and Nählinder’s study, it comes as a surprise that no participants reported being sick. Previous studies have shown the opposite, where the speed of horizontal movement in the simulated environment is positively correlated with ill feelings during and after the study (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990). Individual differences in susceptibility to motion/VR sickness, coupled with the fact that the onset of discomfort is often delayed, can make it rather difficult to obtain solid information on the phenomenon.

VR is not the only simulation medium prone to causing ill-effects in those susceptible to simulator sickness. The occurrence of sickness occurring in screen simulations, both projected and using monitors, has been widely studied in the driving simulation literature. In a study exploring the possibility of predicting the occurrence of motion sickness in a driving simulator, Brooks et al. (2009) found that older participants were far more likely to be affected negatively by the simulation environment. The environment in this study was displayed on three large screens in front of the body of a car, in which the participants were seated. In total, 19 of the 73 participants had to withdraw before the end of the experiment due to debilitating effects related to motion sickness. With a 26% dropout rate, it appears that simulator sickness is not just an issue for VR-based simulation mediums. It is interesting to note that in this study, the time at which participants reported the onset of motion sickness was evenly distributed across the experiment. This appears to show that individual differences in motion sickness susceptibility can affect not only the severity of the symptoms, but also the amount of time an individual can stay in a simulated environment before experiencing negative symptoms (Brooks et al., 2009).

Another important factor to take into consideration when examining the viability of VR as an alternative to traditional simulator setups is the possibility of eye strain. As users spend more and more time operating personal devices with screens, it is becoming increasingly apparent that looking at screens in close proximity for long periods of time has adverse effects (Blehm, Vishnu, Khattak, Mitra, & Yee, 2005). Although the phenomenon of eye strain is not unique to VR technology, the risk of eye strain occurring when using these products grows fairly quickly the longer a user is in the virtual environment. In a study conducted by Morphew, Shively and Casey (2004), participants were required to carry out a search task using a simulated unmanned aerial vehicle. Subjects were required to complete the experiment using a helmet mounted display (VR) and a conventional monitor. They found that although ability to classify targets was equal in both conditions, participants in the VR condition were significantly more likely to experience the classic ill-effects of motion sickness, in particular eye strain and disorientation. It is important to note, however, that this task involved a high rate of vection as the view from the UAV was always facing the ground at a speed of around 70 knots from fairly low altitudes. High rates of vection have been shown to exacerbate motion sickness (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990), although it is interesting that this only had a strong effect in the VR condition, and not when using traditional monitors.

While VR exposure seems to carry with it a higher likelihood of experiencing ill-effects when compared to traditional monitors, it should be noted that these reported effects typically do not negatively affect performance in VR tasks when compared to the same tasks performed using traditional screen-based setups. For example, the Morphew et al. (2004) study found that although the occurrence of simulator sickness was higher in in VR, task performance was not impacted by this sickness when compared to using monitors. These findings may indicate that motion/VR sickness, although unpleasant, is not strong enough to have measurable effects on the user’s ability to perform their task(s). For the heightened immersion that VR can provide, coupled with its relatively low cost when compared to traditional simulator setups, this may prove to be a worthy tradeoff.

Hypotheses

Hypothesis one

Flight path deviation will be unaffected by graphics condition. We hypothesize that the heading, altitude and airspeed deviations will be the same in both VR and BADS graphics conditions.

Hypothesis two

Mental workload will be the same or slightly higher in the VR graphics condition.

Hypothesis three

User experience in terms of VR sickness, measured in terms of queasiness, dizziness and disorientation, will be slightly higher in the VR than in the BADS condition.

Method

Participants

Forty one participants were recruited from the undergraduate and graduate population of Carleton University. Participants ranged in age from 18 to 32 years (M = 21.32, SD = 3.71), with 13 females and 28 males. All participants were current students at the university studying psychology or a related field, five of which were graduate students and the rest undergraduate. Three participants indicated that they had prior experience flying an aircraft, two of them being licensed pilots. Most participants indicated that they had used VR technologies to some degree in the past. All participants provided written informed consent before beginning the experiment, and were reimbursed for their participation with either course credit or refreshments for undergraduate and graduate students, respectively.

Materials

All flight tasks took place in the body of a 1966 Cessna 172 simulator outfitted with working instruments and radio equipment operating under a closed, simulated circuit. In the non-VR condition, all visuals were presented using a Broad-Angle Display System (BADS), which consisted of an eight-projector overhead setup that projected the simulated environment onto a large, concave screen spanning 120 degrees. The VR condition took place in a virtual environment presented on an Oculus Rift headset. Both conditions were rendered by the Prepar3d flight simulation software. Pre-recorded messages were played to the user through a headset to simulate the radio chatter typically heard when flying an aircraft.

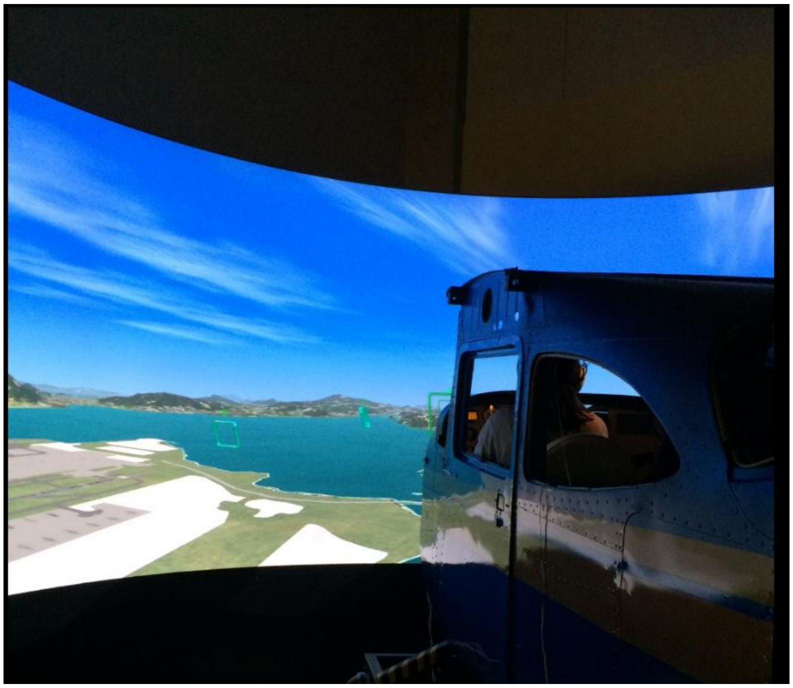

Figure 1. BADS simulated environment.

