Fall 2009

Change Blindness in the Synthetic Vision Primary Flight Display: Comparing Eye Tracking Patterns with Pilot Attention

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CHANGE BLINDNESS IN THE SYNTHETIC VISION PRIMARY FLIGHT DISPLAY:

COMPARING EYE TRACKING PATTERNS WITH PILOT ATTENTION

by

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B.S., Embry-Riddle Aeronautical University, May 2006

A Thesis Submitted to the
Department of Human Factors and Systems
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Human Factors and Systems

Embry-Riddle Aeronautical University
Daytona Beach, Florida
Fall 2009

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This thesis was prepared under the direction of the candidate's thesis committee chair, Shawn Doherty, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Masters of Science in Human Factors & Systems.

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Acknowledgements

There is a long list of people that deserve my sincere gratitude for their encouragement, support, and driving guidance for this thesis. First, I'd like to thank my thesis advisor and whom I admire and respect greatly, Dr. Shawn Doherty. Second, I thank my family for believing in me and never wavering their support and love, no matter what. Finally, I would like to thank my amazing friends, whose encouragement and inspiring drive for life pushed me towards my goals and helped me achieve this great accomplishment.

Abstract

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Title: Change blindness in the synthetic vision primary flight display: Comparing eye tracking patterns with pilot attention

Institution: Embry-Riddle Aeronautical University

Degree: Master of Science in Human Factors and Systems

Year: 2009

There have been a number of important advances in aviation technology that have made the safety rating of flying the best that it has ever been. One of the most important advances made has been in the interface that the pilot relies on for their most critical information during flight. New aviation displays have empirically shown a wide range of improvements across pilot performance. Despite these improvements, there is still a high possibility that pilots may miss pertinent information that changes may occur simultaneously with some sort of distraction – a concept known as change blindness. This study analyzed how pilots use their primary flight display during a change blindness paradigm in conjunction with an eye tracker to investigate the link between where the pilot was visually looking and the instruments they were attending. Patterns indicated that pilots use a hub-and-spoke eye scanning pattern during normal flight, focusing mostly in the center of the display. Despite this, change blindness had little effect, emphasizing the display's inherent ease of use.

Table of Contents

Acknowledgements....iii

Abstract....iv

Table of Contents....v

List of Tables....vii

List of Figures....viii

Introduction....1

Change Blindness....2

Theory of Central or Marginal Interest....4

Theory of Coherence....6

Flicker Paradigm....7

Synthetic Vision Displays....8

Eye Tracking....10

Change Blindness and Attention Allocation in Synthetic Vision Displays....12

Hypotheses....13

Methods....14

Participants....14

Apparatus....14

Design....15

Procedure....15

Results....16

Total Gaze Times....17

Average Trial Times....19

Occurrence of Change Blindness......21

Area of Interest Ratio......23

Discussion......25

Limitations......28

Conclusions......29

References......30

Appendix A......32

Appendix B......33

List of Tables

Table 1 - Descriptive Gaze Statistics of Total Time in Each Area of Interest................................18

Table 2 - Pairwise comparisons of Total Gaze Times...19

Table 3 - Descriptive Statistics of Average Time based on Area of Interest Changed..................21

Table 4 - Pairwise comparisons of Average Trial Times by AOI changed....................................22

Table 5 - Descriptive Statistics of CB Occurrence Based on Type of Change................................23

Table 6 - Descriptive Statistics of CB Occurrence Based on Area of Interest Changed..................23

Table 7 - Descriptive Statistics of the Average Percent of Trials in which CB occurred..............23

Table 8 - Descriptive Statistics of Area of Interest Ratio..25

Table 9 - Pairwise comparisons of Ratio of AOI Viewed to AOI Changed..................................26

Table 10 - Significant Differences Suggesting Hub-and-Spoke..28

List of Figures

Fig 1 – Example of Flicker Paradigm..........7

Fig 2 – Example of SVS Primary Flight Display and Navigation Display..........9

Fig 3 – Traditional Instrument Scanning Patterns..........11

Fig 4 – SVS Scanning Pattern..........11

Fig 5 – SVS Areas of Interest..........12

Fig 6 – Garmin G1000 with AOI's defined..........16

Fig. 7 – Means of AOI's across all trials..........19

Fig. 8 – Average Trial Times across all trials..........21

Fig. 9 – Means and Standard Deviations for the Area of Interest Viewed by Area of Interest Changed Ratio..........25

Fig. 10 – Garmin G-1000 with percent-use for AOI's..........27

Introduction

Cockpits are becoming more and more advanced as designers and avionics manufacturers continually make changes with the intention of improvement of the pilot's ability to fly the plane safely and effectively. Weiner (1989) discusses how pilots are confident in their knowledge of the aircraft systems, yet still fall short in fully understanding how all of the different systems interact with one another. The trend of changing technology in the cockpit has corresponded with the growth of commercial aviation, and the task of flying has become markedly more complex. Recent research has probed the cognitive difficulties that come along with introducing complex new technology into the cockpit, in which pilots fail to note autonomous changes indicated on their instruments during flight (Mumaw, Nikolic, Sarter, & Wickens, 2001). This failure to note changes in automation indicates that pilots are often not focused on factors that play a critical role in the performance of the aircraft but instead are lending their attention to the wealth of other information within the cockpit's flight displays, controls, and interfaces (Mumaw, et al., 2001). The concept that explains why humans miss important changes within their environment because of distractions capturing their attention is known as change blindness. In modern flight instrumentation, critical information that the pilot needs for flight is displayed in a way that is meant to be more intuitive, with the intention of mitigating the effects of change blindness. Despite this intuitive nature that modern displays are suggested to have, there is still a question of how pilots attend to information within modern aviation displays because of a lack of published research concerning the topic.

There is little empirical data examining pilot scanning patterns using modern flight displays, and whether these displays allow for faster and more effective scanning. It is possible with an improved scanning ability that more of their attention resources will be available, allowing the pilot to catch significant changes in the new displays and thus mitigating the effects of change blindness. It is also possible that there are improvements in the salience of sources of important flight information, meaning that the new displays actually present information in a way that is perceptually clearer and physically easier for the eyes to scan, also potentially mitigating the effects of change blindness.

Because there is little research about the effects of change blindness on pilot performance in modern flight displays, there is a great deal of understanding to be gained about how pilots *use* modern displays (where their eyes are actively attending during use) and how they *perceive* modern displays (where their attention is focused and what information they actually process) when confronted with a task that induces change blindness, because of the profound effects that change blindness can have on performance. The following sections will discuss change blindness as it pertains to users of visual displays and how it has been previously studied.

Change Blindness

Our visual field is highly complex and rich with visual cues that draw our attention which is often guided depending on our goals or past experiences. More importantly, there are cues within this visually rich environment that people are supposed to attend to because of their importance, such as pilots' displays and instruments. Change blindness is defined as "when an observer fails to detect an event (e.g., discrete change) in the environment… [or] a failure to notice that something is different from what it was"(Wickens & McCarley, 2008, p22). This is usually because of a lapse in attention, because the viewer's attention is focused elsewhere in their visual field, or because of a visual disruption in the field of view. To give a simple example, a change in vertical speed caused by the aircraft's automation system beginning descent is missed by the pilot because an indicator light for an unrelated warning system flashes during the change. There is a discrete event (the change in vertical speed) and a visual disruption (warning light flashing) causing a lapse in attention for the vertical speed which is ultimately more critical than the warning system. Because change blindness causes a lapse in attending to critical information (such as a shift in altitude), it greatly increases the risk of accidents with disastrous consequences. For example, Ranter (2006) cites lapse in attention as the primary cause for over 150 General Aviation accidents that occurred from aircraft in working condition flying into the terrain between the years of 2002 and 2006.