In both conditions, participants were required to wear some additional devices in order to take various measurements during the experiment. Each participant wore a headset in order to hear instructions as well as calls from other pilots. A microphone attached to the headset was used to confirm that the participant was making the required calls during the flight. A thumb switch was worn on the left thumb and was pressed whenever a tone was heard, which allowed reaction times to be logged. An Empatica wristband was worn on the participant's left wrist, which measured a variety of biometric information including heartbeat, galvanic skin response and blood pressure. This biometric data was not used in the present analysis.

Procedure

Participants were asked to fill out a preliminary questionnaire regarding demographic information, current wellbeing and prior exposure to VR products. Each participant was then familiarized with the flight task by flying practice circuits in the BADS environment before starting the first experimental flight task. Participants then filled out a second questionnaire pertaining to their current wellbeing before completing the second experimental flight task, which was followed by another questionnaire. Flight tasks were counterbalanced, with half of the participants receiving the VR condition prior to the BADS condition and the other half receiving the reverse order.

Flight Familiarization

Before the experiment started, each participant was given an explanation of the basic tasks required in the form of a guided slideshow, where they were free to ask questions about any aspect of the procedure which they did not fully understand. Participants were then seated in the simulator while an instructor flew two circuits around the course, demonstrating how to fly the plane and where different controls were located. The participant then flew three practice circuits, during which time experimental tasks were gradually introduced. All demonstration and practice circuits were carried out in the BADS environment in order to allow the participant to become familiar with the layout of the cockpit before being placed in VR. Once this was complete, participants were assigned to one of the two possible counterbalance orders.

Experimental Environment

Both environments took place in the same simulated space – the Hong Kong airport, but, for the sake of the experiment, renamed to the fictional “Pendleton Airfield”. The simulated space consisted of, in part, a runway over which participants were required to fly circuits. Large hoops were placed mid-air and distributed around the circuit, each hoop having one of three symbols displayed above it. Symbols were a downward arrow, an arrow in a circle, and a question mark and were evenly distributed across the hoops. Symbols were to be called out over the headset as a user passed through certain hoops.

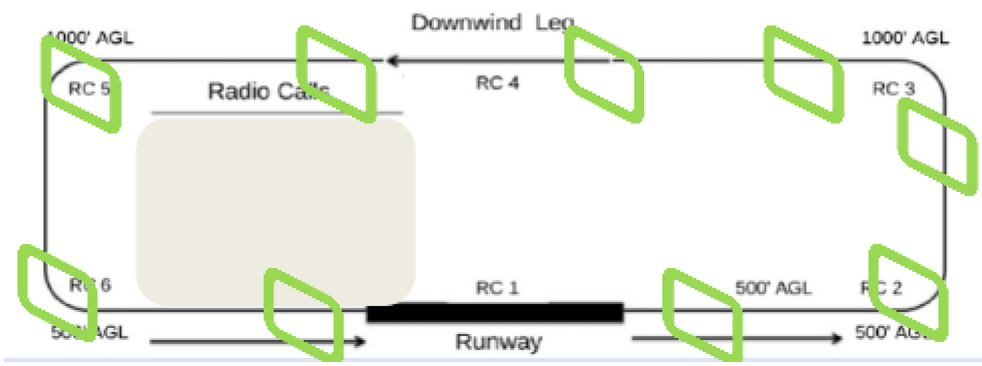

Figure 2. Positions of hoops placed around the experimental circuit

Experimental Tasks

The VR and BADS conditions required students to follow the same procedure. Starting at the beginning of the downwind leg, the participant is told to pass through the center of each hoop, and that whenever they pass through a hoop with a given symbol about it ("the cue"), they are to name the symbol above the next hoop as they pass through it. After completing the first full circuit, the participant is informed that the cue has changed to a different symbol. This also happens a third time after the participant finishes the second circuit. The order in which the three cues are used is different across the VR and BADS conditions in order to ensure that memory of the cue order does not affect performance. Piloting tasks involving radio communications were ongoing throughout the experiment, but were not part of the present analysis. The position and orientation of the plane is logged every second allowing for an analysis of deviations from the optimal path.

In addition to flying through the center of each hoop, participants were subject to three additional tasks while flying the simulator. The first and most frequent task was the auditory tone detection. Every ten to twenty seconds during the experiment, participants heard to a fairly loud beeping tone through the headphones. Upon hearing this tone, the participant activated a thumb switch by pressing it against the yoke as quickly as possible. This sent a signal to a computer which logged the intervals between the tone and the participant's response.

Participants were also subjected to two unexpected situational awareness tests, one at the end of each graphics condition. Each test involved a sudden pause in the simulation where the instrument panel was immediately covered by the experimenter. Participants were asked to report, to the best of their knowledge, their current location and airspeed, as well as the call signs of any other aircraft nearby. Participants were also asked to rate their confidence in their responses. Reports were obtained via pencil and paper, and a map was provided for the participants to mark the location of their aircraft. After the information was collected, participants were invited out of the aircraft to fill out a questionnaire about their experience, including questions pertaining to how they felt after the VR-based and BADS visual display conditions.

Flight Path Deviation

The primary performance measure in this analysis was pilot deviations from the ideal trajectory. The flight simulation system logged the pilots altitude, airspeed, and heading at one-second intervals throughout the flight. The raw trajectory data was converted to root-mean-square-error values, such that the scores reflect the average absolute error in the flight path (heading and altitude) and airspeed. Only the deviations from the ideal trajectory during the downwind legs were analyzed in the present research.

Questionnaires

Prior to beginning the flight simulation tasks, participants were asked to complete the first section of a questionnaire (see Appendix B for the full questionnaire). This portion of the questionnaire pertains mostly to background information of the participant, including experience with VR, when they last ate, and how often they play video games. This pre-flight section also asks some the same questions related to the participant's well-being that are asked again after completing the simulated flight tasks in order to obtain a baseline on the participant. After experiencing each condition, participants completed another questionnaire. This questionnaire contained a number of questions pertaining to their well-being, including factors such as current dizziness, any feelings of nausea, headache, tiredness, etc. Most questions used the same scale as the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993), where answers are provided in the format of a Likert scale as ratings from 1 to 7.

Results

Because a cognitive health screening tool using VR would not allow a BADS or similar setup to be used immediately before VR exposure, the analysis comparing performance across the VR and BADS conditions focused predominantly on data from the first condition that the participants received. Analysis of data from the second flight is only included when results of particular interest were found. Non-parametric tests were used to analyze all data unless stated otherwise.

No significant effect of graphic condition was observed for heading variation, W(1, 38) = 212.12, p = 0.948. Similarly for altitude variation, no significant effect of graphic condition was observed, W(1, 38) = 192.0, p = 0.669.

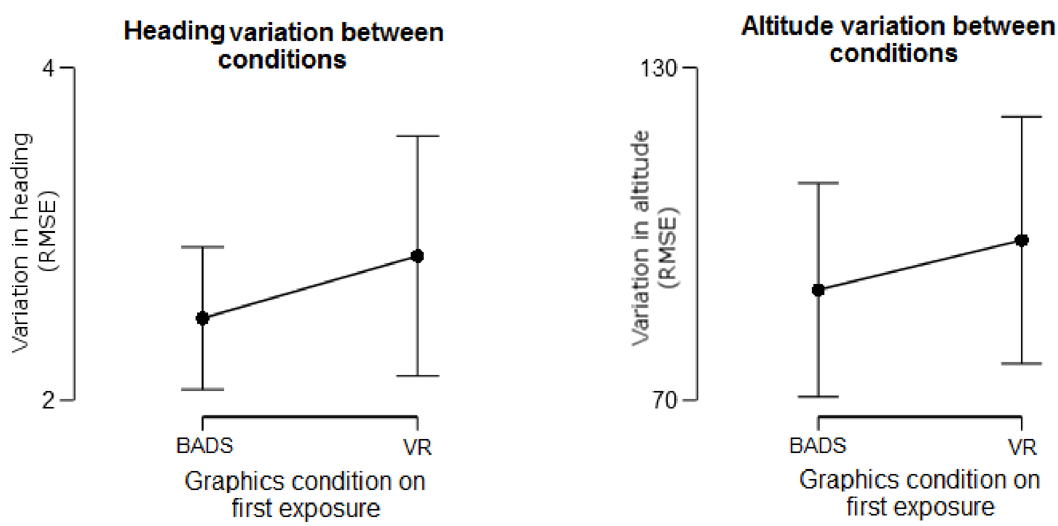

Figure 3. Comparison of Downwind heading and altitude variation across graphics conditions on first exposure. Error bars indicate 95% confidence intervals.

Parametric statistics were used to compare the two groups for airspeed variation and a marginally significant difference was found, F(1, 38) = 2.903, p = 0.096. Participants in the VR condition showed less variation in their airspeed than those in the BADS condition. In order to better understand this relationship, a repeated measures ANOVA was performed on airspeed variation in both the first and second flights, revealing that the difference between the VR and BADS conditions was not significant, $F(1, 38) = 2.187$, $p = 0.147$.

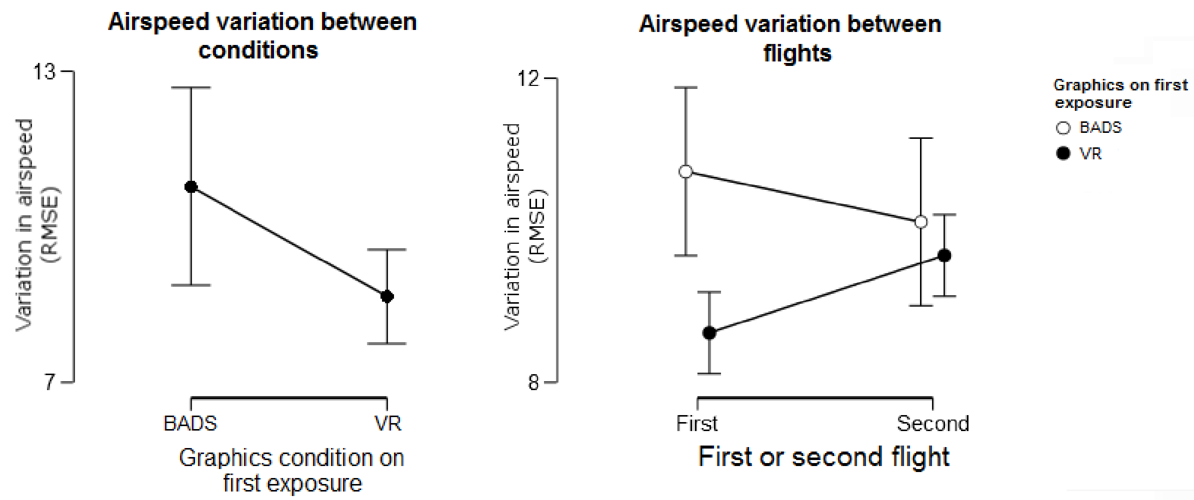

Figure 4. Analysis of variation in airspeed across graphics conditions (left). On the right, variation in airspeed in both graphics conditions shown across first and second flights. Error bars indicate 95% confidence intervals.

A hit rate percentage on the auditory Peripheral Detection Task (PDT) was calculated by dividing the number of tones that were successfully responded to by the total number of tones presented and then multiplied by 100. No significant difference in hit rate was observed between groups, $W(1, 38) = 173.0$, $p = 0.939$.

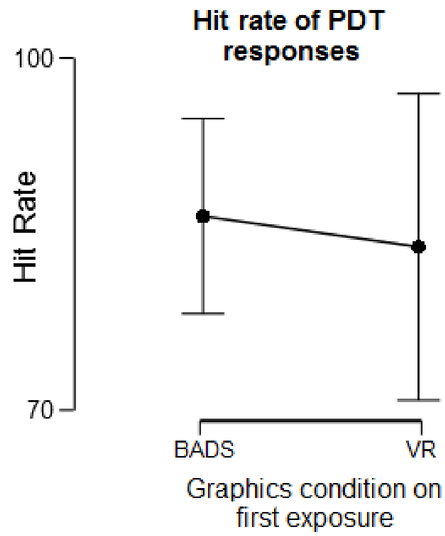

Figure 5. Percentage of successful responses to the tone across graphics conditions. Error bars indicate 95% confidence intervals.