Change blindness can also occur because of some lapse in attention during information processing, causing our working memory to form incomplete representations of information that are unable to be stored effectively or completely (Fougnie & Marois, 2007). Fougnie and Marois (2007) explain that a break in focused attention is what allows for change blindness to have such a strong effect. This means that when our focus is transferred to some other task or visual target we become more susceptible to change blindness. In their study, this was demonstrated by using two simultaneous tasks engaging the central executive (the theoretical stage of information processing that controls where attention is focused) in tasks of different modalities (one visual and one verbal), inducing participants to miss a change in the visual field. This means that our lapse in attention is more fundamentally related to our processing of information, rather than simply seeing the information. The results from Fougnie and Marois' (2007) study can be simply interpreted and applied to an aviation context, indicating that if pilots' are able to remember the information that they need from their displays in a faster and more effective manner which they store in their memory, the presence of a distracting stimulus is less likely to cause change blindness.

This coincides with another view of change blindness in which the phenomenon occurs due to an inability to compare retained information from before the change and after a change had been made (Mitroff, Simons, & Levin 2004). Although observers retained representations of both pre-change and post-change information, they were still unable to detect that a change had actually occurred. This indicates again that a break in focused attention is the causal factor of change blindness, meaning that our representations of the link between pre-change and post-change information can be lost if they are not strongly remembered. In other words, the central executive stage of information processing (which is responsible for where we allocate our attention) can inhibit the concrete formation of the representation of change because it is not focusing on a single modality. Change blindness has also been theorized as a cognitive phenomenon (rather than a visual phenomenon) in which occurrence of change blindness is more likely if concrete representations of information aren't stored.

Theory of Central or Marginal Interest

There are two important theories that further explain why change blindness occurs: the Theory of Central or Marginal Interest and the Theory of Coherence. The Theory of Central or Marginal Interest states simply that changes in objects that are of central interest (e.g., visual targets that are more important to our goals) will be detected more rapidly than objects that are of marginal interest (e.g., visual targets perceived as having less importance than those of central interest) (Rensink, O'Regan, & Clark, 1997). To bring this theory into the context of aviation displays, a display that is more important to flight will yield higher rates of detection in changes over displays that are of lesser importance to flight – such as the primary flight display over the outlying instruments also within the cockpit.

This theory suggests that change blindness is more of a perceptual phenomenon than a sensory phenomenon (meaning that change blindness is based on our ability to process and store information over our ability to see the information), explaining why changes in information that are important to the overall task (flight in this case) can still be overlooked. Objects that are more important receive priority, and therefore are more likely to be detected when a change occurs. So although the eyes might scan across the changed information, Rensink et al. (1997) showed that the change is not perceived because it does not have priority (overall results of Rensink et al.'s (1997) study demonstrated that observers took a long time to note changes, even when the eyes were directly fixed on the change).

This theory is further bolstered with empirical information about attentional tunneling. Attentional tunneling is defined as "the allocation of attention to a particular channel of information… for a duration that is longer than optimal, given the expected cost of neglecting events on other channels… failing to perform other tasks"(Wickens, 2005, p1). In other words, the term 'attentional tunneling' means that attention is fixated on one particular goal or object in the visual field at the expense of all other goals and objects. A change made in the visual scene is more likely to be detected if the eye is fixated on the object that is changed, rather than fixated on a single location within the visual field and not allowed to move (Hollingsworth, Schrock, & Henderson, 2001). So, coming back to the Theory of Central or Marginal Interest, when attention is focused on a given object (the object that is perceived of higher importance), it is more likely that detection of a change will occur.

Despite this, during the study used in developing the Theory of Central of Marginal Interest (Rensink et al., 1997), detecting changes took a long period of time even when the object was rated as important. This seems to indicate that the theory of Central or Marginal Interest does not account for all of the failures in change blindness detection. The Theory of Coherence attempts to further explain how we miss changes.

Theory of Coherence

The Theory of Coherence explains the relationship between focused attention and visual perception. This is done using spatiotemporal mental structures (individuals' mental models of their current surroundings across space and time). Essentially this theory states that our perception of vision is based on our construction of these mental structures which are based on spatial representations (a visual object changing across space) and temporal representations (a visual object changing across time) (Rensink, O'Regan, & Clark, 2000). In order to maintain these coherent mental representations, focused attention is critical. If focused attention is not given to each mental structure, then they will lose their strength, and change detection is less likely. With this in mind, attentional tunneling helps this theory explain how change blindness may occur, specifically within new aviation displays.

According to the Theory of Coherence, if attention is focused entirely in one area of the display because the pilot is drawn to it, it will have a strong mental representation at the expense of other mental structures. As Wickens (2005) explains with regards to aviation displays with 3D imagery, pilots tend to be compelled by these displays and fixate their attention on the display and failed to detect important cues that were not located on the display (such as a runway incursion during their final approach to land which made landing the aircraft impossible without crashing into the incursion). This indicates that the display actually induced attentional tunneling more than a display that gave all the necessary flight information without 3D imagery. Further bolstering this effect as interpreted from Hollingsworth et al. (2001), if a pilot's eye-scan is restricted to a single visual location they are more likely to miss a change in the visual scene than if their eyes are able to scan freely. So, if a pilot's attention is focused solely on one area of their display because by some inherent nature of the display they are drawn to it, it is possible that the lack of eye movement will result in failure to detect a change in the scene. Clearly, if pilots are focusing all of their attention to one area of the display at the expense of other areas because they are drawn to it, in accordance with the theory of coherence, the mental structures in areas of the display which are less attended will be more likely to experience change blindness.

Flicker Paradigm

To study the effects of change blindness during a flight related task, a paradigm that can induce change blindness is necessary. One particular paradigm used in numerous change blindness studies is known as the flicker paradigm. The flicker paradigm induces change blindness by showing an initial image and a modified image in series separated by a blank interval, simulating a visual disruption that would occur naturally (Mitroff, Simons, & Levins, 2004). The images continually alternate until the viewer detects the change between the two images (see Figure 1), or until a time limit (in seconds) has elapsed (Rensink et al 1997).

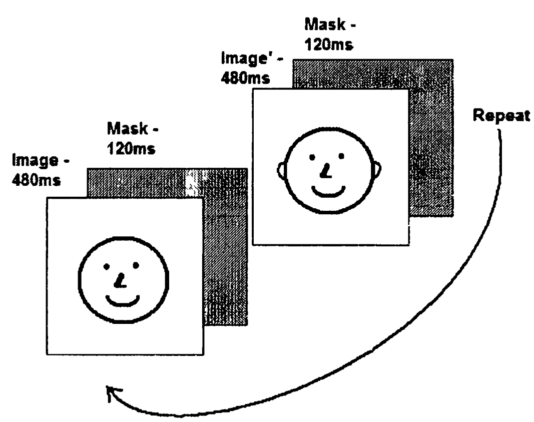

Figure 1 - Example of Flicker paradigm

One of the benefits of the flicker paradigm is that it induces change blindness without the need for a second sensory modality, such as the secondary verbal task used by Fougnie and Marois (2007). This allows for results to be tied to a specified modality – i.e. visual modality – which allows for analysis of one modality without the interference of the other senses when controlled for. Another benefit of the flicker paradigm is that it gives the participant continuing opportunity to recognize the change between the original and modified image, meaning that they are more likely to form a complete representation (or mental structure) of the visual scene and correctly identify the change.

Even though change blindness does have a negative and important effect on all of the displays and gauges that make up a pilot's visual field, the primary display receives the majority of the pilot's attention, and therefore needs the highest occurrence of change detection in order to mitigate the risk of an accident caused by change blindness.