Mean response times for the PDT task were calculated for each participant. No significant difference was observed between the BADS and VR graphics conditions, W(1, 38) = 163.0, p = 0.845.

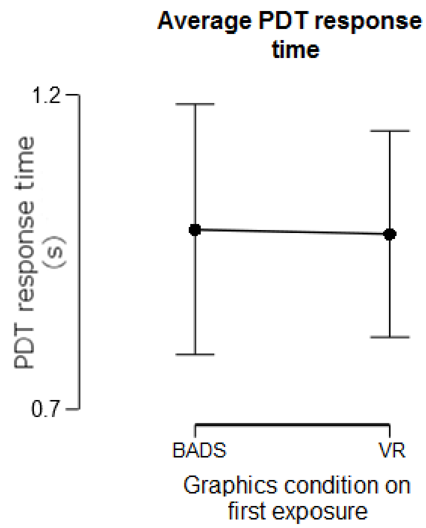

Figure 6. Average response times to the tone across graphics conditions. Error bars indicate 95% confidence intervals.

No significant correlations were found between hit rates and reported mental effort on a 7-point Likert scale in either the BADS or VR graphic conditions, on either the first or second exposure. Self-reported mental effort in both VR and BADS conditions showed a significant correlation, p = 0.012. Similarly, a high correlation of hit rate across exposures was observed, p < .001.

Spearman Correlations

		Bads ME	VR ME	HitRate1	HitRate2
Bads ME	Spearman's rho	—	0.387 *	-0.274	-0.317
	p-value	—	0.012	0.101	0.056
VR ME	Spearman's rho		—	0.087	-0.008
	p-value		—	0.610	0.963
HitRate1	Spearman's rho			—	0.727 ***
	p-value			—	< .001
HitRate2	Spearman's rho				—
	p-value				—

* p < .05, ** p < .01, *** p < .001

Figure 7. Correlation table showing significance of correlations between reported mental effort and objective measurements of mental effort in the simulator.

Self-reported measures of queasiness, dizziness, and disorientation were collected using a 7-point Likert scale. No significant difference was found in queasiness across the BADS and VR conditions, W(1, 38) = 224.0, p = 0.626. Measures of dizziness across the conditions also showed no significant difference, W(1, 38) = 238.0, p = 0.409. Similarly, no significant difference was found in disorientation scores across conditions, W(1, 38) = 220.5, p = 0.761.

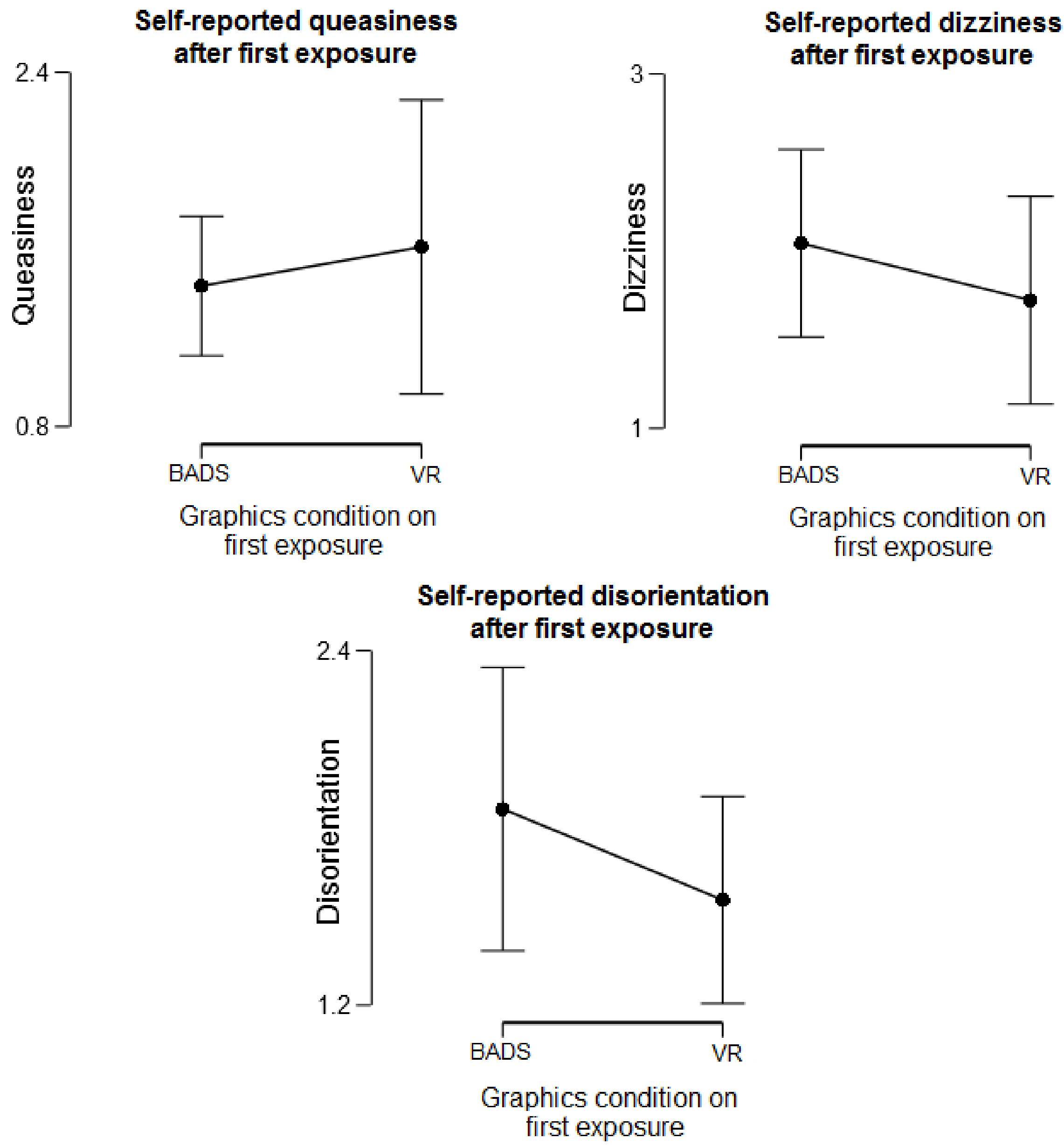

Figure 8. Comparison of self-reported queasiness, dizziness and disorientation after exposure to the BADS and VR conditions. Error bars indicate 95% confidence intervals.