Synthetic Vision Displays

Synthetic vision displays show critical features of the environment that are external to the aircraft using computer generated imagery that comes from databases of topography and landmarks, precise positioning information (e.g., Global Positioning System), and flight display symbol sets that are combined with weather-penetrating sensors and enhanced vision sensors (Prinzell & Kramer 2006). In other words, a synthetic vision display system is a flight display that presents a view of the outside world to the flight crew by combining computer-generated scenes from on-board databases and guidance displays - coupled with information derived from on-board sensors - enabling a view of the external environment that is unaffected by night or inclement weather conditions (Prinzell, et al., 2004). The SVS primary flight display (See Figure 2) matches the pilot's representation of the external environment, (which is similar to the Attitude Directional Indicator [ADI] or 'artificial horizon of old) and integrates all necessary flight information into a single display, and presents pilots with a view of what they would see outside the cockpit under the conditions of a clear day with good visibility.

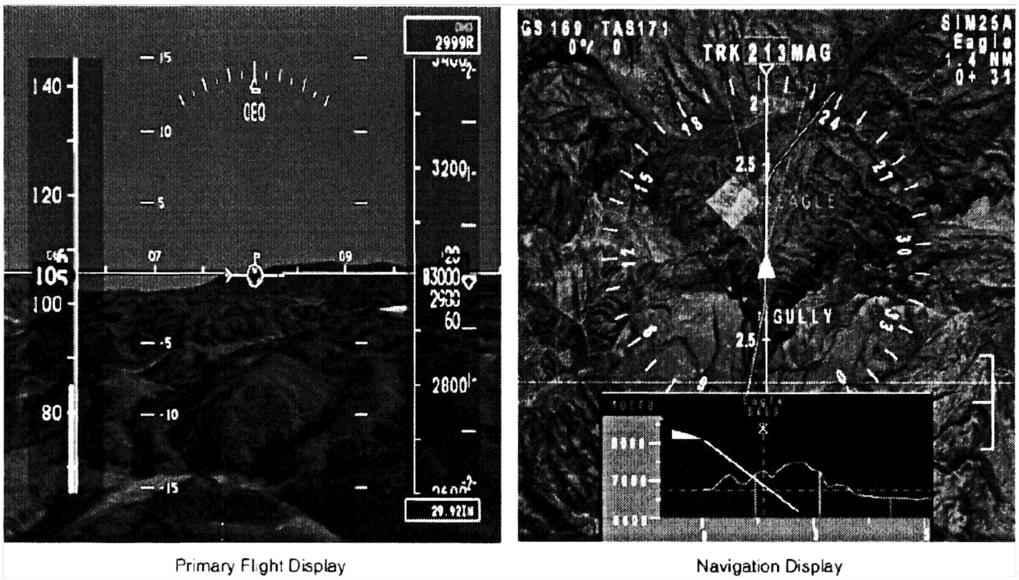

Figure 2 - Example of SVS Primary Flight Display and Navigation Display

A number of beneficial effects such as improved landing flare timing (Mulder, Pleijsant, van der Vaart, & van Wieringen, 2000) and improved overall flight performance (Schnell, Kwon, Merchant & Etherington, 2004), have been attributed to SVS indicating that the displays are intrinsically easier for pilots to use and can improve flight performance and safety. To investigate the ways in which pilots use SVS displays, as well as search for any problems that might be present despite the display's shining track record, pilots' vision during use needs to be tracked.

Eye Tracking

For the purpose of this research, there are a few key terms that should be defined. Eye tracking research requires that key areas within the visual field (in this case the most important areas of the display) be identified, each with specified boundaries. Each of these static areas within the visual field is called an area of interest (AOI), and is used to divide the visual field. Fixations are pauses in the visual scan during which the visual system is processing information (Boyce, 2003). The eyes' movement between any two points in the visual field (in the case of this study, two AOI's) is known as a saccade. These are rapid movements during which little or no visual information is processed and should not to be confused with tremors which are small, involuntary oscillations of the eye during fixation.

Schnell et al. (2004) noted in their literature research that pilots are fixated on their primary flight display about 35% of total time during flight, both in traditional and SVS displays, making it by far the most often used and most important part of a pilot's visual field. Schnell et al. (2004) also noted that unlike traditional displays in which pilots are trained to use specific scanning patterns for different scenarios (see Figure 3), in a SVS display the pilot uses a single "hub and spoke" pattern moving between the center of the display and the other instruments within the total display (see Figure 4). The center of the SVS display (Figure 4) corresponds with the ADI in the traditional display (Figure 3) with regards to scanning patterns, indicating that in both display types the pilot returns to the attitude indication (artificial horizon). Pilots are trained by FAA standards to use a hub-and-spoke pattern, moving from the center to outlying instruments, and returning again to the center during their instrument training so Schnell's findings are congruent with the training that pilots receive (Federal Aviation Administration, 2008).

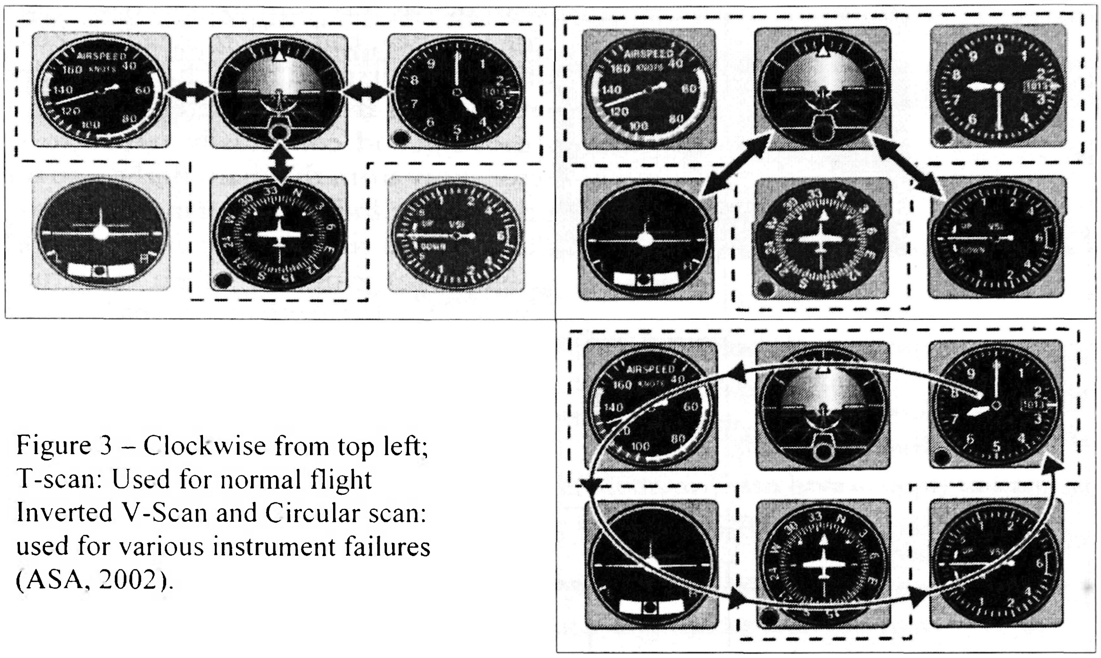

Figure 3 – Clockwise from top left;
T-scan: Used for normal flight
Inverted V-Scan and Circular scan:
used for various instrument failures
(ASA, 2002).

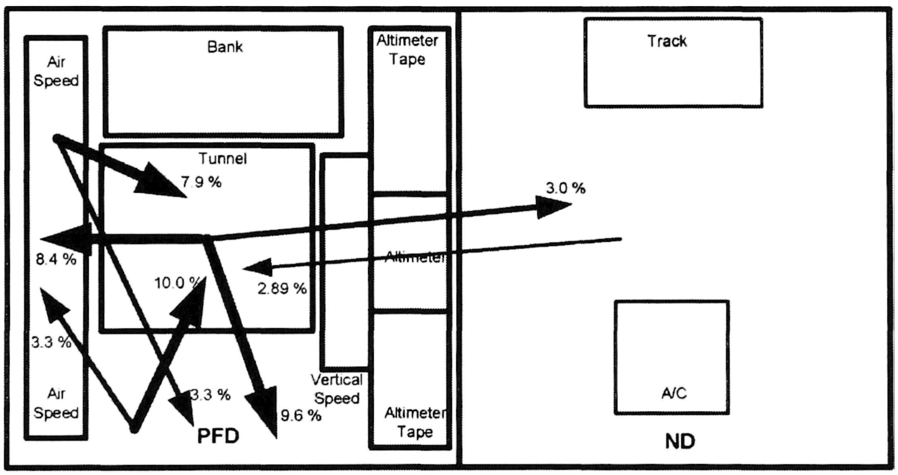

Figure 4 – Hub and spoke scan in PFD (left) and Navigation Display (right). User continually returns to center of PFD.

Schnell et al. (2004) found that pilots flying a simulated approach using a SVS display made significantly fewer total fixations with longer durations during fixation than conventional primary flight displays (PFD's), indicating that the SVS display allowed for understanding of the information presented in less time over conventional displays. Going back to the Theory of Coherence, this indicates that these pilots were able to retrieve the information that they needed and return to the center of the display more quickly, creating strong mental structures with the SVS display. This is demonstrated by a decrease in technical errors during flight – i.e. fewer deviations from commanded speeds, fewer deviations from altitude and fewer lateral deviations: a better overall flight.

There are six key components of the SVS display that should be defined as AOI's in the current study, which correspond with the AOI's used by Schnell et al. (2004). These AOI's are the airspeed indicator, bank indicator, center of tunnel (i.e. the center of the display, which is the SVS equivalent of the ADI), vertical speed indicator, altitude tape, and heading indicator (Figure 5). Changes during the flicker paradigm will occur within these six specified areas, because they are the major components of the display used during flight.

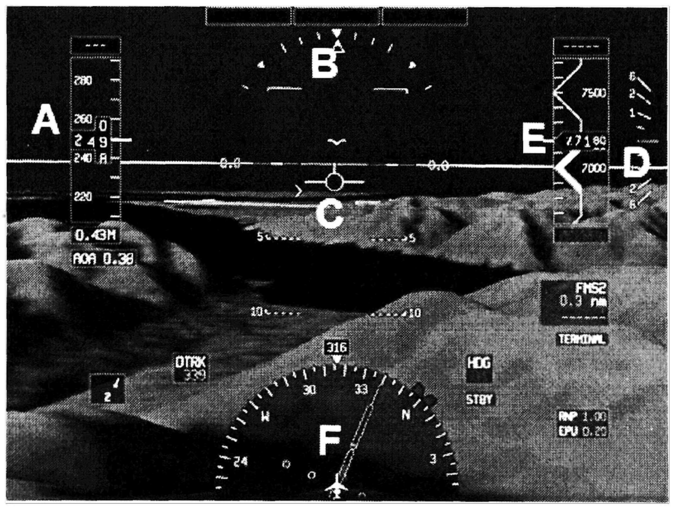

Figure 5 - Areas of Interest: (A) Airspeed indicator, (B) Bank indicator, (C) Center of display, (D) Vertical speed indicator, (E) Altitude tape, (F) Heading indicator

Change Blindness and Attention Allocation in Synthetic Vision Displays

The scanning pattern and improvement in flight performance noted by Schnell et al (2004) indicate an improvement in attention allocation. The pilots spent significantly more time in the center of the display, rather than scanning their instruments, meaning that their attention was able to be focused on flying the aircraft instead of scanning the display. The ability for pilots to locate necessary information without a formal scanning schema is one of the true advantages of the SVS display. The display itself is intrinsically easier to use, as illustrated by novice pilots flying at near-expert levels (Accettullo, 2004; Prinzell et al., 2003) and through the improvement of pilots' overall flying performance (Schnell, et al., 2004). Despite this improvement, the display is captivating as defined by Wickens (2005), increasing the risk of change blindness occurring, because the increased amount of attention given to the SVS display is at the expense of the rest of the flight deck. Also, despite the many improvements in flight performance shown to be elicited by the SVS display, there is little information linking the perception of SVS displays to the way in which they are actually used. In other words, does the information that the pilots are looking at during use actually match with information that they are perceiving? Because previous change blindness research has shown that changes in visual objects are not always detected, even when the eye is fixed directly on the changed object (Rensink et al., 1997), it should be explored whether there is a match between the the perception and use of the display (i.e., information from the eye tracker).

Hypotheses

Previous research has indicated that pilots use a hub and spoke pattern to scan a SVS display, which should be replicated in this study. This also indicates that pilots should be focusing the majority of their attention in the center of the display [35% or more of the total time spent in the center of the display, as taken from Schnell et al. (2004)], possibly at the expense of other areas of the display, which should cause an increase in change blindness in the areas of interest other than the center of the tunnel. The fact that pilots spend the majority of their time in the center of the display as shown by Schnell et al. (2004) indicates that the center of the display is perceived as the most important part of the display, and – in accordance with the Theory of Central or Marginal Interest – should have higher rates of change detection than the outlying instruments within the display. Explained differently – in accordance with the Theory of Coherence – the higher attention to the center of the display should be at expense of the outlying instruments and thus degrade the mental representations of the outlying instruments enough to elicit greater levels of change blindness in the outlying instruments than in the center of the display.

Methods

Participants

Although previous research has shown that novice pilots are able to perform at levels comparable to that of experts (Accetullo, 2004; Prinzell, et al., 2003), specific training is given to pilots during instrument training which details the pattern in which they are to use the primary flight display (in the case of Embry-Riddle, the Garmin G1000) so the participating pilots in this study had at least an Instrument Rating on their pilot's license. No physical limits were placed on participation, as long as particpants' pilot certifications are compliant with FAR 141 guidelines which describes levels at which instrument pilots must perform for certification. Previous research was able to find significant results using 12 pilot participants (Schnell et al., 2004), so this study will used the same number of participants.

Apparatus

The eye tracker used in this study was the Seeing Machines faceLAB eye tracker, which uses the system's included Flea Cameras with precision lenses and Cabling. Three Infrared (IR)

Pods were used to illuminate participants' faces and eyes during the study to allow for optimal tracking. The faceLAB's included software program was run using a Toshiba Tecra S2 Series laptop that recorded the eye tracking/gaze data for the study. Participants viewed images of a Garmin G-1000 display using the Embry-Riddle Human Factors department's Elite PC-based flight training device and a 17 inch plasma display. The flicker paradigm was executed using a custom created software program that randomly assigned participant numbers and presented the 36 images in random order (ending at 30 seconds if no response was made). There were three types of changes made in the six areas of interest for the modified images - the onset or offset of an object, change of a color in an object, or change in object position.

Design

The study used a within-subjects repeated measures design with one independent variable. The independent variable was defined by the area of change in the display with six levels. 1. Airspeed indicator, 2. Bank indicator, 3. Center of display, 4. Vertical airspeed indicator, 5. Altitude tape, and 6. Heading indicator (See Figure 6). There were three dependent variables. 1. Time to detect the change, 2. accuracy of response, and 3. dwell times (in milliseconds)

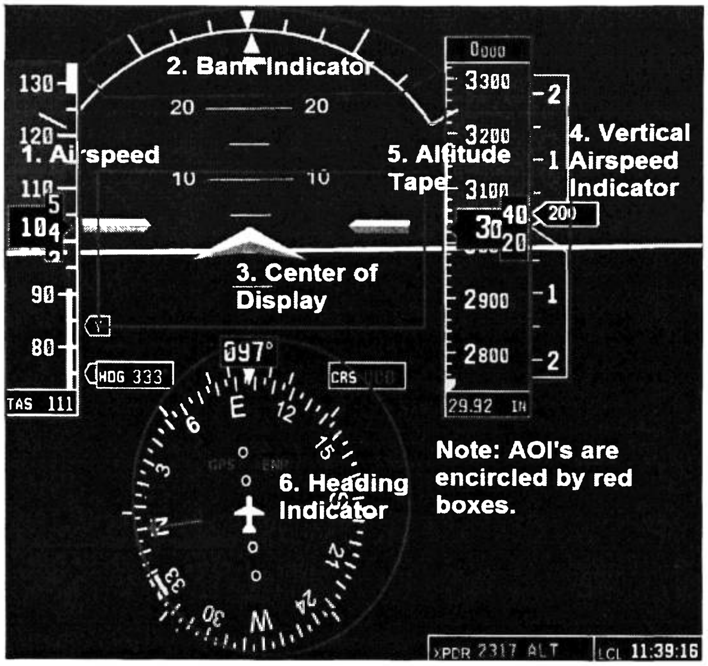

Fig. 6 – Garmin G1000 display with AOI's outlined in red.