Repeated measures ANOVAs were performed on all subjective measures across both flights. Reported queasiness across the two flights showed borderline statistical significance, $F(1, 38) = 4.054$, $p = 0.051$ and an effect size of $\eta^2 = 0.096$. Participants who experienced the BADS condition first experienced higher rates of queasiness after their exposure to the VR, while those who began in the VR condition reported lower queasiness after their exposure to the BADS condition. Dizziness showed no significance across flights, F(1, 38) = 0.909, p = 0.346. Similarly, disorientation across flights showed no significant difference, F(1, 38) = 1.513, p = 0.226.

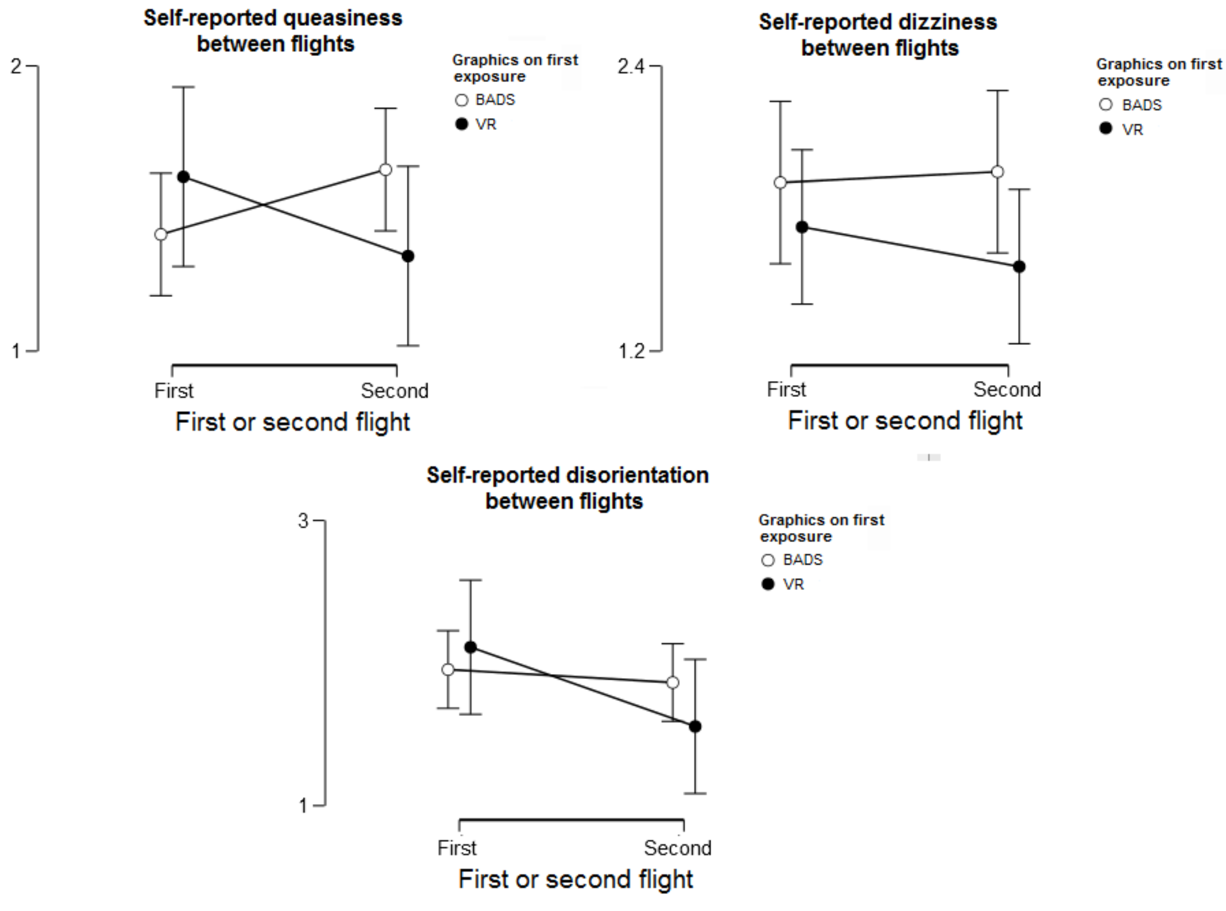

Figure 9. ANOVAs showing changes in subjective experience measures across flights in both VR and BADS conditions. Error bars indicate 95% confidence intervals.

After finishing the experiment, many participants commented on the immersiveness of the VR condition. One of the most often noted comments was on the ability to turn their heads and still be fully within the simulated environment. Participants felt this added to the immersion of the VR condition as it behaved how you would expect it to in real life. Another common comment was how the VR headset felt more comfortable by the end of the flight than the beginning. This was reflected in the questionnaire, where responses regarding headset comfort were given on a 7-point Likert scale. Comfort by the end of the flight was rated significantly higher, $p < .001$. Responses to the physical symptoms portion of the questionnaire varied, with many participants indicating they had felt no physical symptoms while others mentioned headaches, tired eyes and disorientation (see Figure 10).

Figure 10. Word cloud showing prevalence of physical symptoms after exposure to the VR condition. Larger text size indicates prevalence of the term in results.

Discussion

This study examined pilot performance, user experience and mental workload in both VR and BADS environments. Overall, very little difference in these measures was observed across these two graphics conditions.

Maintaining an ideal trajectory is an important aspect of flight, as remaining within a defined path allows other pilots to predict an aircraft's location. Flight path deviations have been shown to correlate with total hours flown in that pilots with more flying expertise are able to minimize flight path deviation (Causse, Dehais, Arexis, & Pastor, 2011). The current results showed that flight path deviation both in terms of altitude and heading were not significantly different across the VR and BADS first exposures. These results suggest that the graphics environment had no effect on deviations in altitude or heading under these simulated flight conditions. Flight path deviation has been previously used as a major measure of flight performance (Causse et al., 2011; Van Benthem & Herdman, 2016), thus demonstrating no difference in performance between the BADS and VR graphics conditions is crucial for the validation of VR as a viable replacement to traditional simulator visual apparatus.