Procedure

Voluntary participants were given a signed consent form prior to the study outlining the goals of the study and informing them of any potential risks associated with the study, as well as describing the study and how it will be carried out (Appendix A). They were also given a questionnaire asking basic information about their flight experience (Appendix B). Participants were then seated in the Elite, and the faceLAB eye tracker was calibrated. To create an accurate eye-tracking model the faceLAB software requires first to build a head-model for each participant individually. This includes selecting facial features with high contrast levels that the cameras can pick up on (such as corners of the eyes and mouth, or eyebrows). With the head model created the faceLAB software then requires an accurate scan of the pupil. The entire calibration process typically took no more than 10 to 15 min per participant. Once the eye tracker was properly calibrated, participants were given an explanation of the types of changes that that would be presented. After the explanation participants were instructed to use the same method that they would use to scan their instruments during normal flight in order to find the change between each set of alternating images displayed during the flicker paradigm. Each of the three changes were used twice per area of interest, with a total of 36 trials, each trial lasting no more than 30s. Randomly presented trials ended either once the participant pressed the left button on their mouse and identified the changed AOI, or once 30 seconds elapsed and the program ended automatically. Upon completion, participants were informally interviewed and thanked for their time.

Results

Data was collected from 12 Instrument Rated pilots, 11 male and 1 female (Flight hours: *M*=428; *SD*=479). One trial was excluded from analysis because the information changed during the trial was not meaningful enough to elicit a response from 11 of the 12 participants. All averages were adjusted accordingly. There were no incorrect detections for any of the participants (either the change was found or it was not). All statistical tests used an alpha level of .05 and a confidence interval of 95%. Scores were normalized using a logarithmic transformation to correct for high variances. All scores were transformed equally to maintain the integrity of the data.

Total Gaze Times

Total gaze times spent in each Area of Interest (AOI) were transformed logarithmically to normalize the distribution of data that contained large variability in scores as seen in the standard deviation in total gaze times for each AOI shown in Table 1. A repeated measures ANOVA showed significant differences between the AOI means $F(1,5)=5.35$, $p<.05$. See Figure 7 for a graphical representation of the data. A Bonferroni pairwise comparison (see Table 2) revealed that the time spent in the Center of the display (CEN) was significantly higher than in the Airspeed

Indicator (ASI) and Turn Coordinator (TC), as was the Heading Indicator (HI). The Vertical Speed Indicator (VSI) gaze time was statistically the same as all other AOI's. The Greenhouse-Geisser observed power for this analysis was .89 and the partial eta squared value was .35.

Table 1

Descriptive Gaze Statistics of Total Time in Each Area of Interest. Values have been logarithmically transformed to normalize data distribution.

	N	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
ASI	12	.04	1.10	.548	.365	-.086	.637	-1.541	1.232
ALT	12	.06	1.55	1.045	.390	-1.377	.637	3.147	1.232
CEN	12	.61	1.93	1.195	.441	.274	.637	-1.226	1.232
HI	12	.72	1.91	1.198	.412	.703	.637	-1.070	1.232
TC	12	.11	1.29	.636	.311	.496	.637	.764	1.232
VSI	12	-.33	1.44	.738	.450	-.883	.637	2.206	1.232

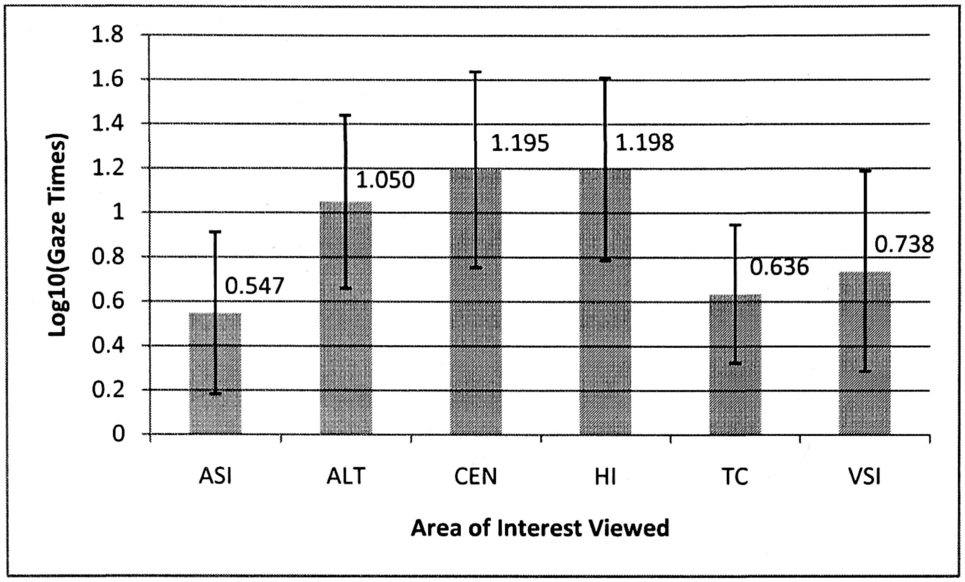

Fig. 7 – Means of AOI's across all trials. Values have been logarithmically transformed to normalize data distribution.

Table 2

Pairwise comparisons of Total Gaze Times

	ASI	ALT	CEN	HI	TC	VSI
ASI		-.502*	-.648*	-.651*	-.088	.0190
ALT	.502*		-.146	-.149	.414	.312
CEN	.648*	.146		-.003	.559*	.457
HI	.651*	.149	.003		.562*	.460
TC	.088	-.414	-.559*	-.562*		-.102
VSI	.190	-.312	-.457	-.460	.102	

Based on estimated marginal means
*The mean difference is significant at the .05 level
a. Adjustments for multiple comparisons: Bonferroni

Average Trial Times

Average times during the trials were computed for each AOI changed because one trial from the Center was omitted, and using the average allows for the data to be treated equally. These values were then transformed logarithmically to normalize the distribution of data in the same manner as the total gaze time data. The median scores of the average times per trial prior to logarithmic transformation are as follows: ASI – 7.793s; ALT – 4.316s; CEN – 5.836s; HI – 4.081s; TC – 5.334s; VSI – 3.614s. Table 3 shows statistics for average times taken to complete trials based on the AOI changed. A repeated measures ANOVA showed significant differences between the means $F(1,5)=4.071$, $p<.05$. See Fig 8 for a graphical representation of the data. The number of flight hours was covaried with this analysis, but did not show significance $F(1,5)=0.45$, $p<.05$. This indicates that pilots did not change their gaze significantly between based on the number of hours that they held. A Bonferroni pairwise comparison (Table 4) indicated that the ASI trial mean was significantly higher than the ALT trials and VSI trials. No other significant differences were found. Although this may seem contrary to the hypotheses for which the CEN condition should have taken significantly less time, the Greenhouse-Geisser Observed Power for this test was 0.84, indicating a high probability that the effects found in this analysis are indeed correct. In addition, the partial eta squared value indicated that 27 percent of the variation is attributable to the manipulation of AOI changed.

Table 3

Descriptive Statistics of Average Time based on Area of Interest Changed. Values have been logarithmically transformed to normalize data distribution.

	N	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
ASI	12	.45	1.08	.828	.209	-.429	.637	-1.117	1.232
ALT	12	.28	.96	.607	.194	.117	.637	-.259	1.232
CEN	12	.17	.94	.701	.227	-1.270	.637	1.535	1.232
HI	12	.35	.98	.618	.204	.264	.637	-.676	1.232
TC	12	.50	1.11	.736	.186	.885	.637	.487	1.232
VSI	12	.10	1.06	.576	.243	.111	.637	.982	1.232

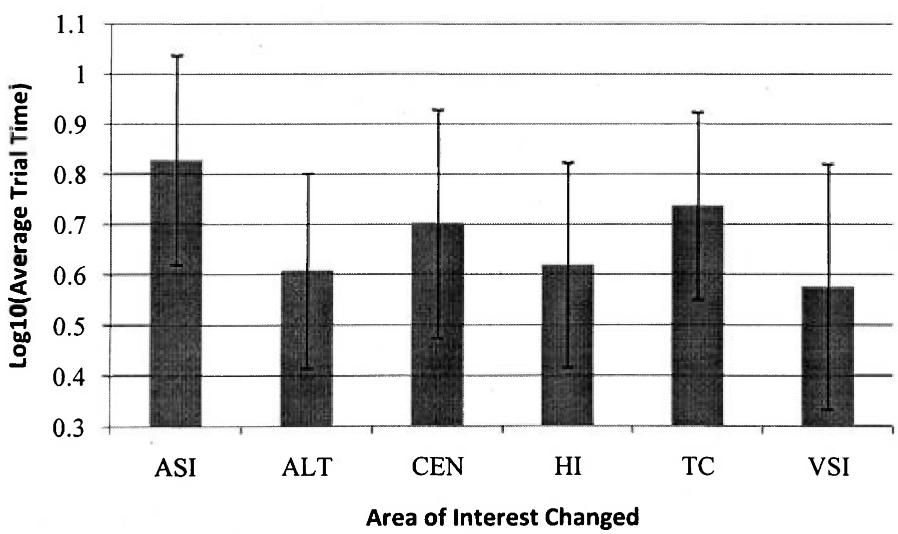

Fig. 8 – Average Trial Times across all trials. Values have been logarithmically transformed to normalize data distribution.

Table 4:
Pairwise comparisons of Average Trial Times by AOI changed

	ASI	ALT	CEN	HI	TC	VSI
ASI		.221*	.127	.210	.092	.252*
ALT	-.221*		-.094	-.011	-.129	.031
CEN	-.127	.094		.083	-.035	.125
HI	-.210	.011	-.083		-.118	.042
TC	-.092	.129	.035	.118		.160
VSI	-.252*	-.031	-.125	-.042	-.160	

Based on estimated marginal means
*The mean difference is significant at the .05 level
a. Adjustments for multiple comparisons: Bonferroni

Occurrence of Change Blindness

Repeated measures ANOVAs were run for occurrence of change blindness based on the type of change made and the AOI in which the change was made. Tables 5 and 6 show the data for percent of occurrence of change blindness based on the type of change made and the AOI changed, respectively. Results were insignificant for both type of change $F(1,3)=2.77$, $p<.05$ and for AOI changed $F(1,5)=1.10$ $p<.05$, indicating that change blindness was not more likely to occur based on change type nor in which AOI the change occurred. Change blindness occurred during 2.86% across all 35 trials (Table 7), indicating that participants were able to correctly detect changes, avoiding change blindness 97% of the time.

Table 5

Descriptive Statistics of CB Occurrence Based on Type of Change

	Mean	Std. Deviation	N
Color Change Totals	.021	.038	12
Position Change Totals	.007	.024	12
Onset Totals	.083	.103	12
Offset Totals	.042	.075	12

Table 6

Descriptive Statistics of CB Occurrence Based on Area of Interest Changed

	Mean	Std. Deviation	N
Percent CB in ASI Change	.056	.082	12
Percent CB in ALT Change	.000	.000	12
Percent CB in HI Change	.014	.048	12
Percent CB in VSI Change	.014	.048	12
Percent CB in TC Change	.042	.104	12
Percent CB in CEN Change	.033	.078	12

Table 7

Descriptive Statistics of the Average Percent of Trials in which CB Occurred Across all Trials

	N	Min	Max	Mean	Std. Deviation
CB Percentage	12	.00	8.57	2.8575	2.72309
Valid N (listwise)	12				

Area of Interest Ratio

A ratio was computed to examine whether pilots viewed an area of interest more when it was the area of interest changed. This was done by dividing the gaze time across trials for one area of interest (based on the area of interest changed) by the sum of all gaze times. For example, during the trials where the airspeed indicator was changed, the equation would look as follows:

$$\mathrm{Log10}\left(\frac{\Sigma(\text{ASI Gaze Time) During ASI Trials}}{\Sigma\,(\text{ASI Gaze Time + ALT Gaze Time + CEN Gaze Time + HI Gaze Time + TC Gaze Time + VSI Gaze Time) During ASI Trials}}\right)$$

This ratio allows a link to be made between where attention should have been focused and where attention is actually focused. In other words, did pilots actually look in the AOI that should have drawn their perceptual attention due to the change in the instrument.

The data for this variable is presented in Table 8. A repeated measures ANOVA showed significant differences between the ratios $F(1,5)=9.38$, $p<.05$. See Fig 9 for a graphical representation of the data. A pairwise comparison shows that the center of the display ratio mean was significantly higher than the airspeed indicator ratio and turn coordinator ratio means, but not significantly different from the other three ratio means (See Table 9, Fig. 9). The altimeter ratio mean was also significantly higher than the airspeed indicator ratio mean, but not significantly different from any of the other ratio means. The Greenhouse-Geisser observed power for this analysis was .89 and the partial eta squared value was .37.

Table 8

Descriptive Statistics of Area of Interest Ratio. Values were transformed logarithmically to normalize the data

	N	Min	Max	Mean	Std. Dev.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
ASI	12	-2.31	-1.38	-1.8294	.331	-.525	.637	-1.379	1.232
ALT	12	-2.53	-.65	-1.1533	.544	-1.846	.637	3.278	1.232
CEN	12	-1.47	-.50	-1.0106	.353	-.101	.637	-1.576	1.232
HI	12	-1.68	-.49	-1.0922	.406	-.172	.637	-1.039	1.232
TC	12	-2.39	-1.07	-1.7257	.433	.039	.637	-.543	1.232
VSI	12	-2.66	-.67	-1.6292	.554	.270	.637	.486	1.232

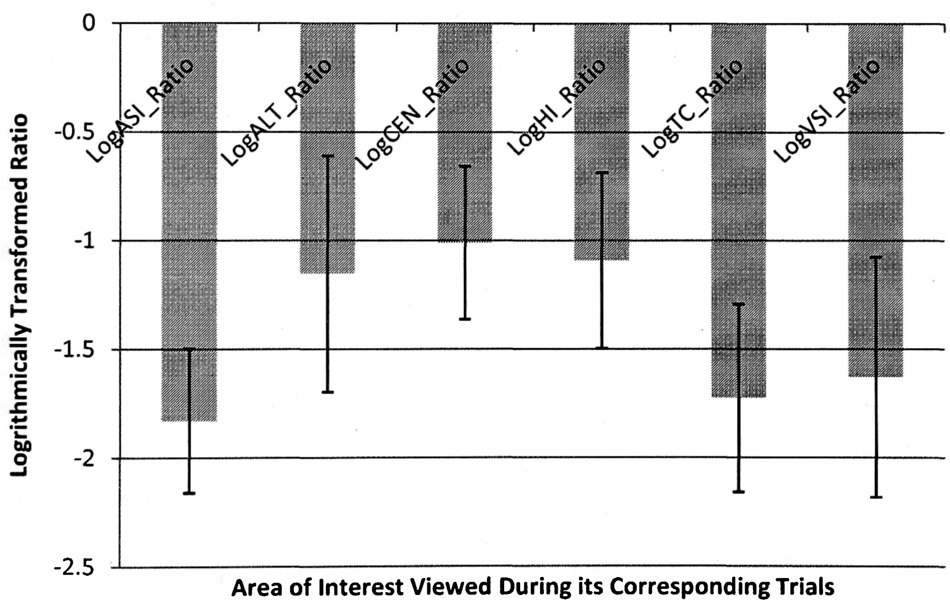

Fig. 9 – Means and Standard Deviations for the Area of Interest Viewed by Area of Interest Changed Ratio