Another important measure of performance is deviations from the ideal airspeed. Airspeed deviation was found to be significantly larger in the BADS condition than in the VR on the first exposure to the flight task, however when differences in the two conditions were compared across first and second exposure no significant interaction was found. A potential explanation for this finding is that participants may have placed more emphasis on attending to airspeed in the VR condition than in the BADS condition. Instruments in the cockpit were more difficult to read due to the visual resolution in the VR headset, and so before the VR condition started, the experimenter asked all participants whether they were able to read the airspeed indicator. The additional emphasis put on this indicator before starting the VR condition may have biased the participants to focus on airspeed.

Objective mental workload was measured using auditory PDT Hit Rate and Response Time data. Longer PDT reaction times and lower hit rates indicate that a participant had less available mental processing resources due to a higher mental workload. Previous research has shown that physiological indicators of higher mental workload, such as an increase in heart rate and blinking, can be expected during complex or stressful maneuvers such as landing (Wilson, 2009). Shorter PDT reaction times or higher hit rates indicate that the participant was experiencing lower mental workload and was able to devote more attentional resources to responding to the secondary PDT task while performing the primary flight tasks. Performance on the PDT is often better during low-stress portions of the flight, such as cruising at a constant altitude. PDT hit rates across the two graphics conditions on first exposure were not significantly different. This result is in line with our results in the path variation data, which also showed no performance differences between the VR and BADS conditions.

Subjective reports of mental effort showed a significantly higher rating in the VR condition than in the BADS condition. Participants indicated that the VR condition felt more immersive, which could account for some of the difference. The high sensory input of VR may have proved to be more intense than expected, making the participants feel as though they were putting more mental effort into the task due to feeling more engaged in the task. Despite the reported higher mental effort in the VR condition, analysis on the actual performance scores of participants (see Figure 4) shows no significant correlation between self-reported mental effort and PDT hit rate, an objective measure of mental effort. The lack of correlation between subjective and objective mental effort indicates that the perceived mental effort required to complete the task does not necessarily reflect the actual mental effort required, a finding that supports other results showing no performance difference between graphics conditions.

Although minimal significant performance differences were found across the two graphics conditions, it is important to note that performance is not the only important factor when considering VR as an alternative to traditional simulator display systems. The use of a new technology often introduces other user experience concerns, such as ergonomic limitations and the potential for ill-adaptation to the product. To address these concerns, participants were asked to fill out a questionnaire immediately after completing the flight tasks in the BADS and VR conditions. The questionnaire dealt primarily with how the participant was currently feeling, any possible ill-effects experienced, the weight of the VR device and how comfortable the device felt on the participant's face.

Self-reported sickness questions showed no significant difference across graphics conditions, indicating that users did not feel worse in the VR than in the BADS condition. This contradicts the findings of other studies showing participants to be more susceptible to motion sickness when using VR devices (Morphew et al, 2004). A possible explanation for this could be the duration of the VR experience. Participants spent roughly 15 minutes in each condition before exiting the simulator and filling out the questionnaire. Treleaven et al. (2015) reported that the longer a user spends in a VR environment, the higher the likelihood that they will experience the effects of VR sickness. It is important to note that although our study showed no difference between graphics conditions when only the data from the first exposure were analyzed, a significant difference in self-reported queasiness was found in graphics conditions when compared across both exposures. Participants who experienced VR in first exposure tended to feel slightly queasier by the end of the experiment than those who began in the BADS condition. This could be due to a possible delay in effects of VR sickness, a phenomenon observed in numerous other studies involving VR (LaViola, 2000).

An interesting observation that should be noted was the reaching problems present in the VR condition. This simulated flight task required participants to reach for two controls – the throttle and flaps. In the BADS condition, these controls were easily found and could be immediately grabbed whenever the participant desired. In the VR condition, the throttle was typically found either immediately or within a second or so of searching in its general area with the hand, while the flap control, in some cases, took upwards of eight seconds to find. This difference in time taken to find the control could possibly be due to the compounding of reaching error, where small errors in initial trajectory of the reaching motion increased as the arm moved further away from the body. In this way, the proximity of the throttle to the natural resting location for the participant's hands on the yoke aided participants in finding the control with relative ease. Due to the participant's hands not being virtually represented in VR, participants were required to rely solely on their proprioceptive intuitions to locate the aircraft's throttle and flap controls. While including a virtual representation of the participant's hands using Leap Motion hand tracker was originally considered, the idea was not implemented in any of the experimental trials. This was due to various issues with the technology that were apparent during pilot testing, including a slow update cycle, hands mysteriously disappearing and difficulties calibrating the exact position of the hands in the virtual environment. The unpredictable behavior of the virtual hands made it even more difficult to situate our own hands in the environment than without having the virtual hands present. Perhaps once this technology is better developed it may serve as a solution to the problem of reaching in the VR environment that was experienced in this experiment.

Difficulty in finding certain controls, although noticeable when watching from the inside of the plane, did not have any measurable effects on performance in this experiment. In many cases where flaps were left down when the aircraft was outside of the appropriate area for flaps down, it was due to the participant simply forgetting that they had been lowered rather than from not being able to find the flap control. The difficulties finding the flap controls, rather than having an overall impact on performance, simply made the approach more hectic for the participant. Although the presentation of the PDT stimuli was not linked to the ongoing flight tasks in the data file, it would probably be the case that performance on the PDT would have been significantly worse when participants were searching for the flap controls in the VR condition while on the approach portion of the circuit.

Results obtained from the questionnaire revealed that many participants described the VR condition as more immersive than the BADS. There are several reasons why this could be the case. One such reason is the visual degrees of freedom. In the BADS environment, the participant’s visual field is fully filled with the simulation environment when they are looking straight ahead. However, when the participant looks to the side, they are met with the stationary, non-simulation visuals of the surrounding room. This could lead the simulation to being less convincing, as the user knows they can quite easily ‘break out’ of the immersion, as well as accidentally breaking out when looking out the side of the plane. In the VR environment, however, the participant’s visual environment is 360°, thus the participant is fully visually immersed regardless of their viewing direction. Participants are even able to lean forward and look up to see the sky in VR, an act that would quickly reveal the testing apparatus and room in the BADS condition. By removing the possibility of easily ‘breaking out’ of the simulation, the

VR does a better job of immersing the user, and therefore creating an overall more immersive experience.

Another possible reason for the VR feeling more immersive could be the realistic lighting that fills the cockpit. In the VR environment, the sun's light casts shadows into the cockpit, which dynamically changes as the plane moves. This is in stark contrast to the BADS environment, where lighting is always consistent. In order for the projectors to work best, the lights in the simulation room must be kept low. This creates a dark environment in the cockpit, which is inconsistent with the sunny weather in which the simulated flight tasks occur.