Table 9
Pairwise comparisons of Ratio of AOI Viewed to AOI Changed

	ASI	ALT	CEN	HI	TC	VSI
ASI		-.676*	-.819*	-.737*	-.104	-.200
ALT	.676*		-.143	-.061	.572	.476
CEN	.819*	.143		.082	.715*	.619
HI	0.737*	0.061	-0.082		.634	.537
TC	0.104	-0.572	-0.715*	-0.634		-.097
VSI	0.200	-0.476	-0.619	-0.537	0.097	

Based on estimated marginal means
*The mean difference is significant at the .05 level
a. Adjustments for multiple comparisons: Bonferroni

Discussion

The results suggested a pattern different from the one proposed by Schnell et al (2004). Rather than spending 35% of the time in the center of the display, pilots distributed their attention evenly across the Center, Heading Indicator, and Altimeter, and to a lesser degree the Vertical Speed Indicator (Fig. 10). Initially it was surprising that the Airspeed Indicator would have such a low rate of use. Insight on this came from interviewing with pilots after the session, in which they indicated that often during flight they pay less attention to the Airspeed Indicator because they can hear the speed of the engines and infer the Airspeed without checking the instrument, allowing them to spend more time maintaining level flight and navigating. To paraphrase one pilot: The Altimeter and Heading are among the most commonly used instruments after the Center of the display because they are necessary to keep from colliding with other aircraft, and all of the others are secondary.

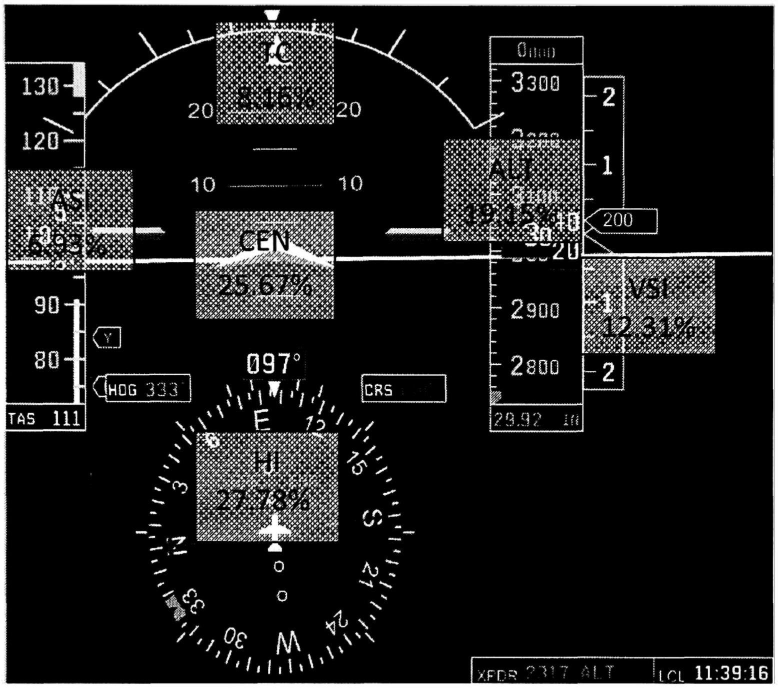

Fig. 10 – Garmin G-1000 with percent-use for AOI's. Values derived from Table 1 by dividing each AOI's mean by the sum of all means.

This does not necessarily indicate that pilots used a scan other than the hub-and-spoke to analyze the Primary Flight Display. Table 10 provides an overview of significant differences for each of the variables outlined in the Results section that suggest the hub-and-spoke pattern may have been present.

Table 10
Significant Differences Suggesting Hub-and-Spoke

Total Gaze Times	ALT/ASI CEN/ASI HI/ASI	 CEN/TC HI/TC
Average Trial (AOI Changed)	ALT/ASI VSI/ASI	
Ratio	ALT/ASI CEN/ASI HI/ASI	CEN/TC

Looking the different results together, it appears that there is a relationship between the AOI's in which the CEN and HI are given the highest amount of perceptual attention. This indicates a potential hub-and-spoke scanning pattern in which the true center is a combination of the CEN and HI – which is based on total gaze time – but the CEN still receives more perceptual attention as taken from the ratio data. These findings are consistent with the hub-and-spoke from Schnell et al (2004). The center receives more physical attention than the other AOI's do (excluding the HI – based on total gaze time). The Center is also attended to more during trials in which it is critical than the other AOI's (based on Ratio data). A post hoc analysis of total gaze times using the True Center indicated that it was significantly higher than all of the other areas of interest but this was done only for explanatory purposes. The overall lack of significant differences between the VSI and the other AOI's deserves attention as well. The VSI draws enough of the pilots' physical attention (i.e. gaze) to compete with the CEN and HI when separated, but still has a use low enough to be the same as the ASI and TC.

The Average trial data revealed only that pilots took significantly longer to respond to the ASI changes than the ALT or VSI, which is surprising considering that the CEN and HI take up so much of the overall gaze and basing the reaction time by how much time they spent looking directly at the AOI should have produced fairly rapid responses in the regions of the true center.

Had the CEN response time been significantly lower than the other AOI's it would have definitively shown that the CEN receives more perceptual attention. Despite this, the results seem to indicate that the CEN is receiving more perceptual attention, but not to the degree hypothesized.

It is possible that the CEN and HI received so much physical attention according to the Total Gaze data because they are physically larger than the other AOI's. In other words, because these AOI's take up more of the visual field they are more likely to be looked at. This argument is countered by several data found in this study. First, the VSI wasn't significantly different in total gaze time from either the CEN or HI yet takes up far less total space in the display. Furthermore, the ALT and ASI are approximately the same physical size on the display yet the ASI had much less total gaze time than the ALT. The TC also takes up more physical space than the ASI and had no significant difference in total gaze time. So, although certain areas of interest were larger than others, it is unlikely that this contributed to the results.

The fact that no AOI in the display was more likely to elicit change blindness was surprising because it is contrary to both the Theory of Central or Marginal Interest and the Theory of Coherence. According to the Theory of Central or Marginal Interest, the CEN and HI should have elicited higher rates of change blindness in the other areas of the display because they are regarded as more important to straight and level flight (which was the type of flight that pilots were instructed to guide their scan according to), yet did not. Furthermore, according to the Theory of Coherence, the CEN and HI receiving so much physical and perceptual attention should have caused a degradation in coherence of the outlying instruments, yet again did not elicit any higher rates of change blindness. This can be accounted for in one of two ways. Either the task itself was too easy or the display is truly intuitive and elicits an effective scan. The study was constrained to making changes that would be possible during normal flight, so changes may not have been difficult enough to elicit change blindness. However, previous studies have demonstrated the intuitive nature of the display (Schnell et al., 2004; Accetullo, 2004), which suggests that even if the task had been more difficult, pilots still could have detected changes with relative ease.

This study used a part-task rather than a whole-task, meaning that pilots weren't actually flying the aircraft but instead viewing screen captures of the display during flight. During actual flight, pilots use their instruments to create and maintain a mental model of the aircraft in relation to other aircraft and the goals of the flight. Once the mental model is successfully created, the pilot is able to return to the center of the display and focus on flying the plane, only rescanning the instruments occasionally to ensure that their mental model is updated. This would likely produce a higher amount of total gaze time in the Center of the display, however the perceptual effects are yet unknown.