The general finding of an absence of significant performance differences between the VR and BADS conditions is a positive result for the feasibility of using VR technology to replace or augment traditional simulator display systems. This finding supports the notion that VR and traditional simulator setups have equivalent effects on user performance, and thus the replacement of traditional simulators with VR apparatus could be a viable solution to the various problems with current simulators outlined earlier in this paper. This is a positive finding, as the introduction of VR technology for use in cognitive health assessments would allow these assessments to become more accessible to the general aviation community.

References

Arns, L. L., & Cerney, M. M. (2005). The relationship between age and incidence of cybersickness among immersive environment users. In *IEEE Proceedings. VR 2005. Virtual Reality, 2005.* (pp. 267–268). https://doi.org/10.1109/VR.2005.1492788

Baltzley, D., Kennedy, R., Berbaum, K., & Gower, D. (n.d.). The Time Course of Postflight Simulator Sickness Symptoms. Retrieved April 23, 2017, from https://ncbi.nlm.nih.gov/labs/articles/2818393/

Bazargan, M., & Guzhva, V. S. (2011). Impact of gender, age and experience of pilots on general aviation accidents. *Accident; Analysis and Prevention*, *43*(3), 962–970. https://doi.org/10.1016/j.aap.2010.11.023

Blehm, C., Vishnu, S., Khattak, A., Mitra, S., & Yee, R. W. (2005). Computer Vision Syndrome: A Review. *Survey of Ophthalmology*, *50*(3), 253–262. https://doi.org/10.1016/j.survophthal.2005.02.008

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., … Wills, R. F. (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*, *42*(3), 788–796. https://doi.org/10.1016/j.aap.2009.04.013

Causse, M., Dehais, F., Arexis, M., & Pastor, J. (2011). Cognitive aging and flight performances in general aviation pilots. *Aging, Neuropsychology, and Cognition*, *18*(5), 544–561. https://doi.org/10.1080/13825585.2011.586018

Christopher, K. (2012). Report on the COPA 2012 membership survey. Ottawa, ON: COPA. Retrieved from http://www. copanational.org/files/2012Survey4Website.pdf

Hardy, D. J., Satz, P., D'Elia, L. F., & Uchiyama, C. L. (2007). Age-Related Group and Individual Differences in Aircraft Pilot Cognition. *The International Journal of Aviation Psychology*, *17*(1), 77–90. https://doi.org/10.1080/10508410709336938

Hays, R. T., Jacobs, J. W., Prince, C., & Salas, E. (1992). Flight simulator training effectiveness: A meta-analysis. *Military Psychology*, *4*(2), 63–74. https://doi.org/http://dx.doi.org.proxy.library.carleton.ca/10.1207/s15327876mp0402_1

Hettinger, L. J., Berbaum, K. S., Kennedy, R. S., Dunlap, W. P., & Nolan, M. D. (1990). Vection and simulator sickness. Military Psychology, 2(3), 171-181

Hultsch, D. F., MacDonald, S. W. S., & Dixon, R. A. (2002). Variability in Reaction Time Performance of Younger and Older Adults. *The Journals of Gerontology: Series B*, *57*(2), P101–P115. https://doi.org/10.1093/geronb/57.2.P101

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., … Ozaki, N. (2012). Slower adaptation to driving simulator and simulator sickness in older adults Aging Clinical and Experimental Research. *Aging Clinical and Experimental Research*, *24*(3), 285–289. https://doi.org/10.1007/BF03325260

Kay, Gary G. COGSCREEN: Professional Manual, Psychological Assessment Resources, Odessa, Florida, 1995.

LaViola, J. J., Jr. (2000). A Discussion of Cybersickness in Virtual Environments. *SIGCHI Bull.*, *32*(1), 47–56. https://doi.org/10.1145/333329.333344

McCauley, M. E., & Sharkey, T. J. (1992). Cybersickness: Perception of self-motion in virtual environments. Presence, 1, 311-318.

Morphew, M. E., Shively, J. R., & Casey, D. (2004). Helmet-mounted displays for unmanned aerial vehicle control (Vol. 5442, pp. 93–103). https://doi.org/10.1117/12.541031

Nichols, S. (2000). Individual Characteristics and Experiences of Virtual Reality Induced Symptoms and Effects (Vrise). *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*(5), 538–541. https://doi.org/10.1177/154193120004400514

Oman, C. M. (1990). Motion sickness: a synthesis and evaluation of the sensory conflict theory. *Canadian Journal of Physiology and Pharmacology*, *68*(2), 294–303. https://doi.org/10.1139/y90-044

Oskarsson, P.-A., & Nählinder, S. (2006). Evaluation of Symptoms and Effects of Virtual Reality Based Flight Simulation and Enhanced Sensitivity of Postural Stability Measueres. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*(26), 2683–2687. https://doi.org/10.1177/154193120605002603

Park, G. D., Allen, R. W., Fiorentino, D., Rosenthal, T. J., & Cook, M. L. (2006). Simulator Sickness Scores According to Symptom Susceptibility, Age, and Gender for an Older Driver Assessment Study. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*(26), 2702–2706. https://doi.org/10.1177/154193120605002607

Pausch, R., Crea, T., & Conway, M. (1992). A Literature Survey for Virtual Environments: Military Flight Simulator Visual Systems and Simulator Sickness. *Presence: Teleoperators and Virtual Environments*, *1*(3), 344–363. https://doi.org/10.1162/pres.1992.1.3.344

Reason, J. T., & Brand, J. J. (1975). *Motion sickness.* London: Academic Press.

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society*, *16*(5), 754–760. https://doi.org/10.1017/S1355617710000706

Treisman, M. (1977). Motion Sickness: An Evolutionary Hypothesis. *Science, 197*(4302), 493–495.