Limitations

There are a few limits of this study. First is the exclusion of data. The trial eliminated had a change in the center of the display, which could have helped to support the main hypothesis. The second limit is the inability to actually demonstrate the hub and spoke pattern, due to issues between the analysis software and the setup of the experiment. The analysis tool is designed to measure the entire data file from the faceLAB software, during which approximately 30% of the time recorded was actual data instead of rest periods between trials.

Another limit of this study is that it utilized a part-task, rather than a whole-task paradigm. It is possible that pilot attention would be different during actual flight as they are using their instruments to maintain level flight. Although this issue was countered by instructing pilots to use the display in the same way that they would during normal flight, there is still the potential that taking examining the use of the display out of context could have affected the data.

No control group was used during the study to see the differences that may be present between pilots with experience and non-pilots. This is a limitation in that pilots,who have extensive training using the display, are expected to utilize the display in a way that matches their training (i.e. the hub-and-spoke). The trained scanning pattern is intended to make use of the display in such a way that optimizes performance. If a control group is able to perform at a level comparable to trained pilots (i.e. that their change blindness scores and reaction times are not significantly different from trained pilots), then the performance on the task can't be attributed to pilot training. Having a control group could have addressed this issue and added support to show the effectiveness of the hub-and-spoke scan.

Conclusions

The data has added support to the hub-and-spoke model proposed by Schnell et al (2004) and trained to pilots by FAA standards. Although replaying eye-tracking data from the trials to demonstrate the hub-and-spoke was not possible, the data evidences that the center of the display dominated the total gaze time and the attention given during trials in which the center was critical. This did not, however, support the hypothesis that paying so much attention to the center of the display would lead to an increase in change blindness in the other areas, once again demonstrating how intuitive and easy to use the display is.

Future research should focus on the use of the display during actual flight, possibly with the addition of new technologies and procedures that are soon to be implemented in commercial aviation. By putting change blindness in context with actual flight it is possible that the scan pattern may be more pronounced, as found by Schnell et al (2004). Also, because new technologies will likely display visual information that requires pilot attention, it would be beneficial to understand how the entire cockpit is utilized as a whole beyond just the primary flight display.

References

Accettullo, E. (2004). Instrument pilot skill acquisition in the early phases of flight training using advanced cockpit display system. Unpublished master's thesis, Embry-Riddle Aeronautical University, Daytona Beach, Florida, United States.

Boyce, P. (2003). The visual system. *Human Factors in Lighting, Second Edition.* (Ch. 2) Boca Raton, FL: CRC Press.

Federal Aviation Administration (2008). *Instrument flying handbook (FAA-H-8083-15A).* United States Department of Transportation, Federal Aviation Administration. Oklahoma City, OK. 2008. 4-II, 24-27.

Fougnie, D. & Marois, R. (2007). Executive working memory load induces inattentional blindness. *Pshychonomic Bulletin & Review.* Feb. 2007. 14, 1. 142-147.

Hollingworth, A., Schrock, G., & Henderson, J. (2001). Change detection in the flicker paradigm: The role of fixation position within the scene. *Memory & Cognition.* 2001. 29 (2), 296-304.

Mitroff, S., Simons, D. & Levin D. (2004). Nothing compares 2 views: Change blindness can occur despite preserved access to the changed information. *Perception & Psychophysics.* 2004, 66 (8), 1268-1281.

Mulder, M., Pleijsant, J., Van der Vaart, h., & Van Wieringen, P. (2000). The effects of pictorial detail on the timing of landing flare: Results of a visual simulation experiment. *International Journal of Aviation Psychology*; July 2000. 10(3), 291-315.

Mumaw R.J., Nikolic M.I., Sarter N.B., & Wickens C.D., (2001). A simulator study of pilots' monitoring strategies and performance in modern glass cockpit aircraft. *Proceedings of the Human Factors and Ergonomics Society... Annual Meeting*; 2001; 1, pg73.

Prinzell, L., Comstock, J., Etherington, T., French, G., Snow, M., Endsley, M., Wickens, C., & Corker, K. (2004). Human factors issues in synthetic vision displays; Government, academic, military and industry perspectives. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting.* 2004.

Prinzell, L., Hughes, M., Arthur, J., Kramer, L., Glaab, L., Bailey, R., Parrish, R., & Uenking, M. (2003). Synthetic vision CFIT experiments for GA and commercial aircraft: "A picture is worth a thousand lives." *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting.* 2003.

Prinzell, L. & Kramer L. (2006). Synthetic vision systems. In *International Encyclopedia of Ergonomics and Human Factors, Second Edition.* (Vol. 1, Ch. 264). Boca Raton, FL: CRC Press.

Ranter, H. (2006). ASN airliner accident statistics. *Aviation Safety Network.* January 1, 2007.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: the need for attention to perceive changes in scenes. *Psychological Science, 8*(5), 368-373.

Rensink, R. A., O'Regan, J. K., & Clark, J.J. (2000). On failure to detect changes in scenes across brief interruptions. *Visual Cognition, 7*, 127-145.

Schnell T., Kwon Y., Merchant S. & Etherington, T. (2004). Improved flight technical performance in fight decks equipped with synthetic vision information system displays. *International Journal of Aviation Psychology*. Feb, 2004. 14:1, 79-102.

Weiner, E. (1989). Human factors of advanced technology ("Glass Cockpit") transport aircraft. *NASA Contractor Report 177528*; June 1989.

Wickens, C. (2005). Attentional tunneling and task management. *NASA Technical Report AHFD-05-23/NASA-05-10.* Dec 2005.

Wickens, C. & McCarley, J. (2008). Attention Control. *Applied Attention Theory*. (pg 21-39) Boca Raton, FL. CRC Press.

Appendix A

Pre-Participation Questionnaire

All information on this form will be completely confidential.

Name ____

Do you currently or have you ever had a history of epilepsy? (Yes/No)__________________

How many flight hours do you currently have? ___________________________________

What pilot certifications do you currently hold (private, commercial, etc)?

____

On the scale below, please indicate how comfortable you are with using ADS-B displays.

1 (Low)   2   3 (Moderate)   4   5 (High)

On the scale below, please indicate your experience with ADS-B displays.

1 (Low)   2   3 (Moderate)   4   5 (High)

Appendix B

Change Blindness in the Primary Flight Display: Eye Tracking Patterns and Attention Allocation

Stephen Mayo
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Human Factors Research Laboratory
ERAU, Daytona Beach, FL 32114-3977

Informed Consent Form

The purpose of this research is to examine the scanning patterns that pilots use with ADS-B displays during a change blindness occurrence which simulates a natural visual disruption. This study will involve viewing two slightly different photos of ADS-B displays in rapid succession, and identifying the difference between the two. There will be a total of 36 trials, each lasting no more than 30 seconds. The research will use an eye tracker to monitor use of the display. Prior to beginning the study the eye tracker will be calibrated to your specific facial and eye features. This will ensure accurate data is recorded. Once the calibration is complete you will be given a non-aviation practice round to familiarize you with the task. Because the study will show images alternating in rapid succession, individuals with a history of epilepsy **should not participate** in this study. Although unlikely, should you experience a seizure, the image flicker will be halted and 911/campus safety will be called immediately. For the experiment, you will be assigned a number so that your responses and actions remain anonymous and your name will not be associated with your data nor published.

Thank you for your participation. If you have any questions please contact Stephen Mayo at mayodcb@gmail.com or Shawn Doherty Ph.D. at doherts@erau.edu .

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed as to the general scientific purposes of the study.

Participant's name (please print): ____

Signature of Participant: _________________________________ Date: ___________

Experimenter: ____ Date: ___________