Treleaven, J., Battershill, J., Cole, D., Fadelli, C., Freestone, S., Lang, K., & Sarig-Bahat, H. (2015). Simulator sickness incidence and susceptibility during neck motion-controlled virtual reality tasks. *Virtual Reality*, *19*(3–4), 267–275. https://doi.org/10.1007/s10055-015-0266-4

Van Benthem, K. D., Herdman, C. M., Tolton, R. G., & LeFevre, J.-A. (2015). Prospective memory failures in aviation: Effects of cue salience, workload, and individual differences. Aerospace Medicine and Human Performance, 86(4), 366–373. doi: 10.3357/AMHP.3428.2015

Van Benthem, K., & Herdman, C. M. (2016). Cognitive factors mediate the relation between age and flight path maintenance in general aviation. *Aviation Psychology and Applied Human Factors*, *6*(2), 81–90. https://doi.org/http://dx.doi.org.proxy.library.carleton.ca/10.1027/2192-0923/a000102

Wilson, G. F. (2002). An Analysis of Mental Workload in Pilots During Flight Using Multiple Psychophysiological Measures. *The International Journal of Aviation Psychology*, *12*(1), 3–18. https://doi.org/10.1207/S15327108IJAP1201_2

Winter, J. C. F. de, Dodou, D., & Mulder, M. (2012). Training Effectiveness of Whole Body Flight Simulator Motion: A Comprehensive Meta-Analysis. *The International Journal of Aviation Psychology*, *22*(2), 164–183. https://doi.org/10.1080/10508414.2012.663247

Yesavage, J. A., Taylor, J. L., Mumenthaler, M. S., Noda, A., & O'Hara, R. (1999). Relationship of Age and Simulated Flight Performance. *Journal of the American Geriatrics Society*, *47*(7), 819–823. https://doi.org/10.1111/j.1532-5415.1999.tb03838.x

Appendix A

Ethics approval for this study

Carleton
UNIVERSITY
Canada's Capital University

Research Compliance Office
511 Tory | 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 # 104515 10-034

Principal Investigator: Dr. Chris Herdman

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

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

Funding Source:

Effective: **January 30, 2017** Expires: **September 30, 2017**.
Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions or if you require a clearance certificate with a signature.
CLEARED BY: **Date: January 30, 2017**
Andy Adler, PhD, Chair, CUREB-B

Shelley Brown, PhD, Vice Chair, CUREB-B

Appendix B

Questionnaire used for collecting participant background information as well as user-experience information

Simulator Sensation Parts One - Three

Please complete each question below.

*Required

1. Code *

2. On a scale of 1 to 7 how alert are you right now? *

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

3. 1.2 On a scale of 1 to 7 how fatigued are you right now? *

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

4. 1.3 When did you last eat? *

   - Within the last hour
   - Within the last 2 to 5 hours
   - More than 5 hours ago

5. 1.4 On a scale of 1 to 7 how queasy are you feeling right now? *

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

6. 1.5 On a scale of 1 to 7 how dizzy are you feeling right now? *

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

7. 1.6 On a scale of 1 to 7 how disoriented are you feeling right now? *

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

8. 1.7 Are you prone to motion sickness? *

- Yes
- No

9. 1.8 Have video games ever made you feel sick or queasy in the past? *

- Never.
- Sometimes I feel a little queasy.
- I always feel queasy when playing video games.
- No- I don't play video games

10. 1.9 Have you ever used Virtual Reality products before? E.g. Oculus Rift goggles *

- Never
- Maybe once or twice
- I am a regular user of virtual reality products

11. 1.10 Have Virtual Reality products ever made you feel sick or queasy in the past? *

- 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. 1.11 How often do you play video games? *

- Everyday once or twice a
- week once or twice a
- month
- Rarely
- I used to play years ago, now I don't at all

13. 1.12 Do you have any piloting experience? *

- I have no piloting experience
- Yes I am a licensed pilot
- Yes, I used to be a licensed pilot
- I am in pilot training

14. 1.13 Gender *

- Male
- Female
- Other
- Prefer not to say

15. 1.14 Age *

____

16. 1.15 Language *

- English is my first language
- English is my second language

17. 1.16 Handedness *

- I am right-handed
- I am left-handed

18. STOP HERE *

- OK

19. 2.1 On a scale of 1 to 7 how queasy are you feeling right now? *

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

20. 2.2 On a scale of 1 to 7 how dizzy are you feeling right now? *

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

21. 2.3 On a scale of 1 to 7 how disoriented are you feeling right now? *

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

22. STOP HERE *

◯ OK

23. 3.1 On a scale of 1 to 7 how queasy are you feeling right now? *

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

24. 3.2 On a scale of 1 to 7 how dizzy are you feeling right now? *

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

25. 3.3 On a scale of 1 to 7 how disoriented are you feeling right now? *

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

26. 3.4 On a scale of 1 to 7 how comfortable was the Oculus Rift at first? *

	1	2	3	4	5	6	7	
Very uncomfortable	◯	◯	◯	◯	◯	◯	◯	Very comfortable

27. 3.5 On a scale of 1 to 7 how comfortable was the Oculus Rift by the end of your flight? *

1	2	3	4	5	6	7

Very uncomfortable	○	○	○	○	○	○	○	Very comfortable

28. 3.6 On a scale of 1 to 7 how would you rate the heaviness of the Oculus Rift? *

	1	2	3	4	5	6	7	
Very light- barely felt it	○	○	○	○	○	○	○	Very heavy

29. 3.7 On a scale of 1 to 7 how would you rate the crispness of the visual scene in the Oculus Rift? *

	1	2	3	4	5	6	7	
Not crisp at all e.g. very blurry	○	○	○	○	○	○	○	Extremely crisp e.g. no blurriness

30. 3.8 On a scale of 1 to 7 how would you rate the reality of the look of the visual scene in the Oculus Rift? *

	1	2	3	4	5	6	7	
Not real looking at all	○	○	○	○	○	○	○	Extremely real looking

31. 3.9 On a scale of 1 to 7 how would you describe the fact that you could not see your own hands on the yoke (steering wheel) in the Oculus Rift? *

	1	2	3	4	5	6	7	
I barely noticed, and this did not affect my flying	○	○	○	○	○	○	○	This really bothered me, and this affected my flying

32. 3.10 On a scale of 1 to 7 how would you describe the fact that you could not see your own hands when reaching for the throttle or flaps in the Oculus Rift? *

	1	2	3	4	5	6	7	
I barely noticed, and this did not affect my flying	○	○	○	○	○	○	○	This really bothered me and this affected my flying

33. 3.11 List any physical symptoms you felt, not

already mentioned above, while flying with the
Oculus Rift? *

34. 3.12 Indicate when these physical symptoms started while flying with the Oculus Rift? *

- Right away
- After about 10 minutes
- Near the end NA- no
- symptoms Other: