CONTROL OF EGOSPEED IS BASED ON ATTENDED RATHER THAN GLOBAL OPTICAL FLOW

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Psychology

in the

College of Graduate Studies

University of Idaho

by

Mark T. Meyer

January 2016

Major Professor: Brian Dyre, Ph.D.

Committee Members: Rajal Cohen, Ph.D.; Craig McGowan Ph.D.

Department Administrator: Todd Thorsteinsson, Ph.D.

Authorization to Submit Thesis

This thesis of Mark Meyer, submitted for the degree of Master of Science with a Major in Psychology and titled "Control of Egospeed is Based on Attended Rather than Global Optical Flow," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ______________________________ Date: ___________

Brian P. Dyre, Ph.D.

Committee Members: ______________________________ Date: __________

Rajal G. Cohen, Ph.D.

______________________________ Date: __________

Craig P. McGowan, Ph.D.

Department Administrator: ______________________________ Date: __________

Todd Thorsteinsson, Ph.D.

Abstract

Previous studies examining speed control in simulated flight through a dual planar environment with changes in altitude found *ground dominance:* participants adjusted speed based on the optical flow created by the ground texture below even when explicitly instructed to attend only to the cloud texture above (Adamic, 2011; Wotring, 2008). This thesis sought to determine whether ground dominance of speed control occurred due to an inability of participants to inhibit attention to the ground texture or due to pre-attentional processing of the ground texture, by measuring eye movements as an indicator of attentional locus. The results suggest that ground dominance for participants instructed to attend upward resulted from attentional shifts towards the ground texture. Even though the majority of participants fixated on the instructed plane, there was a significant relationship between the frequency of eye fixations on the ground and the strength of the ground dominance effect. These results suggest the control of egospeed is influenced by attended rather than global optical flow.

Acknowledgements

I would like to thank my major professor Dr. Brian Dyre for the opportunity to work in his lab, and for the many hours of assistance discussing these studies, and reviewing my writing. Additionally I would like to thank my committee members Dr. Rajal Cohen and Dr. Craig McGowan for their valuable input and time. Finally I would like to thank Eric Adamic and Marlena Warner for their assistance with data collection.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Optical flow is the dynamic pattern of light projected onto a moving point of observation by a structured environment (Gibson, 1950; Koenderink, 1986). This information is used in the visual perception of egospeed, or self-motion. As we move through a three-dimensional (3D) environment filled with objects, each of our retinae capture a two-dimensional (2D) perspective projection of optical flow in which objects located close to us project faster angular velocities than objects located further away, a phenomenon known as motion parallax (see Figure 1). Optical flow represents information potentially available to an observer for perceiving and controlling egospeed (Warren, 1982), and a number of studies have examined the influence different aspects of optical flow have on the perception and control of egospeed (e.g., Larish & Flach, 1990; Dyre, 1997, McDevitt, 2000). However, one important issue that has received little attention is whether optical flow is sampled isotropically for perceiving and controlling egospeed. Recent research (Wotring, 2008; Adamic, 2011) has found egospeed to be affected by *ground dominance:* a sampling bias favoring optical flow in the lower half of the visual field of an upright observer. This thesis examined whether the sampling bias resulted from an automatic (non-attentional) visual process or rather the result of attentional selection (Folk, Remington, & Wright, 1994). Following reviews of previous research examining optical flow, egospeed, ground dominance, and attentional selection, this thesis measured eye movements to assess how attentional locus modulates the effects of ground dominance on egospeed control.

Optical Flow, EgoSpeed, and Altitude-Speed Crosstalk

Several aspects of optical flow have been shown to contribute to the perception and control of egospeed, including edge rate, the magnitude of motion parallax, and global optical flow rate (GOFR). Edge (or discontinuity) rate is the number of edges (or discontinuities) that pass a given location in the visual field per unit time. Increases in edge rate created by increased texture density at constant speed have been shown to increase judgments of perceived egospeed (Larish & Flach, 1990; Dyre, 1997), and increasing edge rate has been found to cause drivers to decelerate (Denton, 1980; Dyre, Lew, Meyer, & Abdel-Rahim, 2014). Increases in motion parallax resulting from increasing ranges of object distances at constant speed have been shown to have similar effects (McDevitt, Eggleston, & Dyre, 1999; McDevitt, 2000; Dyre, Cooper, Lew, and Wotring, 2006). However, while both edge rate and motion parallax affect perception and control of egospeed, GOFR has a much larger effect.

Conceptually, GOFR is the mean rate of optical flow sampled across the entire sphere of flow surrounding the observer. Warren (1982) defined a special case of GOFR for movement parallel to a planar surface: the ratio of forward speed to altitude (see Figure 2), which defines GOFR in units of eyeheights (the distance from the eye to the planar surface) per second. Ballard, Roach, and Dyre (1998) generalized this definition for any 3-D environment to be the ratio of forward speed to average object distance, which defines GOFR in units of average-object-distance per second. The relationships between distance, GOFR, and perception of egospeed can be easily observed while flying in a commercial aircraft. During take-off, when the aircraft is close to the ground and other objects in the environment, we perceive higher rates of egospeed than when the aircraft is at a high cruising altitude, far away from the ground and other objects. The decrease in perceived speed parallels the decrease in GOFR as the aircraft gains altitude, and occurs despite the fact that the actual speed of the aircraft has actually increased. Larish & Flach (1990) experimentally confirmed the effect of altitude change on speed judgments. Subsequent studies have also shown that GOFR accounts for a much greater proportion of the variance in speed judgments than edge rate or motion parallax (Ballard, Roach, & Dyre, 1998; Dyre, 1997; McDevitt, 2000).

Flach, Warren, Garness, Kelly, & Stanard (1997) examined the interaction of GOFR with speed and altitude in the context of vehicular control using an altitude control task that instructed participants to maintain constant altitude using a joystick in the presence of a pseudo-random altitude disturbance defined by a sum of sines. On half of the trials a second sum-of-sines speed disturbance caused the simulated aircraft to slow down or speed up. Importantly, each disturbance had a unique set of frequencies and the frequencies of the two disturbances were interleaved such that they covered approximately the same bandwidth of the spectrum. They found evidence of speed-altitude cross-talk: increased amplitude of altitude control input at the speed disturbance frequencies on trials with a speed disturbance compared to trials that did not have a speed disturbance. Participants misperceived the changes in GOFR due to the speed disturbance as resulting from a change in altitude and made altitude control inputs in response to this misperception.

Subsequent studies have utilized a similar experimental technique to identify the opposite effect: altitude-speed cross-talk (Bennett, Flach, McEwen, & Russell, 2006; Wotring, Dyre, & Behre, 2008). These studies modified the experimental task of Flach et al.

in three ways: a) participants controlled speed rather than altitude, b) every trial presented a speed disturbance, and c) half of the trials also included an altitude disturbance. Wotring et al. (2008) found evidence of altitude-speed cross-talk: increased amplitude of speed control input at the altitude disturbance frequencies on trials with an altitude disturbance as compared to trials with no altitude disturbance. Essentially, participants misperceived changes in GOFR due to the altitude disturbance as resulting from changes in speed and made speed control inputs in response to this misperception.

Anisotropic Sampling of Optical Flow: Ground Dominance

To evaluate potential mitigations of altitude-speed (or speed-altitude) cross-talk in flight simulation, Wotring (2008) examined whether cross-talk is reduced when a second parallel planar surface representing a cloud bank was placed above the moving point of observation (see Figure 3). As shown in Figure 4, the addition of a second plane creates a *dual planar environment* (Adamic, 2011), which keeps average object distance constant as altitude changes and produces a direct relationship between egospeed and GOFR that is independent of altitude change. During descent the optical flow rate from the ground texture increases at the same rate that the optical flow rate from the ground texture increases, keeping GOFR constant. If altitude-speed cross-talk occurred due to the changes in GOFR then altitude-speed cross-talk should not occur within a dual planar environment. However, Wotring found adding a second planar surface did not, in and of itself, eliminate or even significantly reduce altitude-speed cross-talk. Participants appeared to be unaffected by the second plane representing the cloud layer above them; their responses revealed they controlled speed based on only the optical flow projected by the ground plane. The biased sampling of the ground surface represented the first empirical evidence of anisotropic sampling of optical flow for egospeed control, which Wotring referred to as *ground dominance*. Ground dominance has been found for other tasks as well, such as binocular rivalry (Ozkan & Braunstein, 2009), and in determining the layout of a 3-D environment (Bian et al, 2006). Seno & Sato (2008) also found ground dominance for vection, the visual illusion of self-motion, to be defined by the world coordinate rather than the body centered coordinates, where the ground was used to judge vection, regardless of body orientation (upright, inverted, sideways).

Subsequently, Dyre, Wotring, Adamic, and Behre (manuscript in preparation) replicated Wotring's observation of anisotropic sampling of optical flow for egospeed control and further demonstrated how phase relations between control inputs and the altitude disturbance can identify the location of optical flow being sampled. They found simulations of flight through a dual planar environment produced control inputs with nearly identical amplitude and phase (control input relative to the altitude disturbance) as flight through an environment consisting of a single ground plane. Further, they found a control-disturbance phase shift of 180 degrees (π radian) for flight through an environment consisting of a single cloud plane located above. A 180 degree phase shift results from the fact that as the point of observation increases in altitude the distance to the cloud surface located above decreases, increasing the projected flow rate of the cloud texture. The opposite occurs when altitude increases during movement over a ground surface located below, increasing the distance from the ground surface results in a slower projected flow rate from the ground texture. The opposing changes in optical flow between the ground and cloud textures results in a mirror-image relationship between control stick movements resulting from altitude changes, which appear as a 180 degree phase shift.

While Wotring (2008) did not identify the exact mechanism underlying anisotropic sampling in egospeed perception of optical flow, he suggested a number of possibilities. First, the textures representing the ground and sky differed in hue and luminance contrast, which have been shown to affect perceived egospeed (Dougherty et al., 1999; Stone & Thompson, 1992). Wotring speculated lower luminance contrast might lead to lower sampling of the cloud plane. However, Meyer, Adamic, and Dyre (2013) have subsequently refuted the color contrast hypothesis by reversing the hue and contrast assignments, putting the ground texture above and the cloud texture below, and found the same pattern of anisotropic oversampling of the surface below. A second possibility suggested the visual system is insensitive to optical flow in the upper visual field for controlling egospeed. However, Dyre et al. (manuscript in preparation) refuted the upper-visual-field-insensitivity hypothesis when they found altitude-speed cross-talk with a stimulus consisting of only the cloud plane located above the point of observation. A third explanation offered for anisotropic sampling proposed the visual system is unable to integrate flow across surfaces for determining egospeed and naturally favors attentional selection of the ground surface. Meyer, Adamic, and Dyre (2013) tested the hypothesis by examining speed control with a dual planar environment rotated 90 degrees so that the experiment simulated flight between two walls. They found no evidence of altitude-speed (technically, lateral movement-speed) crosstalk in a rotated dual planar environment, rather control responses appeared to be based on the GOFR integrated across both planes. Taken together, these results suggest when a ground surface is present in the environment, egospeed control is based on anisotropic sampling of optical flow that favors or prioritizes the ground surface; but when the ground surface is undefined, other surfaces afford effective egospeed control.

One important question remains unanswered: is anisotropic sampling of the ground surface (ground dominance) due to a non-attentional (automatic) process or a process of attentional selection? Adamic and his colleagues (Adamic et al., 2010; Adamic, 2011) attempted to answer this question in a series of studies that replicated Wotring (2008) and introduced manipulations of visual attention. Adamic et al. (2010) first attempted to manipulate attention exogenously by adding a secondary task in which participants judged whether or not an oncoming aircraft—located either above or below the horizon—would collide with them as they performed the speed control task. However, Adamic found identical patterns of control amplitudes and phases as Wotring (2008), which could result from either an ineffective manipulation of attention or a non-attentional basis for ground-dominance. To attempt to resolve between these possibilities, Adamic (2011) developed a stronger manipulation of attention: explicitly instructing participants to attend to only the ground or only the clouds, and to ignore the other plane while controlling speed (Figure 5). Adamic found participants instructed to attend to the cloud texture in a dual planar environment did not display altitude-speed cross-talk; the altitude disturbance did not result in inappropriate speed control, as evidenced by no reliable difference in control amplitudes and zero phase lag at the altitude disturbance frequencies (See the right panel labeled "DPE up" in Figure 6 for the amplitude data from Adamic, 2011). Participants instructed to attend to the ground texture of a dual planar environment demonstrated the typical pattern of altitude-speed cross-talk: significant increases in control amplitudes and non-zero phase lags at the altitude disturbance frequencies (left-panel of Figure 6). The elimination of altitude-speed cross-talk and zero phase lag for participants instructed to attend upward suggested participants used GOFR to control egospeed, optical flow from both the cloud and ground textures. Adamic concluded ground dominance caused participants instructed to attend up to also take into account optical flow of the ground surface below, while participants instructed to attend down ignored the cloud surface above them.

However, because Adamic (2011) did not measure attentional locus, it is unclear whether reduced altitude-speed crosstalk for participants instructed to attend up resulted from the ground being processed non-attentively or participants simply being unable to ignore the ground and dividing their attention between both planar surfaces. Attention has been shown to affect motion perception; increasing the motion aftereffect (Chaudhuri, 1990), and improving the ability to discriminate the direction of movement in transparent motion processing (Felisberti & Zanker, 2005).

A study by Ernst, Palmer, & Boynton (2012) demonstrated the difficulty in attempting to sample a single source for speed control when attention is shared between multiple speed sources. Ernst et al. (2012) investigated the effects of sharing attention between two separately-colored dots which moved in separate directions (up/down). There were three attention conditions with participants instructed to attend to only the speed of one set of dots, the luminance of one set, or a dual task where participants attended to the luminance of one color of dots, and to the speed of the other set of dots. They found participants did not appropriately share attention between two transparent motion surfaces, with decreased performance in the dual task condition. The inability to adequately share attention between both sets of dots resulted in cross-talk when judging changes in luminance and speed, due to attention being shared between both sets of dots. The speed of both sets of dots affected the decision, even though participants were instructed to look for changes in speed for one set of dots, and change in luminance for the other set of dots.

Ernst's findings relate to the experiments of this thesis concerned with ground dominance of speed control, because participants are hypothesized to shift attention towards the ground texture in the attend-up condition because the ground draws our attention. Therefore when participants momentarily shift attention towards the ground texture, the optical flow from the ground texture affects speed control, and causes a reduction in altitude-speed cross-talk.

To determine whether the anisotropic sampling of optical flow and ground dominance found by Adamic (2011) resulted from a non-attentional or attentional process requires we monitor whether participants are indeed able to obey the instructions and maintain attention upward in the attend-up condition. The two experiments presented here specifically address the participant's ability to maintain their attention on the instructed plane. These experiments replicated the speed control task from Adamic's (2011) studies but also monitored attentional locus by measuring eye movements using an eye tracker. A number of studies have shown attentional locus is typically coincident with eye fixation location (e.g., see Duc et al., 2008; Shepherd et al., 1986). Thus eye movements are a reliable indicator of a shift of attention from one point to another.

Previous studies hypothesized participants shifting attention towards the ground texture reduced or eliminated altitude-speed cross-talk in the attend-up condition. If participants tasked to attend up demonstrate a lack of altitude-speed crosstalk while simultaneously maintaining their eye fixations (and locus of attention) upward, anisotropic sampling of optical flow from the ground surface would occur due to a non-attentional process. Optical flow from the ground texture affects egospeed control even when eye fixations and attention occurred only on the cloud texture. If, on the other hand, participants in the attend-up condition are unable to maintain fixations and attentional focus on the cloud surface above and “sneak peeks” toward the ground surface, then anisotropic sampling of optical flow would result from attentional selection, that attended optical flow is the basis of egospeed control.

The two experiments contained the same stimuli and operations except participants in Experiment 1 received explicit directions that informed them the eye tracker measured eye movements, while participants in Experiment 2 received deceptive instructions that stated the eye tracking device measured mental workload. Experiment 2 sought to determine if the pattern of eye movements changes when observing participants in a more natural environment, and better controlling for subject reactivity (the *Hawthorne Effect*; Landsberger, 1958): participants changing their behavior due to knowledge of being monitored. Subsequent analysis of eye movement data showed the pattern of eye movements for the two experiments were essentially the same. Thus the two experiments were combined into a single analysis.

Chapter 2: Experimental Method

The two experiments of this thesis used identical methods with one exception: the instructions regarding the purpose of the head-worn eye-tracker differed. The instructions for Experiment 2 used deception to reduce participant suspicions the eye tracker monitored eye movements. Thus the general method is described here, and it can be assumed the methods used for Experiments 1 and 2 were identical except where specifically noted.

Participants

Experiment 1 tested 31 students from the University of Idaho. Data from three participants were excluded due to extended periods of control inactivity[1] leaving full data sets for 28 participants. Experiment 2 tested 22 students from the University of Idaho. Data from six participants were excluded due to prolonged periods of inactivity leaving full data sets for 16 participants. All participants received class credit for their participation in the experiment, and passed a Snellen visual acuity test for a minimum of 20/30 visual acuity. Participants were randomly assigned to the between-subjects conditions, frequency assignment and attention.

Stimuli & Apparatus

The stimuli and apparatus for Experiments 1 and 2 were identical. The software package ViEWER rendered the simulations of low altitude flight used in this thesis (Dyre, Grimes, & Lew, 2007). The dual planar environment consisted of a ground and cloud texture with a width of 16,000 m, and a length of 83,000 m (Adamic et al., 2010; Adamic, 2011; Wotring, 2008). The ground and cloud textures used a 256 x 256 pixel pseudo random swirling pattern repeated 35 times across the plane with different shades of blue and white for the cloud texture, and different shades of green for the ground texture.

Participants viewed the display on a 60 inch rear projection screen with a resolution of 1280 x 1024, and a 60 Hz refresh rate. Participants sat 1.625 m away from the display, to produce a viewing angle of 45° x 32.75° (Horizontal x Vertical). To control speed during flight, participants used a CH F-16 Combat Stick, with first-order control and exponential lag with a time constant of 100 ms. The joystick recorded data at a rate of 20 Hz, with a gain of ± 200 meters per second when pushed all the way forward or pulled all the way backward. The joystick only affected speed, and did not affect horizontal or vertical position within the environment.

Sums of five sine waves interleaved at non-harmonically related frequencies created the simulated wind disturbances (Adamic et al., 2010; Adamic, 2011; Wotring, 2008). These frequencies made up the altitude or speed disturbances that occurred throughout each trial. The particular frequencies in each set minimized the digital artifacts of discrete Fourier transforms (DFTs) causing spectral leakage between the frequency sets. The degree of spectral leakage for our frequency sets can be visualized in Figure 7, which shows the normalized power spectra estimated by a Fast Fourier Transform of each disturbance digitally sampled over the trial duration at 20 Hz (the same as our data sampling rate). Note the presence of clear peaks in the power spectrum of each disturbance at the defined frequencies, and lower power – due to some spectral leakage– at the other disturbance’s frequencies. Because both disturbances create peaks at their defined frequencies that clearly exceed the spectral leakage from the other disturbance we do not expect spectral leakage due to digital sampling artifacts to significantly affect the data analysis.

The frequencies chosen also avoided the frequency band between 0.2 and 0.3 Hz, which has a higher probability of causing motion sickness (Reason & Brandt, 1975). The altitude and speed disturbances each were assigned a set of frequencies (Table 1). Frequency assignment S<A received Set 2 for the altitude disturbance, and Set 1 for the speed disturbance, while frequency assignment A<S contained Set 1 for the altitude disturbance, and Set 2 for the speed disturbance. The neighboring frequencies within each set were close enough to allow comparison between five ordinal channels of frequency, with one being the lowest frequency value of each set. Using ordinal values allowed us to treat frequency as a categorical quasi-independent variable in an analysis of variance (ANOVA) on the data, and test the effects of the speed and altitude disturbances across frequencies.

To measure eye movements, participants wore an ASL 5000 head mounted eye tracker, which recorded horizontal and vertical gaze position of the left eye at 60 Hz, to a spatial accuracy of approximately one degree. To calibrate the eye tracker, participants' pupil location and corneal reflection were measured as they looked through a set of nine target points. Successful calibration of the eye tracker occurred when a crosshair, representing the gaze location, fell within a 1-deg diameter circle that surrounded each of the nine target points. If the crosshairs resided outside of that circle, we recalibrated the eye tracker until an acceptable calibration was found. Typically, recalibration only occurred once or twice during the experiment, mostly due to participants attempting to adjust the eye tracker themselves to relieve discomfort.

Procedure

The procedures used in Experiments 1 and 2 were identical, except for the instructions given to participants. Prior to the start of the study, participants signed a consent form (Experiment 1: Appendix A; Experiment 2: Appendix B), and completed a Snellen visual acuity test that screened for a minimum 20/30 visual acuity. Next, we read the instructions to the participant, explaining their task was to maintain constant speed throughout the duration of each trial while simulated wind disturbances slowed down and sped up their plane (Appendix C; Appendix D). After we read the instructions to the participant, we placed the eye tracker on the participant's head and the eye tracker was calibrated using a set of nine target points. We examined the calibration between each trial to ensure the validity of the data being collected throughout the duration of the experiment. If the calibration appeared to be off, participants went through the calibration process again before proceeding to the next trial. Participants in Experiment 1 were aware that the purpose of the eye tracker was to monitor eye movements during each trial.

Participants in Experiment 2 received deceptive instructions that aimed to reduce subject reactivity by deceiving participants as to the purpose of the eye tracker. We stated the eye tracker measured pupillometry, which can be used to assess mental workload throughout the duration of each trial. The participant had each step of the eye tracker calibration process explained to them with regards to pupillometry to enhance the deception (Appendix E). To initially calibrate the eye tracker, we told participants pupil diameter must be measured from multiple angles to obtain an accurate measure of the pupil, hence the reason the participants had to look through the nine target points on the screen. After the initial calibration participants glanced through the target points on the screen once more to ensure the eye tracker had a good track of the participants' eye. We stated the reason for glancing through the nine points another time ensured we maintained a clear view of the pupil at all times when participants glanced across the entire display. Once calibration was completed, the participant began the experiment.

At the beginning of each 220-second trial, a five-second preview period denoted the speed the participant should maintain throughout each trial. Participants controlled their speed using only the visual information from the ground and cloud textures. During the preview period, the simulated eye point moved at a speed of 185.2 meters per second at an altitude of 92.6 meters, resulting in a GOFR of 2.0 eyeheights s^{-1}. During this time either the ground texture or cloud texture, depending on the assigned attention condition, had a flashing black border around it with text that stated "Attend the Clouds, Ignore the Ground" or "Attend the Ground, Ignore the Clouds." After the preview period ended, the black border and text disappeared, and participants now controlled speed using the joystick. For the remainder of the trial they had to try and maintain the speed shown during the preview period. Over the next five seconds, the amplitudes of the altitude and speed disturbances linearly increased to their maximum, and remained there for the duration of the trial. Throughout all trials, simulated wind disturbances sped up or slowed down the simulated aircraft, and on half of the trials the simulated wind disturbances also resulted in a change in altitude. Therefore, the task required careful control of the joystick to counter the wind disturbance and accurately maintain the speed shown in the preview period.

Participants completed four blocks of two trials, consisting of one trial with the altitude disturbance present, and one with the altitude disturbance absent. We randomized the order of trials within each block. To account for possible practice or learning effects, the analysis only used the last two blocks of trials. Participants had the opportunity to take a short break at the end of each block to rest and take the eye tracker off. In addition, all participants stopped for a mandatory break halfway through the experiment, after the second block of trials. In Experiment 2, participants rated the perceived difficulty of each trial using a five point Likert scale with choices ranging between very low and very high. Upon completion of the final trial, participants answered a series of debriefing questions (Experiment 1: Appendix F and Appendix G; Experiment 2: Appendix H and Appendix I).

Design

Both experiments used identical experimental designs: a 2 x 2 x 2 x 5 mixed factorial design with between-subject factors of frequency assignment (S<A vs. A<S) and attention (Up vs. Down), and within-subject factors of altitude disturbance (present vs. absent), and frequency component (1-5). To determine whether changes in altitude were misinterpreted as changes in speed, trials with an altitude disturbance were compared to trials without the altitude change. Manipulating attention allowed us to examine how attentional allocation affects the ground dominance effect. Frequency assignment and frequency component are not directly related to the hypotheses of the experiment. However, by keeping the variables in the experiment we increase power, due to segregating out the potential variance due to frequency by reducing the error term.

Chapter 3: Instructional Manipulation Check

To determine if the deceptive instructions altered the pattern of eye movements between the two experiments, we compared the eye movement data between Experiments 1 and 2. Assuming the presence of the eye tracker caused reactivity in Experiment 1, the deceptive instructions, aimed to reduce reactivity, should cause the pattern of eye movements in Experiment 2 to differ from Experiment 1. A reduction in reactivity would be displayed by increased dwell time and a higher frequency of fixations towards the non-instructed plane. However, if we observe no difference in the pattern of eye movements between the two experiments, either our assumption of reactivity in Experiment 1 was invalid, or the deception failed to affect participant behavior in allocating attention.

Data Reduction

To analyze eye movements, I used the software package *Eyenal* from Applied Science Laboratories to calculate dwell times and fixation locations across the display. Eyenal defines a fixation as maintaining gaze within 1-degree of visual angle, for a minimum of 100 milliseconds. The simulated environment consisted of three areas of interest (AOIs): a) the cloud texture, b) the ground texture, and c) the thin band between the two textures surrounding the horizon (Figure 8). Categorizing fixations into AOI's allowed us to determine how often participants fixated on each planar surface and the duration of the fixations.

Results

Figures 9 and 10 show fixation sequences superimposed over a screenshot of the simulated flight environment for the attend-down and attend-up conditions for Experiment

1, respectively. Figures 11 and 12 display the same fixation sequences for the attend-up and attend-down conditions for Experiment 2, respectively. As can be seen in the figures, participants primarily fixated on the instructed plane in both the attend-up and attend-down conditions with few fixations on the non-instructed plane or horizon (see Table 2). Participants instructed to attend up in Experiment 1 had 98.4% of their fixations on the instructed plane, compared to only 1.2% on the non-instructed plane. Experiment 2 found participants had 97.3% of their fixations on the instructed plane, and 1.6% of their fixations on the non-instructed plane. Participants instructed to attend down in Experiment 1 had 97.5% of their fixations on the instructed plane, compared to only 1.1% on the non-instructed plane. Experiment 2 found participants had 97.9% of their fixations on the instructed plane, and only 0.8% of their fixations on the non-instructed plane. The horizon, considered neutral in the analysis, contained the majority of the remaining fixations with a small number of fixations located off the display.

As you would expect the pattern of dwell time closely followed the pattern of fixations across each AOI. Examination of dwell time across the three AOIs revealed participants spent the majority of their dwell time on the instructed plane, and only a small amount of dwell time on the non-instructed plane (see Table 3). Participants instructed to attend up in Experiment 1 spent 99.01% (217.8 seconds out of a 220 second trial) of their dwell time on the instructed plane, and only 0.73% of their dwell time on the non-instructed plane. In Experiment 2 participants had 98.40% (216.5 seconds) of their dwell time on the instructed plane, and 0.99% of dwell time on the non-instructed plane. This led to an average dwell time per trial on the non-instructed plane in Experiment 1 of only 1.4 seconds and 1.6 seconds for Experiment 1 and 2, respectively. In the attend-down condition for

Experiment 1, 97.57% (214.7 seconds) of dwell time was on the instructed plane, and only 0.93% of dwell time was on the non-instructed plane. Experiment 2 had 97.54% (214.6 seconds) of dwell time on the instructed plane, and only 0.61% of dwell time was on the non-instructed plane. The average dwell time per trial on the non-instructed plane was approximately the same between Experiments 1 and 2, 1.6 and 1.8 seconds respectively. An independent samples t-test found no significant difference in dwell time on the non-instructed plane between both attention conditions in Experiment 1, t(25) = 0.339, p = .738, and Experiment 2, t(14) = 0.545, p = .594, respectively. The surface participants were instructed to use had no effect on the percentage of dwell time on the non-instructed plane.

Discussion

I hypothesized using deceptive instructions would affect participants' pattern of eye movements. However the analysis of the eye tracking data from Experiments 1 and 2 found no difference in the frequency of fixations and dwell time on the non-instructed plane between the two experiments. Participants in both experiments had very few fixations on the non-instructed plane, with the vast majority of their fixations on the instructed plane for both the attend-up and attend-down conditions.

Contrary to our a priori expectation, the deceptive instructions used in Experiment 2 had no effect on eye movement behavior compared to Experiment 1. This result indicates either the eye tracker did not produce significant reactivity, the eye tracker did not produce reactivity that affected eye movements, or the deceptive instructions did not actually deceive participants as to the purpose of the eye tracker. Consistent with the latter hypothesis, 9 out of the 16 participants that received deceptive instructions reported in post-experiment debriefings they believed the eye tracker measured eye movements. These debriefing responses suggest that the deceptive instructions did not have an effect as originally intended, possibly because there was no reactivity in the first place, participants were not affected by the presence of the eye tracker, or participants saw through the deceptive instructions and knew we were measuring eye movements.

Because both experiments used identical methods except for the instructions, which had no effect on the patterns of eye movements, we analyzed the speed control data from Experiments 1 and 2 together to increase the sample size and therefore power of our analysis.

Chapter 4: Analysis of Both Experiments Combined

Here we discuss the results of the speed control and eye movement analyses of data for both experiments combined. We treated the speed control data and eye movement data in the same manner as described in Chapter 3. In the next section we describe the methods used to analyze the speed control task.

Speed Control Data Reduction

We assessed speed control performance by transforming the time series of the joystick input for a given trial into its frequency spectra, which allowed us to compare joystick amplitudes at the different disturbance frequencies. If participants misinterpreted changes in altitude as changes in speed, then trials with an altitude disturbance present should have higher joystick amplitudes at the altitude disturbance frequencies. If these higher amplitudes induced by the altitude disturbance occur at the altitude disturbance frequencies only and not the speed disturbance frequencies, this indicates altitude-speed cross-talk. If, on the other hand, the altitude disturbance increases joystick amplitudes across both the altitude and speed disturbance frequencies equally, then the altitude disturbance is simply causing more joystick activity in general, not altitude-speed cross-talk.

To compare frequency across groups, we transformed the disturbance frequencies into an ordered set labeled 1-5, with one being the lowest frequency and five the highest (Adamic, 2011; Wotring, 2008). The joystick amplitudes were computed by taking the vector sum of the three frequency bins closest to each frequency (Adamic, 2011). Because we interleaved the frequencies of the disturbances, the transform produced an ordered set of five component altitude and phases for each frequency. The transformation allowed us to define a quasi-independent variable of frequency component in the analysis. Similar to Wotring (2008) and Adamic (2011), we log transformed (base 10) the joystick amplitudes to account for large differences in variance across conditions that would violate the homogeneity of variance assumption of the ANOVA.

The spectral analysis of joystick movements also allowed us to examine phase lags between joystick movements and the altitude and speed disturbances. Altitude disturbance phase lags are particularly important to our hypotheses because they indicate the direction of participants' joystick inputs for controlling speed in response to the altitude disturbance. The direction of joystick movement allows us to infer which planar surface participants sampled to control speed. A 180° difference in phase occurs between participants who sampled the ground texture compared to those who sampled the cloud texture. To better understand the 180 degree difference in phase, consider that when altitude increases, the ground plane moves farther away and the cloud plane moves closer, decreasing the optical flow rate projected by the ground plane and increasing the optical flow rate projected by the cloud plane. If participants sampled only optical flow from the ground plane to control speed, they would perceive this decrease in optical flow rate as a deceleration and respond by pushing the joystick forward to speed back up to the preview speed. However, if during ascent participants sampled only the optical flow from the cloud plane, they would perceive the increase in optical flow rate as an acceleration and respond by pulling back on the joystick to slow down. Another possibility is optical flow from both the ground and cloud textures is used, in which case increases in optical flow rate from the cloud surface would be countered by decreases in optical flow rate from the ground surface producing no overall increase in optical flow rate, and no consistent phase lag at the altitude disturbance frequencies. When averaged across experimental conditions and participants, these inconsistent lags would average to zero. Such a result would indicate participants did not exclusively use the optical flow from the instructed plane to control speed, but used optical flow from both the ground and cloud textures to control speed.

The analysis consisted of four mixed factorial ANOVAs, two for the joystick amplitudes and phase lags at the speed disturbance frequencies, and two for the joystick amplitudes and phase lags at the altitude disturbance frequencies. The separate analyses for the speed and altitude frequencies determined if participants only responded to the speed disturbance, or if they also responded to the altitude disturbance, misinterpreting the change in altitude as a change in speed. We examined the relationship between eye movements and speed control by correlating the percentage of fixations on the instructed plane with the amount of altitude-speed cross-talk. The correlation examined how eye movements off the instructed plane affected speed control, and determined if ground dominance resulted from a shift of attention or resulted from non-attentional processing.

Results

We analyzed the 44 individual data sets from the two experiments, treating the two experiments as a single experiment. All significant main effects and interactions found from the ANOVA at the altitude and speed disturbance frequencies can be seen in Table 4. and Table *5*.

Evidence For Attentional Modulation of Altitude-Speed Cross-Talk. The analysis of joystick amplitude at the altitude disturbance frequencies found significant main effects of altitude disturbance and attentional locus as well as a significant interaction between altitude disturbance and attentional locus (see Table 4). The amount of altitude-speed cross-talk at the altitude disturbance frequencies depended upon where attention was allocated. When the altitude disturbance was present, the attend-down condition exhibited significant increases in joystick amplitude, while the attend-up condition produced a smaller increase in joystick amplitude. The main effect of altitude disturbance showed higher joystick amplitudes when the altitude disturbance was present as compared to when the disturbance was absent (Figure 13). Participants inappropriately responded to changes in altitude as if they were a change in speed. A main effect of attention occurred due to higher overall joystick amplitudes in the attend-down condition, compared to the attend-up condition.

The analysis of joystick amplitude at the speed disturbance frequencies found no main effect of the presence or absence of the altitude disturbance (p>.05; see Figure 14). There was no effect of speed disturbance with the other variables. The lack of an effect on the altitude disturbance at the speed disturbance frequencies, taken together with the increase in joystick amplitude at the altitude disturbance frequencies indicates participants responded to the altitude disturbance as if it were a change in speed. Observing no difference in joystick amplitude at the speed disturbance frequencies was the key result from the analysis of the speed disturbance frequencies, and indicated the presence of altitude-speed cross-talk.

Phase lag analysis at the altitude disturbance frequencies found significant main effects of attention and frequency component (see Figure 15). The main effect of attention occurred because the phase lag for the attend-up condition did not significantly differ from zero, and the attention down condition had a strong negative phase lag. Because phase lag indicates the direction of participants' joystick inputs for controlling speed in response to the altitude disturbance, we can infer which planar surface participants used to control speed. These results indicate participants attending down referenced the optical flow from the ground texture to control speed, while participants attending up sampled the optical flow from both the cloud and ground textures.

The phase lag analysis also found a significant interaction between frequency assignment and attention, which resulted from weaker, or more zero phase lags for frequency assignment S<A compared to A<S. Based on previous results of Adamic (2011) that did not find an effect of frequency assignment, we did not expect to observe different patterns of data between the two frequency assignment groups. Even though we randomly assigned participants to the frequency assignment group, these results suggest the groups were not balanced with participants on how often they attend to the non-instructed plane, which may have caused individual differences to be correlated with frequency assignment, a topic we turn to next.

Relationship Between Attentional Allocation and Altitude-Speed Cross-Talk. To examine individual differences and how they relate to altitude-speed cross-talk, we examined the fixation sequences across the three AOIs. The fixation sequences for the attend-down (see Figure 16) and attend-up condition (see Figure 17) revealed similar percentages of fixations on the non-instructed plane. Participants attending up had 98.0% of their fixations on the clouds, and only 1.4% of fixations on the ground. Participants in the attend-down condition had 97.6% of their fixations on the ground and only 1% of fixations on the ground. Analyzing dwell time on the non-instructed plane found participants spent 0.8% of their fixation time (1.5 seconds per trial) attending to the ground in the attend-up condition, and participants in the attend-down condition spent 0.8% of their fixation time (1.6 seconds per trial) attending to the clouds. In sum, participants spent the majority of their time attending to the instructed plane and spent similar amounts of time attending to the non-instructed plane in both attention conditions.

Because the analyses of fixations and dwell time were averaged across all participants of a group it could cause individual differences to be masked. Therefore I used a correlational analysis to examine the relationship between the difference in joystick amplitude when the altitude disturbance was present compared to when the altitude disturbance was absent, to the percentage of fixations on the correct plane. This analysis examined the data in more detail, on a participant by participant basis, in an attempt to determine how fixating on the non-instructed plane affected participant's speed control. This analysis sought to determine if participants who maintained their eye fixations on the instructed plane had larger differences in joystick amplitude than those who had more fixations on the non-instructed plane. It is important to remember if participants attended to the optical flow from a single planar surface, they should show altitude-speed cross talk, or increased joystick amplitude at the altitude disturbance frequencies for trials with the altitude disturbance present compared to when the disturbance is absent. If participants used the global optical flow from both surfaces, changes in altitude do not change GOFR and therefore should not affect the control of speed if it is based on GOFR. Therefore participants who make eye movements towards the non-instructed plane may have reduced differences in joystick amplitudes compared to those who predominantly fixate on the instructed plane.

Using a Spearman correlation, the overall correlation between difference in joystick amplitude and percentage of eye fixations on the correct plane was 0.226, p = .128. The attend-down condition had a correlation of -0.066, p = .376, while the attend-up condition had a significant correlation of 0.575, p = .006 (see Figure 18). The attend-up condition contained the only significant correlation from this analysis, which had a strong positive correlation. The results from the attend-up condition indicated decreased fixations on the ground texture resulted in a larger difference in joystick amplitude, while increased fixations on the ground texture resulted in a reduction in altitude-speed cross-talk. Therefore this analysis indicated participants who had larger differences in joystick amplitude also exhibited a higher percentage of eye fixations on the instructed plane. Participants who did not make eye movements towards the non-instructed plane and sampled the optical flow from the instructed plane only, produced altitude-speed cross-talk.

To assess the effect the fixations on the non-instructed plane had on speed control, we used Spearman correlations to test the relationship between the percentage of fixations on the instructed plane and the average phase lag across the five frequencies for both attention conditions. The attend-down condition had a correlation of -.113, and the attend-up condition had a correlation of -.195. However these correlations were not found to be statistically significant (p>0.05).

Discussion

Taking the speed control data in combination with the eye tracking data, ground dominance of speed control resulted from momentary eye movements towards the ground surface. The speed control data found the elimination of cross-talk in the attend-up condition for the log joystick amplitude analysis at the altitude disturbance frequencies, and the phase lag analysis displayed a zero phase lag. Additionally the eye tracking data revealed that participants primarily attended to the instructed plane, with few eye fixations on the non-instructed plane.

Given that eye movements indicate attentional locus, the most important conclusion resulted from the correlational analysis, which found a significant relationship between the percentage of eye fixations on the instructed plane, and the amount of altitude-speed cross-talk for participants in the attend-up condition. Participants who maintained fixation on the cloud texture appeared not to use optical flow from the ground texture, and exhibited altitude-speed cross-talk. The more participants fixated on the ground texture the more they integrated the flow from the ground and cloud textures together, reducing the amount of altitude-speed cross-talk. The ground texture did not reduce the amount of altitude-speed cross-talk unless participants made eye movements towards the ground texture. This result suggests that ground dominance results from an attentional shift rather than the result of pre-attentional processing. This conclusion was supported further by participant responses during debriefing. Many participants in the attend-up condition stated the difficulty in ignoring the ground texture during the task, whereas no participants in the attend-down condition mentioned any difficulty in ignoring the cloud texture. This difference in the difficulty of following our attentional instructions suggests that the ground texture may have been drawing attention in the attend-up condition, and participants had to make a concerted effort not to look at the ground texture, whereas the cloud texture did not affect participants in the attend-down condition.

An interesting result was observing a significant correlation for only the attend-up condition, and not the attend-down condition despite the fact both attentional conditions had similar amounts of fixations on the non-instructed plane. When participants in the attend-down condition looked up at the cloud texture, the optical flow from the clouds did not affect speed control as it did in the attend-up condition when participants looked down at the ground texture. This suggests optical flow from the ground is processed differently than optical flow from other sources such as the cloud surface used in these experiments.

Chapter 5: Differences in Eye Movements Between Attentional Conditions

Rationale

Despite equivalent fixation frequency and gaze duration on the non-instructed plane between the attend-up and attend-down conditions, the attend-up group displayed a significant decrease in altitude-speed crosstalk as compared to the attend-down group. These results indicated sampling of optical flow from the non-instructed plane influenced speed control in the attend-up condition but not in the attend-down condition. The greater influence of the non-instructed plane in the attend-up condition could be a result of different factors other than fixation frequency or gaze duration on the non-instructed plane. The eye movement patterns could differ on the attended plane between the attention conditions. To further investigate eye movement behavior between the two attention conditions, additional post hoc analyses examined fixation dispersion across the display and fixation duration.

Dispersion of Fixations

Examination of the figure plots for eye fixations suggest the dispersion of fixations may have differed between the attention conditions (Figure 16; Figure 17). From the figures, it appears the attend-up condition had greater lateral dispersion compared to the attend-down condition. To determine if participants look up the same way they look down, we analyzed the distribution of eye movements, and compared the standard deviation of the lateral (x) and vertical (y) distribution of fixations across the display between the two attention conditions. An independent samples t-test examined the standard deviation of the lateral distribution of fixations and found a significant difference between the two attention conditions, t(42) = -2.840, p = .007. A similar analysis compared the standard deviation of the vertical distribution of fixations between the two attention conditions, and found a significant effect as well, t(42) = -2.192, p = .034. The dispersion of fixations significantly differed in both their horizontal and vertical positions in the attend-up condition, compared to the attend-down condition. The mean standard deviation of vertical position for the attend-up condition was 2.79, compared to 2.21 for the attend-down condition. The mean standard deviation of lateral position for the attend-up condition was 5.60, compared to a mean standard deviation of 3.16 for the attend-down condition. Higher amounts of dispersion indicated participants in the attend-up condition shifted attention across the cloud texture significantly more than participants in the attend-down condition shifted attention across the ground texture.

During debriefing participants were specifically asked to describe their strategy in terms of attentional allocation: Where did you focus most of your attention? Did you focus on the whole display or did you look further ahead, to the sides or at the bottom of the display? A review of the debriefing forms found only 6 of 22 participants in the attend-up condition focused on the center or middle of the cloud texture to perceive speed, whereas 13 of 22 participants in the attend-down condition focused on the center of the ground texture. Of the remaining nine participants in the attend-down condition, four participants said they focused on the sides, one participant focused near the horizon, and four participants had no consistent strategy, and used the entire ground texture. Many participants were accurately aware of their eye movement strategy. Thus there was not a common pattern to where participants in the attend-up condition focused their attention, whereas participants in the attend-down condition demonstrated a pattern of primarily focusing on the middle of the ground texture.

As observed from the debriefing forms, differences in the dispersion of fixations are likely due to the attentional allocation strategy used by the participant. One hypothesis on a potential attentional strategy is that participants fixate on a point and follow it as it flows towards the edge of the screen. At some point (edge of screen, or eyes move certain distance) the participant stops fixating on the first point, and makes an eye movement towards the middle of the screen to select a new point to fixate on. This behavior is repeated throughout the duration of the trial resulting in longer fixation durations. However, an alternate hypothesis is that participants use a scattered strategy, with fixations all over the screen, resulting in shorter fixation durations. To determine how the dispersion is accounted for, I examined fixation duration between the two attention conditions.

Fixation Duration

For the fixation duration analysis I examined the average fixation duration to determine if participants used different attentional allocation strategies between the two attention conditions. This analysis sought to determine if participants in the two attention conditions used different attentional strategies, resulting in altitude-speed cross-talk in the attend-up condition but not the attend-down condition. A t-test on the geometric mean of fixation duration between the two attention conditions found no significant difference between the two attention conditions, t (42) = 0.323, p = .749. The attend-up condition had geometric mean[2] fixation duration of 0.54 seconds, while the attend-down condition had a geometric mean of 0.56 seconds.

Participants in the attend-up condition began fixations all over the display, and still had similar fixation durations to participants in the attend-down condition. Since both attention conditions used similar strategies, the presence of altitude-speed cross-talk in the attend-up condition but not the attend-down condition did not occur as a result of different attentional strategies. Even though participants have similar mean fixation durations, additional information is needed to determine the attentional strategy used by participants. To determine how dispersion affected fixation duration, I correlated fixation duration with the standard deviation of lateral dispersion.

Lateral Dispersion Correlational Analyses

To observe if the dispersion of fixations increased due to overall longer fixations, using a Spearman correlation we correlated the standard deviation of the lateral dispersion of fixations with the geometric mean of fixation duration. This analysis observed a significant overall correlation of -0.394 (p= 0.011), and a significant correlation in the attend-down condition,-0.428 (p= 0.047). The attend-up condition had a correlation of -0.330. (p= 0.117). These correlations indicated higher standard deviations of lateral dispersion resulted in lower geometric means of fixation duration. However the main objective of this analysis focused on the method participants in the attend-up condition used to perceive speed, but the lack of significant results in the attend-up condition refuted the original hypothesis that increased dispersion of fixations in the attend-up condition resulted from longer fixation durations. Therefore participants did not use the hypothesized method of perceiving speed. This indicated the dispersion of fixations in the attend-up condition resulted from participants using a scattered strategy, fixating all across the cloud texture to perceive speed, instead of fixating on a single point, and following it to the edge of the screen.

Additional Spearman correlational analyses examined the effect of lateral dispersion on the amount of altitude-speed cross-talk by correlating the standard deviation of lateral position with the difference in joystick amplitude when the altitude disturbance is on compared to when the disturbance is off. This analysis sought to determine if the amount of altitude-speed cross-talk was dependent upon the amount of lateral dispersion. However, no significant correlations were found in the attend-up, t (21) = -0.737, p = .300, or attend-down conditions, t (21) = -0.963, p = .248. Hence, the degree of ground dominance does not appear to be related to the lateral dispersion of fixations on the attended plane.

Chapter 6: General Discussion

By measuring eye movements in a speed control task, this study aimed to discern how attention modulates the perception of speed during altitude change in simulated flight. Although the overall pattern of speed data was replicated, the presence of the eye tracker did seem to reduce the amount of altitude-speed cross-talk, compared to what Adamic (2011) found. When tasked to attend down, we observed the same pattern as Adamic with the presence of altitude-speed cross-talk. But when tasked to attend up we found reduced altitude-speed cross-talk, whereas Adamic found altitude-speed cross-talk to be eliminated. Adamic did not measure eye movements in his study, which may have had an influence on the eye movements of participants. Participants may have glanced towards the ground texture more often in his study compared to when they wore the eye tracker in this study. A correlation analysis confirmed the reduction in altitude-speed cross-talk was greater the more participants glanced at the non-instructed plane. Thus the presence of the eye tracker in this study may have reduced the number of glances towards the ground texture in the attend-up condition compared to Adamic's study, which resulted in altitude-speed cross-talk.

The most important finding of this thesis is that human perception of egospeed is influenced by attentional sampling of optical flow, and not based on an ambient analysis of GOFR (Dyre, 1997; Julesz & Bergen, 1983; Warren, 1982). Attended optical flow dominates our speed perception. Optical flow from the non-instructed plane had more of an effect on speed control when participant's attention shifted towards the non-instructed plane. If participants did not fixate on the non-instructed plane the optical flow from the non-instructed plane had less of an influence on speed control. Therefore attended optical flow has more of an effect on the control of speed than non-attended optical flow. To date, no research has investigated attentional effects on the perception of speed of self-motion. Thus this study provided the first empirical data that attention modulates the sampling of optical flow, and egospeed control is based on this sampling rather than GOFR, which averages all available optical flow, regardless of attention.

Although attentional modulation of the speed of self-motion has not been studied, studies have investigated the perceived speed of object motion. Rees, Frith, & Lavie (1997) found neural responses in area V5/MT, part of the brain that has been shown to be involved in the perception of motion, to be modulated by attention. Psychophysical studies have also shown attentional modulation of motion processing, with attention increasing the perception of speed (Anton-Erxleben, Herrmann, & Carrasco, 2012; Turatto, Vescovi, & Valsecchi, 2006), increasing perceived size (Anton-Erxleben, Henrich, & Treue, 2007), and increasing stimulus contrast (Carrasco, Ling, & Read, 2004). Attention has also been found to play a critical role in studies of the motion after effect (MAE; Chaudhuri, 1990; Lankheet & Verstraten, 1994).

The MAE occurs after being exposed to visual motion in a particular direction for an extended period of time, resulting in adaptation to the motion direction. This causes the neurons associated with the motion direction to become fatigued. Then a stationary stimulus is presented, resulting in temporary illusory movement in the opposing direction of the adapted visual motion. This illusory movement is known as the motion after effect. Chaudhuri (1990) observed a reduction in the strength of the MAE for non-attended motion, compared to attended motion. When stimuli do not receive attention, the neurons did not become fatigued as the neurons do when attending to a stimulus. Lankheet & Verstraten

(1994) expanded on Chaudhuri's study, and found selective adaptation to the attended stimulus. They used stimuli consisting of dot patterns moving in opposite directions, and gave participants no attentional instructions, or tasked participants to attend to stimuli moving in a specific direction (left or right). When no attentional instructions were given, no MAE occurred, but when tasked to attend to either the leftward or rightward moving stimuli the MAE is present. The MAE found for the leftward and rightward moving stimuli had opposing effects. When attending to the leftward stimuli the MAE is towards the right, and when attending to the rightward stimuli the MAE is towards the left. This demonstrated only the attended motion is processed, and non-attended motion signals can be ignored, even when the two sets of stimuli are superimposed.

The attentional effect found by Lankheet & Verstraten (1994) is consistent with the attentional effect we found in this study. Optical flow can be inhibited in one part of the visual field by attending to different part of the visual field. In the attend-up condition, participants attending to the optical flow of the cloud plane inhibit the optical flow from the ground plane from being processed. But when participants shifted attention towards the ground plane, the optical flow from the clouds is inhibited. From prior research, and the results of this study, attention seems to affect the sampling of optical flow for perceiving object motion and controlling self-motion.

The results of this thesis, most importantly the significance of attended optical flow for the control of speed, can be applied to other research domains. One important domain is surface transportation, and distracted driving. Thus when tasks take our eyes off of the road (distracted driving), driving performance decreases (Horberry et al., 2006). When a driver takes their eyes off of the road, the optical flow of the environment outside the vehicle is no longer being attended to, and is not readily available for the driver to use, which contributes to the decrease in driving performance. As this thesis found, attended optical flow has a strong influence on speed control. Thus driving performance deteriorates when our eyes are taken off of the road, demonstrating the significance of attended optical flow in motion processing.

Remaining Questions

Previous studies have implemented the speed control task without an attentional manipulation (Wotring, 2008), but have never simultaneously measured attentional locus. Therefore it would be beneficial to observe how participants allocate attention when given no attention instructions, and compare that to the results of this thesis. Thus future research should use an eye tracker to investigate how eye movements and attention are allocated without specific attentional instructions.

Many participants noted the difficulty of ignoring the ground when tasked to attend up, while only one participant mentioned the difficulty of ignoring the clouds when tasked to attend down. This perceived difficulty suggested there could be an attentional bias towards the ground, with the ground inherently drawing our attention for speed control. An attentional bias could explain the occurrence of ground dominance in previous studies, even though this study did not display a strong ground dominance effect which may have occurred due to reactivity to the eye tracker.

Another possible explanation suggests the attentional bias occurs due to the direction of the gravity vector. All previous findings of ground dominance have occurred when the direction of the gravity vector has been oriented downwards, towards the ground texture in the display. Therefore if a downward bias does exist due to the direction of the gravity vector, this could help explain ground dominance. The ground has always been the source of information for motion, and from an evolutionary standpoint the ground presents an inherently greater risk than the sky does (Previc, 1990). This could create a potential bias for the gravity vector since the ground is always coupled with the direction of the gravity vector.

To examine the direction of gravity vector hypothesis, participants could lay supine and view the display via a mirror mounted directly above them. Laying supine eliminates the bias of the gravity vector due to the gravity equally affecting both the upper and lower visual fields. If the direction of gravity vector caused ground dominance, I would expect to find participants' speed control to not be influenced by the non-instructed plane, indicated by significant altitude-speed cross-talk for both the attend-up and attend-down conditions. This would be further supported by observing a positive phase lag for participants in the attend-up condition, and observing a negative phase lag for participants in the attend-down condition.

Another hypothesis suggests ground dominance results from a visual field bias or processing differences between the upper visual field (UVF) and lower visual field (LVF), with a LVF bias towards the ground texture. Many studies have found performance differences between the UVF and LVF, with the LVF being superior in most cases (Previc, 1990). Studies have found a faster reaction time for the LVF compared to the UVF (Rizzolatti et al, 1987), greater acceleration of eye movements in the LVF (Tychsen &

Lisberger, 1986), and higher LVF sensitivities to low or moderate spatial frequencies (Previc, 1990). Also an inferior visual field advantage has been found in attentional weighting (Rezec & Dobkins, 2003). There are also physiological differences between the UVF and LVF, with the LVF containing a higher density of ganglion cells compared to the UVF (Curcio & Allen, 1990). A LVF bias could also occur because the LVF contains objects that are generally closer to us than the UVF which contains objects that are farther away (Previc, 1990). This bias could be an innate defense mechanism which weights the visual information that is closer to us, located in the LVF, as more valuable than information that is further away in the UVF. These differences found between the UVF and LVF could explain an attentional bias towards the ground texture, thus future studies must examine this possibility.

The visual field hypothesis could be examined by manipulating the orientation of the ground and cloud planar surfaces of the simulation with regards to visual field. To test this hypothesis, participants could perform the speed control task while inverted, which reverses what texture is located in each visual field. Previously the ground has always been located in the LVF, but when the participant is inverted the ground would now be in the UVF. Therefore if ground dominance resulted from a visual field bias, the pattern of speed control data should be reversed from previous studies with altitude-speed cross-talk eliminated in the attend-down condition.

An attentional bias towards the ground could also be due to hand position. Studies have found a kinesthetic effect of hand position on attention, with hand position prioritizing attention (Cosman & Vecera, 2010; Reed, Grubb, & Steele, 2006). In the experiments of this thesis, it is possible participants may have prioritized the ground texture due to their hands being located below them, and towards the ground texture. Therefore future studies should manipulate hand position in reference to the orientation of the ground and cloud textures by changing the location of the joystick, and placing the joystick above the participants head. In terms of global coordinates participants hands would now be above them and towards the cloud texture instead of the ground texture as in previous studies

Additionally, future studies should test people with flight experience, because this study has only been conducted on students which limit the generalizations that can be made. Participants' naïve to flying may inherently improperly control speed due to their lack of familiarity with flight. Therefore experienced pilots may be able to better differentiate between changes in altitude and changes in speed, eliminating altitude-speed cross-talk. Thus obtaining a sample of participants with flying experience would be beneficial to observe if they exhibit similar effects to what has been found.

To increase flight realism, a higher fidelity flight simulator would allow participants to use vestibular cues to assist them in decoupling changes in speed from a change in altitude. Vestibular cues are an important aspect in flight as they help detect acceleration or decelerations of air speed as well as changes in altitude. Therefore the absence of vestibular cues could contribute to altitude-speed cross-talk, and when these cues are present, altitude-speed cross-talk is eliminated.

Conclusion

Ground dominance of speed control in the attend-up condition is not a result of participants pre-attentively processing the ground texture, but instead shifting attention towards the ground. Therefore control of egospeed is affected by attended optical flow instead of GOFR. Previous research has found GOFR to be a critical aspect of controlling egospeed (Dyre, 1997), however this study provided the first empirical data that attended optical flow has more of an effect on the control of speed than non-attended optical flow. A significant correlation found increased dwell time on the non-instructed plane decreased the amount of cross-talk present in the attend-up providing strong evidence of ground dominance being an attentional effect. If a participant did not glance at the ground plane in the attend-up condition, altitude-speed cross-talk would occur. The correlation was only significant for the attend-up condition, and was not significant for the attend-down condition even though both attentional conditions had similar amounts of dwell time on the non-instructed plane. Optical flow from the ground texture in the attend-up condition affected speed control more than optical flow from the cloud texture did in the attend-down condition. This result indicates there is something special about the optical flow from the ground texture that causes it to affect speed control more. Future research should investigate what causes optical flow from the ground texture to affect speed control more than the optical flow of the cloud texture.

References

Adamic, E. (2011). Determinants of altitude-speed cross-talk during simulated low altitude flight. Unpublished Masters Thesis: University of Idaho.

Adamic, E., Behre, J., & Dyre, B. P. (2010). Attentional locus and ground dominance in control of speed during low altitude flight. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 54*, 1665-1669.

Anton-Erxleben, K., Henrich, C. & Treue, S. (2007). Attention changes perceived size of moving visual patterns. *Journal of Vision,* 7(11), 1–9.

Anton-Erxleben, K., Herrmann, K., & Carrasco, M. (2012). Independent effects of adaptation and attention on perceived speed. *Journal of Vision*, 11, 1–8.

Ballard, T.G., Roach, T, & Dyre, B.P. (1998). Use of global optical flow rates depends on their validity as determinants of ego-speed. *Proceedings of the 42nd Annual Meeting of the Human Factors and Ergonomics Society, 2,* 1440-1444.

Bennett, A. M., Flach. J. M., McEwen, T.R., & Russell, S.M. (2006). Active regulation of speed during a simulated low-altitude flight task. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting.*

Bian, Z., Braunstein, M. L., & Andersen, G. J. (2006). The ground dominance effect in the perception of relative distance in 3-D scenes is mainly due to characteristics of the ground surface. *Perception & Psychophysics, 68*(8)*,* 1297-1309.

Carrasco, M., Ling, S. & Read, S. (2004) Attention alters appearance. *Nature Neuroscience*.

Cosman, J. D., & Veccera, S. P. (2010). Attention affects visual perceptual processing near the hand. *Psychological Science, 20,* 293-295.

Curcio, C. & Allen, K. (1990) Topography of ganglion cells in human retina.

Denton, G. G. (1980). The influence of visual pattern on perceived speed. *Perceptio*n*, 9,* 393-402.

Dougherty, R., Press, W., & Wandell, B. (1999). Perceived speed of color stimuli, *Neuron* 24, 893–899.

Duc, A. H., Bays, P., & Husain, M. (2008) Eye movements as a probe of attention. *Progress in brain research*, 171, 403-411.

Dyre, B.P. (1997). Perception of accelerating self-motion: Global optical flow rate dominates discontinuity rate.

Dyre, B.P., Cooper, S., Lew, R., & Wotring, B. (2006). The magnitude of motion parallax affects control of egospeed. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting.*

Dyre, B.P., Grimes, J.G., & Lew, R. (2007). ViEWER: A Virtual Environment Workbench for Education and Research. http://www.webpages.uidaho.edu/~bdyre/viewer.htm

Dyre, B.P., Lew, R., Meyer, M., & Abdel-Rahim, A. (2014). Improving passing lane safety and efficiency.

Ernst, Z., Palmer, J., & Boynton, G. (2012). Dividing attention between two transparent motion surfaces results in a failure of selective attention. *Journal of Vision.* 12

Felisberti, F. and Zanker, J. (2005). Attention modulates perception of transparent motion. *Vision Research,* 45, 2587-2599.

Flach, J. M., Warren, R., Garness, S. A., Kelly, L., & Stanard, T. (1997). Perception and control of altitude: Splay and depression angles. *Journal of Experimental Psychology: Human Perception and Performance, 23, 8,* 1764-1782.

Folk, C., Remington, R., & Wright, J. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 2, 317-329

Gibson, J.J. (1950). The perception of the visual world. Houghton Mifflin

Hoffman, J. & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57, 6,* 787-795.

Horberry, T., Anderson, J., Regan, M., Triggs, T., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention*, 38, 1, 185-191

Julesz, B. and Bergen, J. R. (1983). Textons, the fundamental elements in preattentive vision and perception of textures. *The Bell System Technical Journal,* 60, 6,1619-1645.

Koenderink, J. (1986). Optical flow. *Vision Research. 26, 1,* 161–179.

Landsberger, H. (1958). Hawthorne revisited: Management and the worker, its critics, and developments in human relations in industry.

Lankheet, M.J.M. & Verstraten, F. A. (1994). Attentional modulation of adaptation to two-component transparent motion. *Vision Research,* 35, 1401-1412.

Larish, J. & Flach, J. (1990). Sources of optical information useful for perception of speed of rectilinear self-motion. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 295-302

McDevitt, J. (2000). Quantifying the biasing effect of motion parallax on speed perception. Unpublished Masters Thesis: University of Idaho.

McDevitt, J., Eggleston, J., & Dyre, B.P. (1999). Perception of egospeed from absolute and relative motion. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting.*

Meyer, M., Dyre, B., & Adamic, E. (2013). Further evidence for ground dominance in control of speed during low altitude flight. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.*

Ozkan, K. & Braunstein, M. (2009). Predominance of ground over ceiling surfaces in binocular rivalry. *Attention, Perception, & Psychophysics.*

Previc, F., (1990). Functional and specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. *Behavioral and Brain Sciences. 13.* 1029-1037.

Rizzolatti, G., Riggio, L., Dascola, I., & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention.

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

Reed, C. L., Grubb, J.D., & Steele, C. (2006). Hands up: Attentional prioritization of space near the hand. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 166-177

Rees, G, Frith, CD, & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science*, 278, 1616-1619.

Rezec, A. & Dobkins, K. (2004). Attentional weighting: A possible account of visual field asymmetries in visual search. *Spatial Vision.*

Shepherd , M., Findlay, J., & Hockey, R.(1986): The relationship between eye movements and spatial attention. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology.* 38:3. 475-491.

Stone, L. & Thompson, P. (1992). Human speed perception is contrast dependent. *Vision Research.* 32, 1535–1549.

Turatto, M., Vescovi, M., & Valsecchi, M. (2006). Attention makes moving objects be perceived to move faster. *Vision Research*, 47, 166–178.

Tychsen, L. & Lisberger, S.G. (1986). Visual motion processing for the initation of smooth-pursuit eye movements in humans.

Warren, R. (1982). Optical transformations during movement: Review of the optical concomitants of egomotion (Tech. Rep. AFOSR-TR-82-11028). Washington, DC: Air Force Office of Scientific Research. (NTIS No. AD-A122 275).

Wotring, B. M. (2008). Altitude changes affect speed control during simulated low-altitude flight for both planar and non-planar environments. Unpublished Masters Thesis: University of Idaho.

Wotring, B., Dyre, B. P., & Behr, J. (2008). Cross-talk between altitude changes and speed control during simulated low-altitude flight. *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting.*

Endnotes

[1] Participants were excluded from the analysis due to control inactivity: no joystick input from the participant for more than one cumulative minute throughout a trial. The inactivity indicated one of two things; either participants did not properly understand the task, or they did not give the task as much effort and attention as required.

[2] Arithmetic mean is more affected by outliers of a non-normal distribution thus geometric mean was used in the fixation duration analysis.

Appendix A

Experiment 1 Consent Form

CONSENT FORM
Idaho Visual Performance Laboratory
Department of Psychology and Communication Studies
College of Liberal Arts and Social Sciences
University of Idaho

The University of Idaho Institutional Review Board has approved this project. During this experiment you will be presented a series of displays simulating a virtual environment. Various parameters of these displays will be manipulated to examine the processes underlying vision and decision making. The experimental tasks may require you to discriminate different features or information presented in a display and make a judgment, control your movement or the movement of objects in the virtual world using an input device such as a joystick, or make and execute decisions about system states for controlling a process, such as monitoring fuel or temperature levels.

Your participation will help increase knowledge of visual processes underlying locomotion and aid in the design of visual displays used in transportation. Subsequent to your participation the purpose and methods of the study will be described to you and any questions you have about the study will be answered. It is our sincere hope that you will learn something interesting about your visual system from this debriefing.

We believe the risks in this study are minimal, however displays simulating movement through virtual environments may on rare occasion cause motion sickness or eye fatigue. If at any time during the experiment you feel any discomfort, eye fatigue, dizziness, headache or nausea, please let the experimenter know immediately so that you can prevent these symptoms from becoming more intense. We endeavor to adjust our monitoring equipment so that it is comfortable and design our virtual environments to minimize eye fatigue and motion sickness. We also schedule periodic breaks to further reduce the occurrence of these risks. As a result, these risks are generally avoided, but it is important for you to inform us immediately if they do occur. At such time we will immediately terminate the experiment and provide you with a comfortable place to rest. If your discomfort is mild and passes quickly you will be given the opportunity to continue the experiment if you so desire. Any new information developed during the course of this research which might affect your willingness to continue participation will be provided as soon as it is available.

Your participation will require 1 session of approximately 120 minutes. You may withdraw from this study at any time without penalty. If you do wish to withdraw, simply inform the experimenter; you will receive full compensation for your time spent in the experiment up to that point. However, please be aware that your data will have the greatest scientific value if you complete the experiment in its entirety.

The data you provide will be kept confidential. The only link between your identity and your particular set of data will be a master list stored as a secure file on a secure computer accessed only by the experimenters. This information is maintained solely for the purpose of identifying which participant(s) qualify for performance incentive awards on our experimental tasks. Once such awards have been distributed, the master list linking your identity to your data will be destroyed, effectively rendering your data anonymous.

If you have further questions or issues please contact:

Dr. Brian P. Dyre
Department of Psychology and Communications Studies
University of Idaho
(208) 885-6927
bdyre@uidaho.edu

I have reviewed this consent form and understand and agree to its contents.

Participant Name ____

Date of Birth __________________________________

Signature _____________________________________

Date ____

Experimenter Name_______________________________________

Signature____________________________________

Date _______________________________________

Thank you for your participation.

Appendix B

Experiment 2 Consent Form

CONSENT FORM

Idaho Visual Performance Laboratory

Department of Psychology and Communication Studies

College of Liberal Arts and Social Sciences

University of Idaho

The University of Idaho Institutional Review Board has approved this project.

During this experiment you will be presented a series of displays simulating a virtual environment. Various parameters of these displays will be manipulated to examine the processes underlying vision and decision making. The experimental tasks may require you to discriminate different features or information presented in a display and make a judgment, control your movement or the movement of objects in the virtual world using an input device such as a joystick, or make and execute decisions about system states for controlling a process, such as monitoring fuel or temperature levels.

Your participation will help increase knowledge of processes underlying locomotion, decision making, and process control. This knowledge will inform the design of visual displays used in transportation and process control systems. Subsequent to your participation the purpose and methods of the study will be described to you and any questions you have about the study will be answered. It is our sincere hope that you will learn something interesting about how your brain works from this debriefing.

During the experiment, we will need you to wear a headband-mounted camera that records pupil size, and a chest-band and finger-tip sensors that record physiological responses such as pulse, peripheral temperature, and skin conductance. These measures allow us to estimate how much mental effort you are exerting while performing the task.

We believe the risks in this study are minimal; however our displays may on rare occasion cause motion sickness or eye fatigue.

The eye-tracking and physiological recording equipment may also cause discomfort if not properly adjusted or worn for extended periods.

If at any time during the experiment you feel any discomfort, eye fatigue, dizziness, headache or nausea, please let the experimenter know immediately so that you can prevent these symptoms from becoming more intense. We endeavor to adjust our monitoring equipment so that it is comfortable and design our virtual environments to minimize eye fatigue and motion sickness. We also schedule periodic breaks to further reduce the occurrence of these risks. As a result, these risks are generally avoided, but it is important for you to inform us immediately if they do occur. At such time we will immediately terminate the experiment and provide you with a comfortable place to rest. If your discomfort is mild and passes quickly you will be given the opportunity to continue the experiment if you so desire. Any new information developed during the course of this research which might affect your willingness to continue participation will be provided as soon as it is available.

Your participation will require 1 session of approximately 60 minutes. You may withdraw from this study for any reason and at any time without penalty. If you do wish to withdraw, simply inform the experimenter; you will receive full compensation for your time spent in the experiment up to that point. However, please be aware that your data will have the greatest scientific value if you complete the experiment in its entirety.

The data you provide will be kept anonymous. There will be absolutely no link between your identity and your particular set of data.

If you have further questions or issues please contact:

Dr. Brian P. Dyre

Department of Psychology and Communications Studies

University of Idaho

(208) 885-6927
bdyre@uidaho.edu

I have reviewed this consent form and understand and agree to its contents.

Participant Name ____

Date of Birth ___________________________________

Signature _____________________________________

Date ____

Experimenter Name_______________________________________

Signature_____________________________________

Date ____

Thank you for your participation.

Appendix C

Experiment 1 & 2 Instructions - Attention Up

INSTRUCTIONS

Idaho Visual Performance Laboratory
Department of Psychology and Communication Studies
College of Liberal Arts and Social Sciences
University of Idaho
Up

This is an experiment on the perception of speed. You will be shown a series of displays simulating flight. While viewing the displays imagine you are flying a plane at low altitudes. Your goal during each trial is to maintain constant speed. At the beginning of each trial, there will be a 5 second preview period in which the clouds will be highlighted by a black outlining border and the words “Attend The Clouds, Ignore The Ground” are shown on the screen. During this time, carefully note how fast you appear to be moving by using only the clouds in your perception and ignoring the ground. After the words disappear the trial begins and it is now your job to maintain the speed shown in the preview period via movement of the joystick. By moving the joystick forward you speed up, by pulling it back, you slow down. Careful control of speed is required in this experiment so be sure to be as accurate as possible. Any deviation in speed is very undesirable. Accurately maintaining the preview period speed is extremely important. There will be virtual wind gusts that will slow down or speed up your plane. Therefore you will have to make frequent adjustments of speed in order to correctly account for the wind gusts. Also, on some trials, there will be changes in altitude that occur that you will have no control over. You will only have control over forward speed. Remember, to use only the clouds in your speed judgments and control while ignoring the ground. Each trial will last roughly 4 minutes and there will be 8 trials in all. At the end of each trial you will be asked to rate the difficulty of that trial. You have the option for a break after every two trials, and a mandatory break half way through the experiment. We ask that during this break you get up and walk around for a couple minutes.

Given this, would you like me to repeat the instructions?
Can you please describe to me what your task is?

Appendix D

Experiment 1 & 2 Instructions - Attention Down

INSTRUCTIONS

Idaho Visual Performance Laboratory
Department of Psychology and Communication Studies
College of Liberal Arts and Social Sciences
University of Idaho
Down

This is an experiment on the perception of speed. You will be shown a series of displays simulating flight. While viewing the displays imagine you are flying a plane at low altitudes. Your goal during each trial is to maintain constant speed. At the beginning of each trial, there will be a 5 second preview period in which the ground will be highlighted by a black outlining border and the words “Attend The Ground, Ignore The Clouds” are shown on the screen. During this time, carefully note how fast you appear to be moving by using only the ground in your perception and ignoring the clouds. After the words disappear the trial begins and it is now your job to maintain the speed shown in the preview period via movement of the joystick. By moving the joystick forward you speed up, by pulling it back, you slow down. Careful control of speed is required in this experiment so be sure to be as accurate as possible. Any deviation in speed is very undesirable. Accurately maintaining the preview period speed is extremely important. There will be virtual wind gusts that will slow down or speed up your plane. You will have to make frequent adjustments of speed in order to correctly account for the wind gusts. Also, on some trials, there will be changes in altitude that occur that you will have no control over. You will only have control over forward speed. Remember, to use only the ground in your speed judgments and control while ignoring the clouds. Each trial will last roughly 4 minutes and there will be 8 trials in all. At the end of each trial you will be asked to rate the difficulty of that trial. You have the option for a break after every two trials, and a mandatory break half way through the experiment. We ask that during this break you get up and walk around for a couple minutes.

Given this, would you like me to repeat the instructions?
Can you please describe to me what your task is?

Appendix E

Deception Cover Story

Deception Cover Story

Next, we will place this device on your head, and have you adjust the tightness as needed. It should be tight enough where you feel as if it will not move, but not so tight that it is unbearable. This device is used to measure the diameter of your pupil, or pupillometry. This allows us to assess workload throughout each trial.

To get an accurate reading we will first have to measure pupil diameter from multiple angles (Initial Calibration). To do that we will have you look through a set of numbers that will be displayed one at a time on the screen.

Also we must ensure we maintain a clear view of your pupil at all times, while you are looking at the display. Therefore we may ask you to look at different locations on the screen a few times. (Calibration Check)

Appendix F

Experiment 1 Debriefing Form - Attention Up

DEBRIEFING FORM

Idaho Visual Performance Laboratory

Department of Psychology and Communication Studies

College of Liberal Arts and Social Sciences

University of Idaho

Up

Participant _______

Date_______________

1. To what degree did the displays provide you with the sensation that you were moving?
    a. Strong, Moderate, Weak, None?

2. Did you feel that there was enough information in the displays to accurately adjust your speed?

3. Did you feel as though you had enough control over the vehicle's speed to accurately maintain the proper speed?

4. Did you ever base your speed responses on a specific cue or method other than just your overall perception of speed? If so, please explain what cues or methods you used.

5. Where did you focus most of your attention? Did you focus on the whole display or did you look further ahead, to the sides or at the bottom of the display?

6. Did you notice that there was sometimes variation in your vehicles speed and/ or altitude during the course of the trials?

7. Did you believe that these changes affected your perception and adjustments of your speed?

8. Did you feel as though you were able to attend the clouds and ignore the ground?

Appendix G

Experiment 1 Debriefing Form - Attention Down

DEBRIEFING FORM

Idaho Visual Performance Laboratory

Department of Psychology and Communication Studies

College of Liberal Arts and Social Sciences

University of Idaho

Down

Participant _______

Date_______________

1. To what degree did the displays provide you with the sensation that you were moving?
    a. Strong, Moderate, Weak, None?

2. Did you feel that there was enough information in the displays to accurately adjust your speed?

3. Did you feel as though you had enough control over the vehicle's speed to accurately maintain the proper speed?

4. Did you ever base your speed responses on a specific cue or method other than just your overall perception of speed? If so, please explain what cues or methods you used.

5. Where did you focus most of your attention? Did you focus on the whole display or did you look further ahead, to the sides or at the bottom of the display?

6. Did you notice that there was sometimes variation in your vehicles speed and/ or altitude during the course of the trials?

7. Did you believe that these changes affected your perception and adjustments of your speed?

8. Did you feel as though you were able to attend the ground and ignore the clouds?

Appendix H

Experiment 2 Debriefing Form - Attention Up

DEBRIEFING FORM

Idaho Visual Performance Laboratory

Department of Psychology and Communication Studies

College of Liberal Arts and Social Sciences

University of Idaho

Up

Participant _______

Date_______________

1. To what degree did the displays provide you with the sensation that you were moving?
   a. Strong, Moderate, Weak, None?

2. Did you feel that there was enough information in the displays to accurately adjust your speed?

3. Did you feel as though you had enough control over the vehicle's speed to accurately maintain the proper speed?

4. Did you ever base your speed responses on a specific cue or method other than just your overall perception of speed? If so, please explain what cues or methods you used.

5. Where did you focus most of your attention? Did you focus on the whole display or did you look further ahead, to the sides or at the bottom of the display?

6. Did you notice that there was sometimes variation in your vehicles speed and/ or altitude during the course of the trials?

7. Did you believe that these changes affected your perception and adjustments of your speed?

8. Did you feel as though you were able to attend the clouds and ignore the ground?

9. What do you think we were looking for in this experiment?

10. Have you ever worn a device like this before?

11. What do you believe the device on your head was measuring?

If participant does not say anything about eye movement ask:

a. Did you suspect that this device also measured eye movements?

If answered yes to either of the questions above:

b. Did this affect where you were looking?

12. Did you have any doubts concerned with what we were measuring?

Explanation to participants after debriefing questions

- This device has the ability to measure pupillometry, but we were actually interested in eye movements during this experiment
- Rationale: A previous experiment found that when we have participants wear an eye tracker, they behave differently than in previous experiments without it. Therefore this deception was used to see if the behavior changed because participants knew their eye movements were explicitly being monitored.

Appendix I

Experiment 2 Debriefing Form - Attention Down

DEBRIEFING FORM

Idaho Visual Performance Laboratory

Department of Psychology and Communication Studies

College of Liberal Arts and Social Sciences

University of Idaho

Down

Participant _______

Date_______________

1. To what degree did the displays provide you with the sensation that you were moving?
    a. Strong, Moderate, Weak, None?

2. Did you feel that there was enough information in the displays to accurately adjust your speed?

3. Did you feel as though you had enough control over the vehicle's speed to accurately maintain the proper speed?

4. Did you ever base your speed responses on a specific cue or method other than just your overall perception of speed? If so, please explain what cues or methods you used.

5. Where did you focus most of your attention? Did you focus on the whole display or did you look further ahead, to the sides or at the bottom of the display?

6. Did you notice that there was sometimes variation in your vehicles speed and/ or altitude during the course of the trials?

7. Did you believe that these changes affected your perception and adjustments of your speed?

8. Did you feel as though you were able to attend the ground and ignore the clouds?

9. What do you think we were looking for in this experiment?

10. Have you ever worn a device like this before?

11. What do you believe the device on your head was measuring?

If participant does not say anything about eye movement ask:

c. Did you suspect that this device also measured eye movements?

If answered yes to either of the questions above:

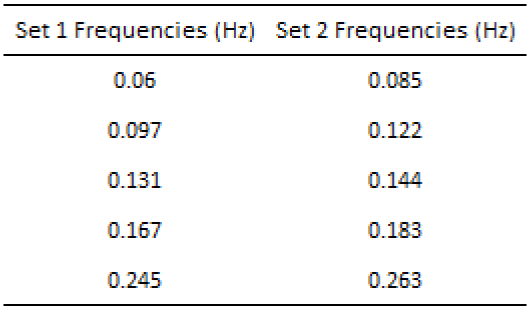
d. Did this affect where you were looking?

12. Did you have any doubts concerned with what we were measuring?

Explanation to participants after debriefing questions

- This device has the ability to measure pupillometry, but we were actually interested in eye movements during this experiment
- Rationale: A previous experiment found that when we have participants wear an eye tracker, they behave differently than in previous experiments without it. Therefore this deception was used to see if the behavior changed because participants knew their eye movements were explicitly being monitored.

Table *1*. Interleaved frequency sets assigned to either the speed or altitude disturbances in Experiment 1 and 2. Frequency assignment S<A received Set 1 for the speed disturbance, and Set 2 for the altitude disturbance while frequency assignment A<S received Set 1 for the altitude disturbance, and Set 2 for the speed disturbance.



Set 1 Frequencies (Hz)	Set 2 Frequencies (Hz)
0.06	0.085
0.097	0.122
0.131	0.144
0.167	0.183
0.245	0.263

Table 2. *Eye Tracking Analysis –Percentage of Fixations on each AOI Across Attention in Experiment 1 and 2*

	Attention Up		Attention Down	
AOI	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Cloud	98.35%	97.29%	1.12%	0.83%
Horizon	0.30%	1.05%	1.32%	0.98%
Ground	1.23%	1.63%	97.45%	97.87%
Off	0.12%	0.03%	0.11%	0.32%

Table *3. Eye Tracking Analysis – Percentage of Dwell Time on each AOI Across Attention in Experiment 1 and 2*

	Attention Up		Attention Down	
AOI	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Cloud	99.01%	98.40%	0.93%	0.61%
Horizon	0.19%	0.60%	1.45%	1.29%
Ground	0.73%	0.99%	97.57%	97.54%
Off	0.07%	0.01%	0.05%	0.56%

Table *4*.Combined Analysis Log Joystick Amplitudes at Altitude and Speed Disturbance

Frequencies: Significant Main Effects and Interactions

Source	df source, error	*F*	*P*	ε	MSE
Altitude Frequencies					
Altitude Disturbance	1,40	31.117	< .0005	1.000	0.053
Frequency Component	4, 160	208.719	< .0005	0.309	0.035
Attentional Locus	1, 40	4.630	< 0.05	-	0.306
Frequency Component x Attentional Locus	4, 160	3.944	< 0.05	0.309	0.035
Altitude Disturbance x Attentional Locus	1,40	4.542	< 0.05	1.000	0.053
Speed Frequencies					
Frequency Component	4, 160	589.086	< .0005	0.269	0.023
Frequency Assignment	1,40	19.820	< .0005	-	0.453
Frequency Component x Frequency Assignment	4,160	10.695	< .01	0.269	0.016
Frequency Component x Altitude Disturbance	4,160	2.959	< 0.05	0.809	0.006
Frequency Component x Altitude Disturbance x Attentional Locus	4,160	5.092	< .01	0.809	0.006

Note: All effects and interactions not listed were insignificant (p > .05)

Table 5. *Combined Analysis Joystick Phase Lags at Altitude and Speed Disturbance Frequencies: Significant Main Effects and Interactions*

Source	df source, error	*F*	*p*	E	MSE
Altitude Frequencies					
Attentional Locus	1,40	27.001	< .0005	-	3.094
Frequency Component	4,160	3.443	< 0.05	0.887	0.023
Frequency Assignment x Attentional Locus	1,40	4.392	< 0.05	-	3.094
Speed Frequencies					
Frequency Component	4, 160	48.194	< .0005	0.559	0.172

Note: All effects and interactions not listed were insignificant (p > .05)

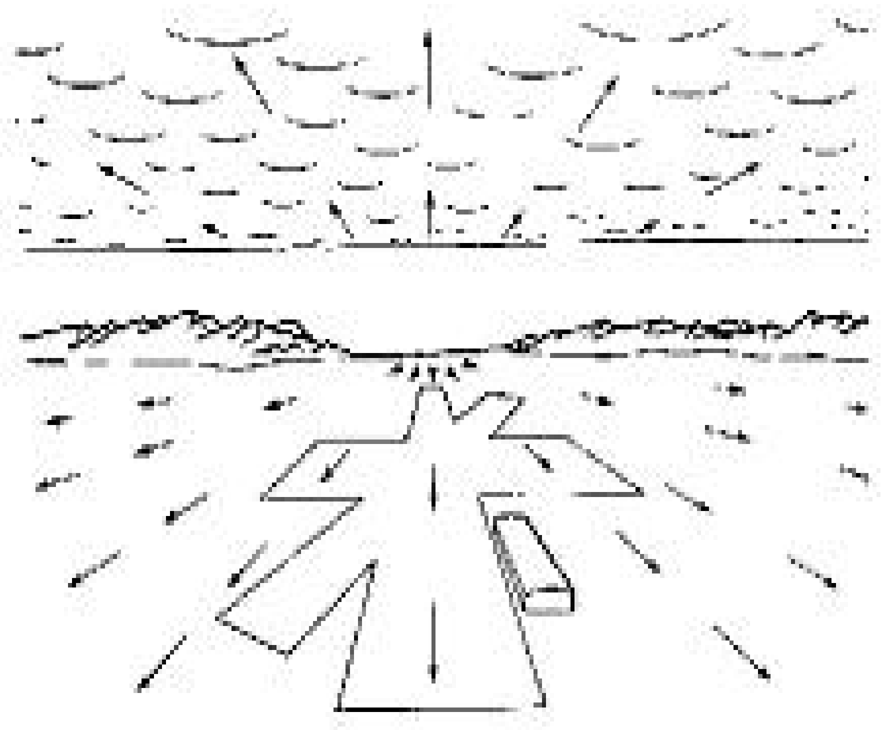


Figure 1. Optical flow field of a pilot's perspective as they approach a runway. The length of the arrows represents velocity, with longer arrows representing faster movement.

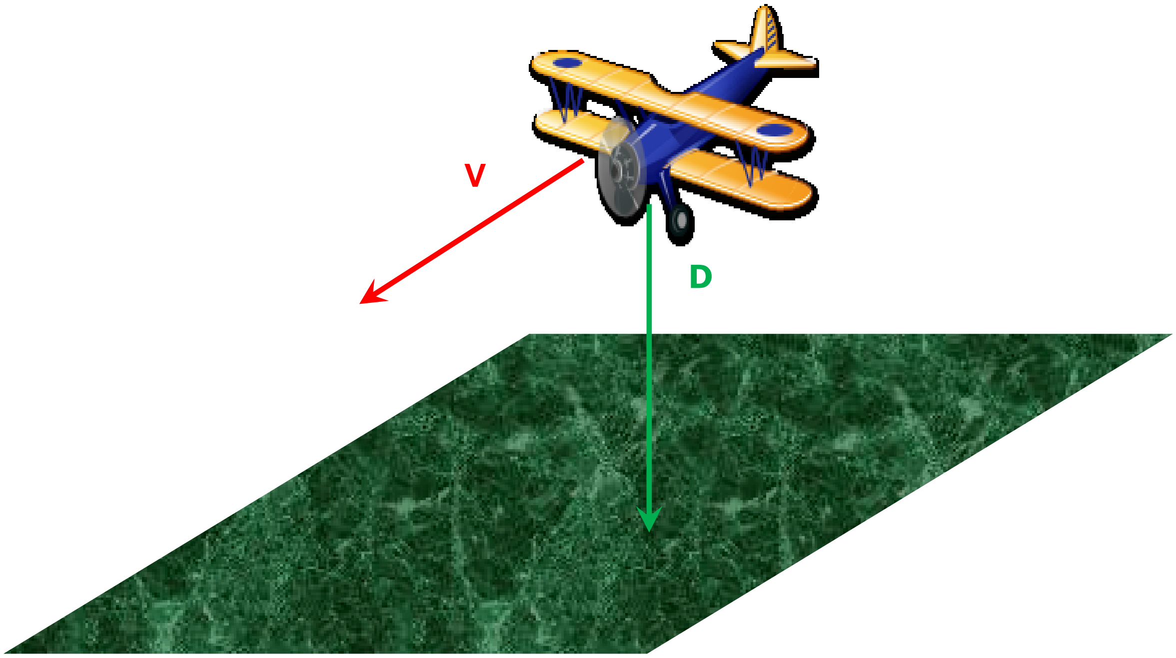


*Figure 2***.** Global Optical Flow Rate (GOFR) is calculated as a ratio of forward speed (V) over altitude (D)

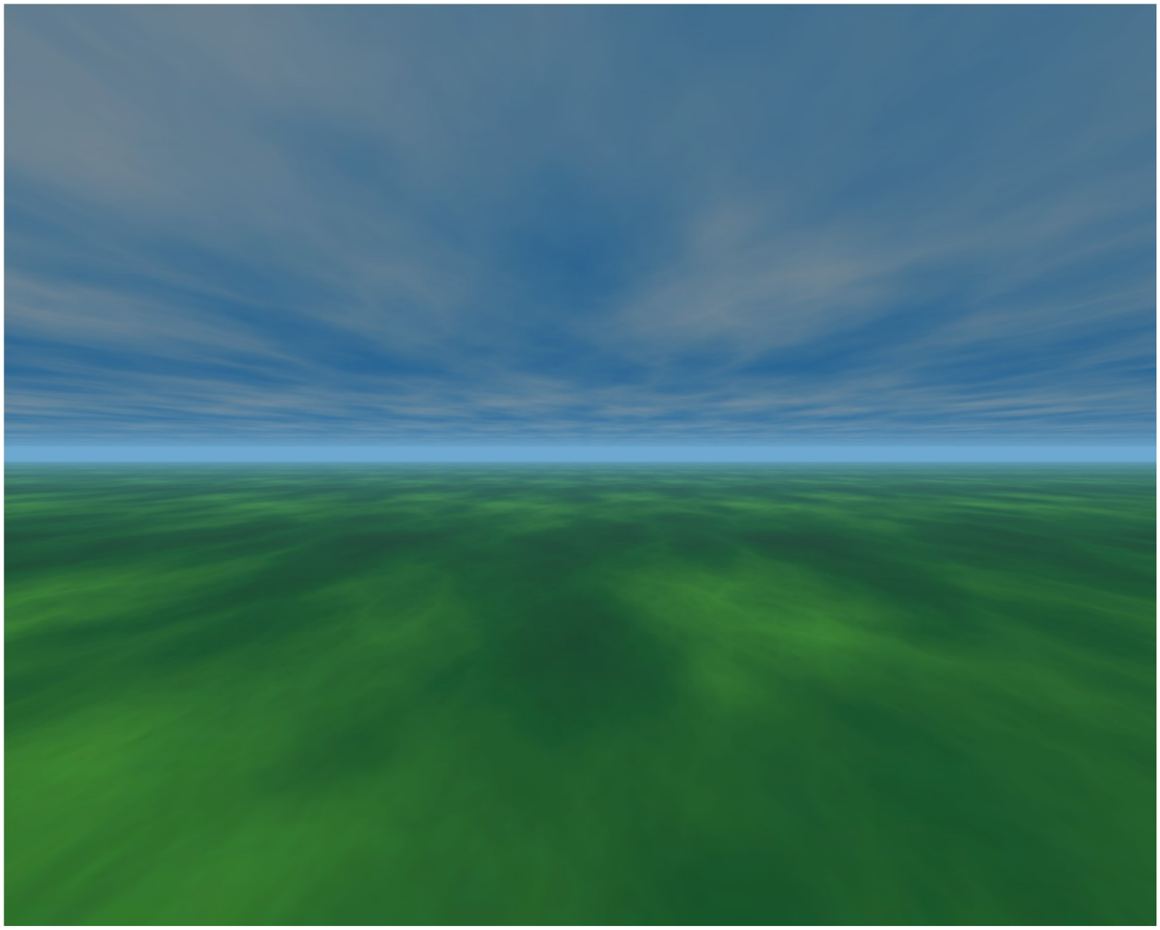


Figure 3. Dual Planar Environment used by Wotring (2008), and used in both experiments of this thesis.

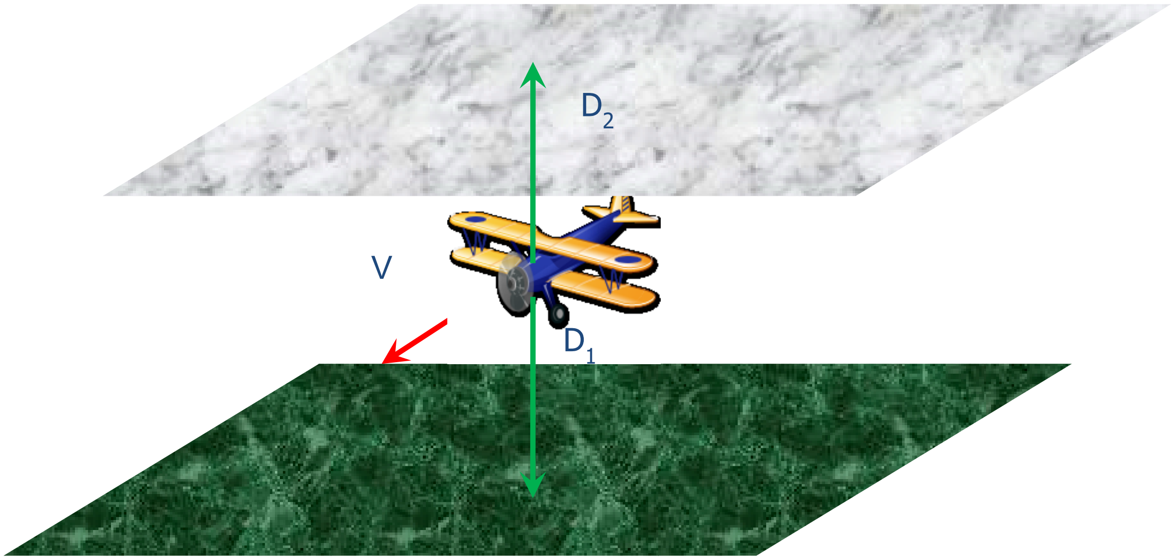


Figure 4. Dual Planar Environment illustrating how GOFR remains constant because as you get farther away from one planar surface, you become closer to the other surface. GOFR = V/(D1+D2), D1+D2 = k (a constant), hence GOFR = V/k.

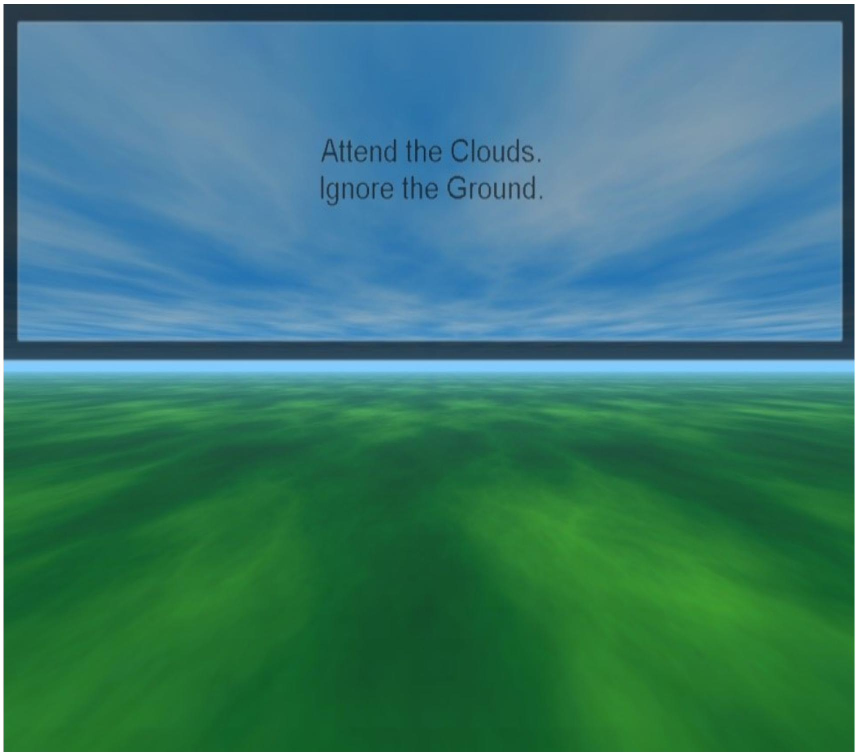


*Figure 5***.** Environment used for the explicit attention manipulation in the Attention Up condition (Adamic, 2011).

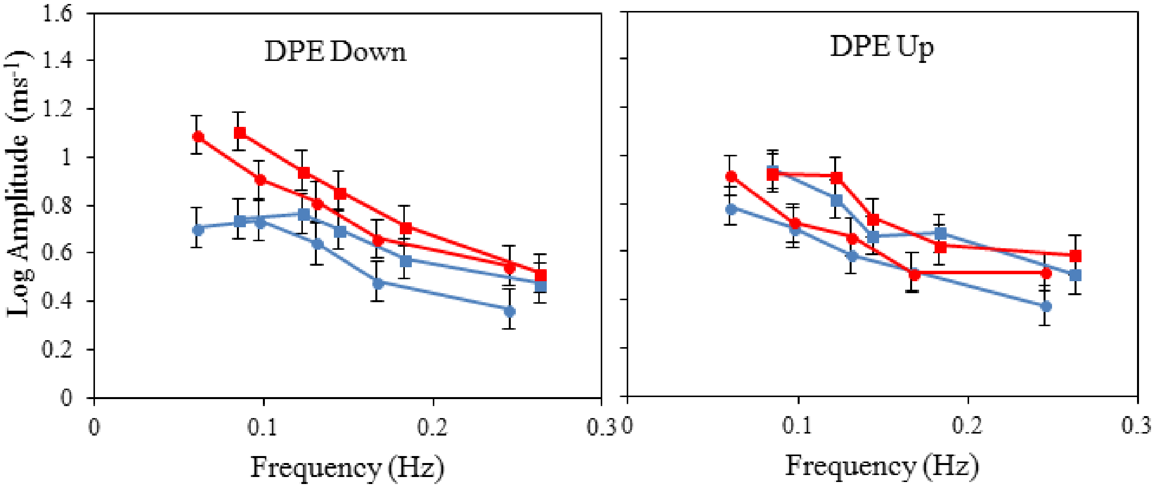


Figure 6. Joystick Log Amplitudes at the altitude disturbance frequencies from Experiment 1 in Adamic (2011) which shows the elimination of cross-talk during the DPE Up condition. The elimination of cross-talk is displayed by the collapsing of the joystick amplitudes when the altitude disturbance is on. As shown in the graph on the right, there is not a significant difference between trials with the altitude disturbance on (red line), versus when the disturbance is off (blue line).

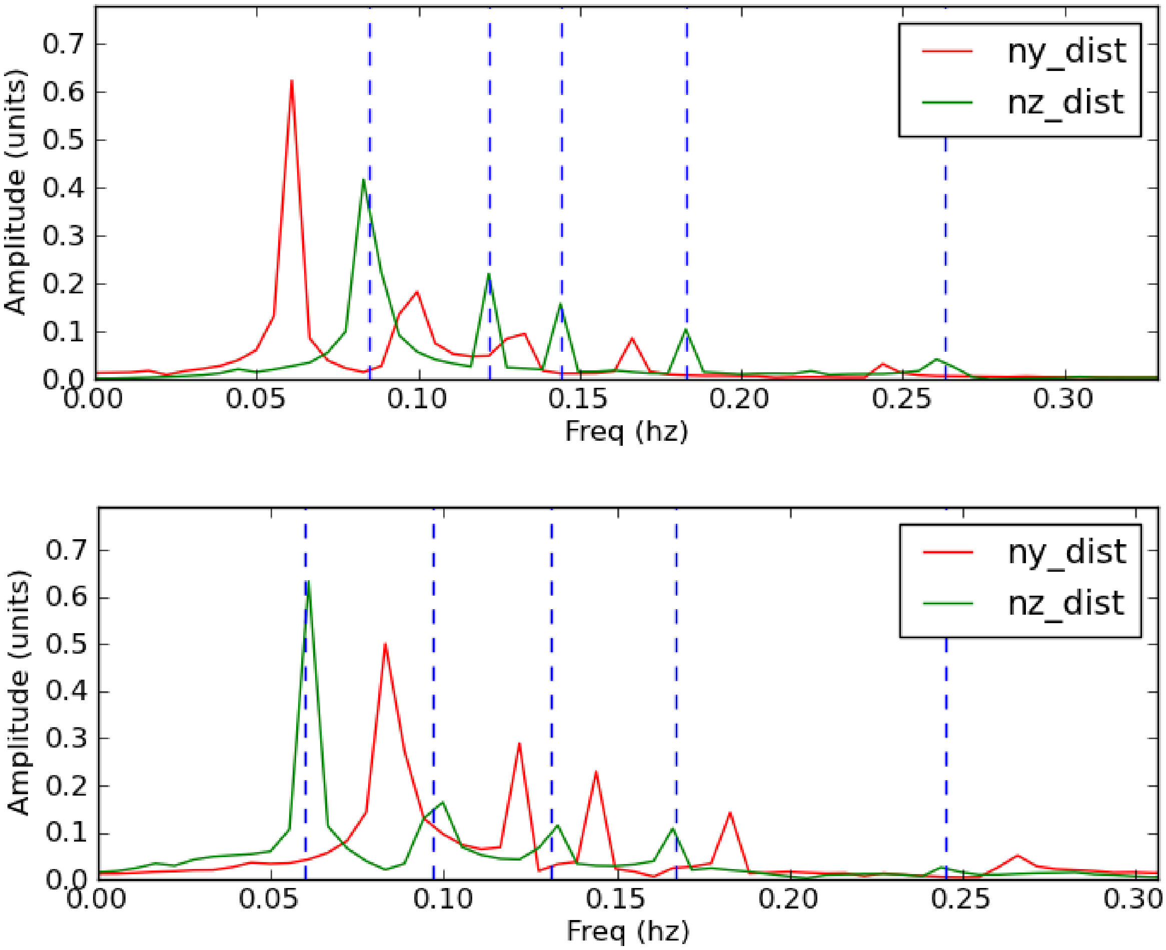


*Figure 7***.** Normalized power analysis at each of the disturbance frequencies for frequency assignment A<S (top) and frequency assignment S<A (bottom). The red line represents the altitude disturbance frequencies for each condition, and the green line represents the speed disturbance frequencies for each condition.

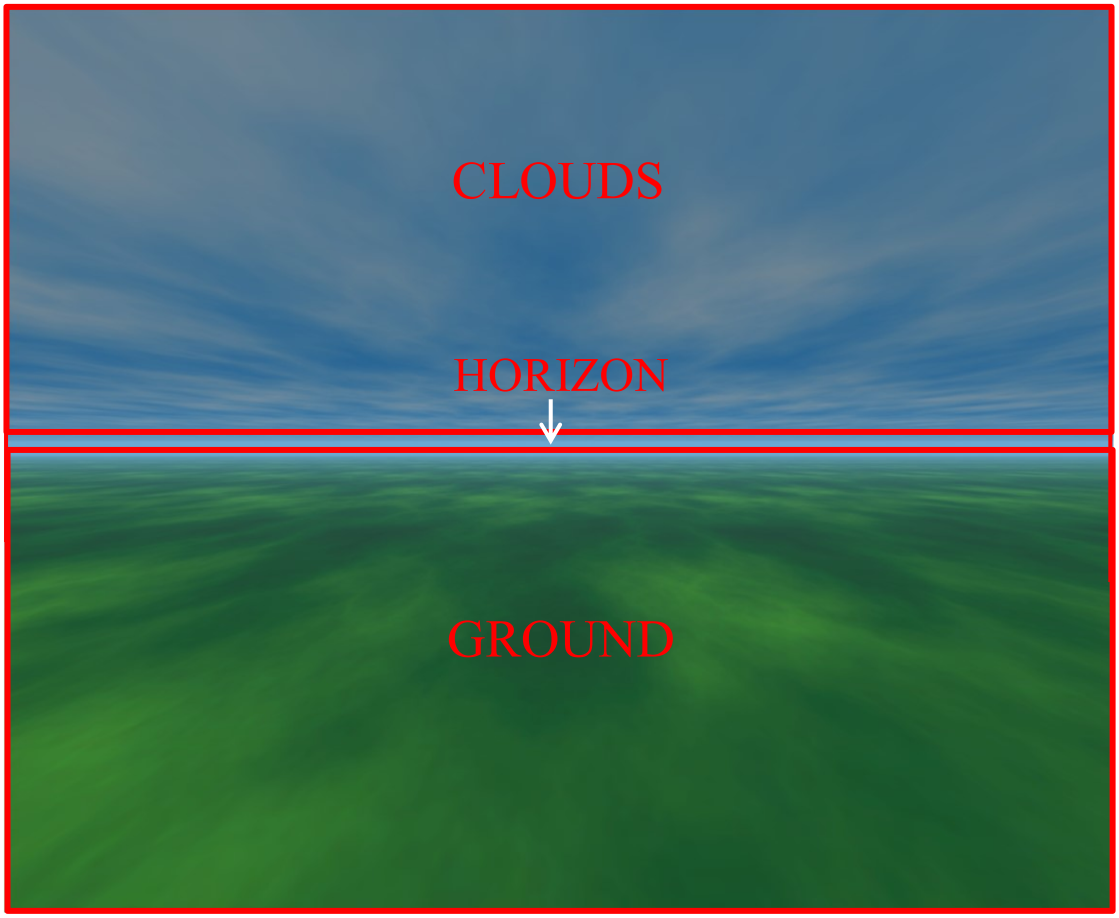


Figure 8. Three areas of interests used in the eye tracking analysis.

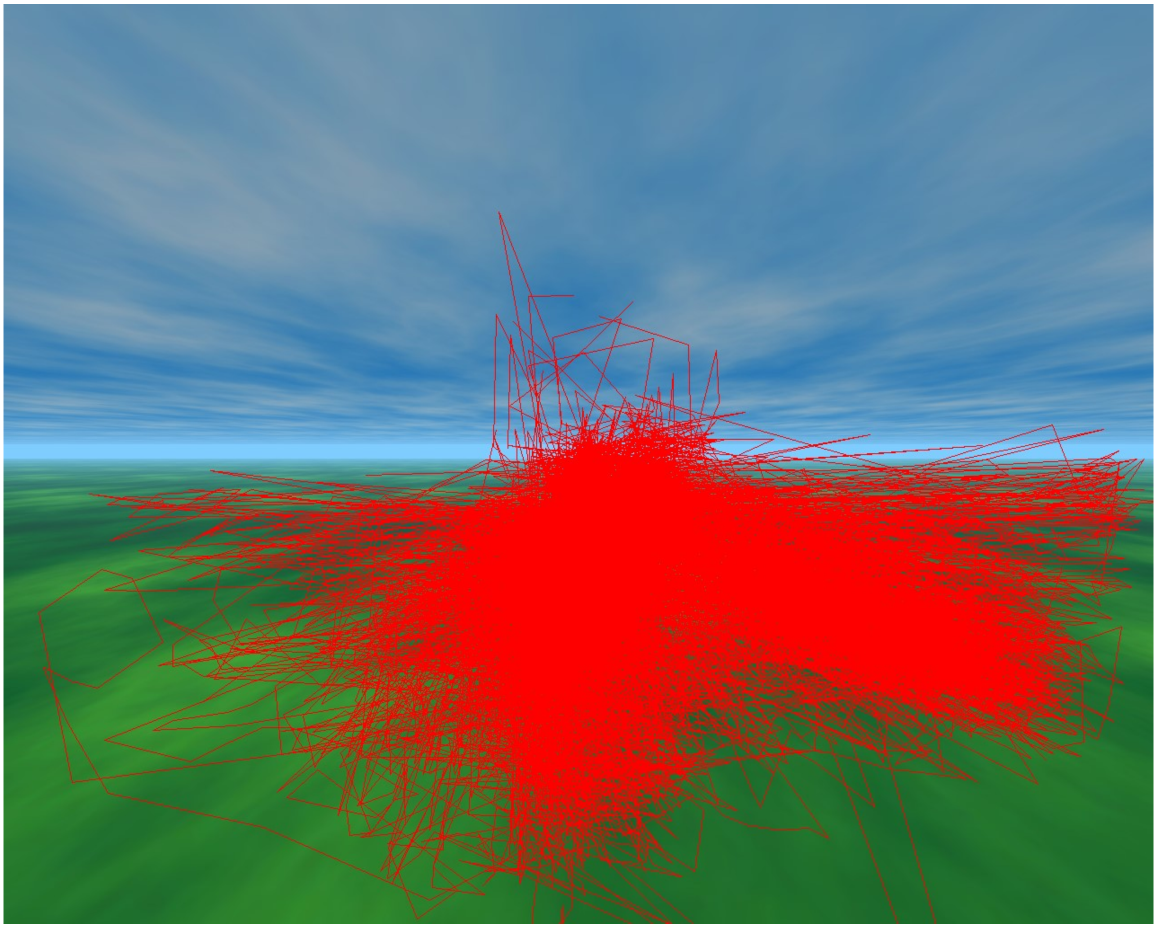


Figure 9. Experiment 1 fixation sequences for all participants in the attend-down condition. The red lines represent changes in eye position, and the vertexes represent fixations

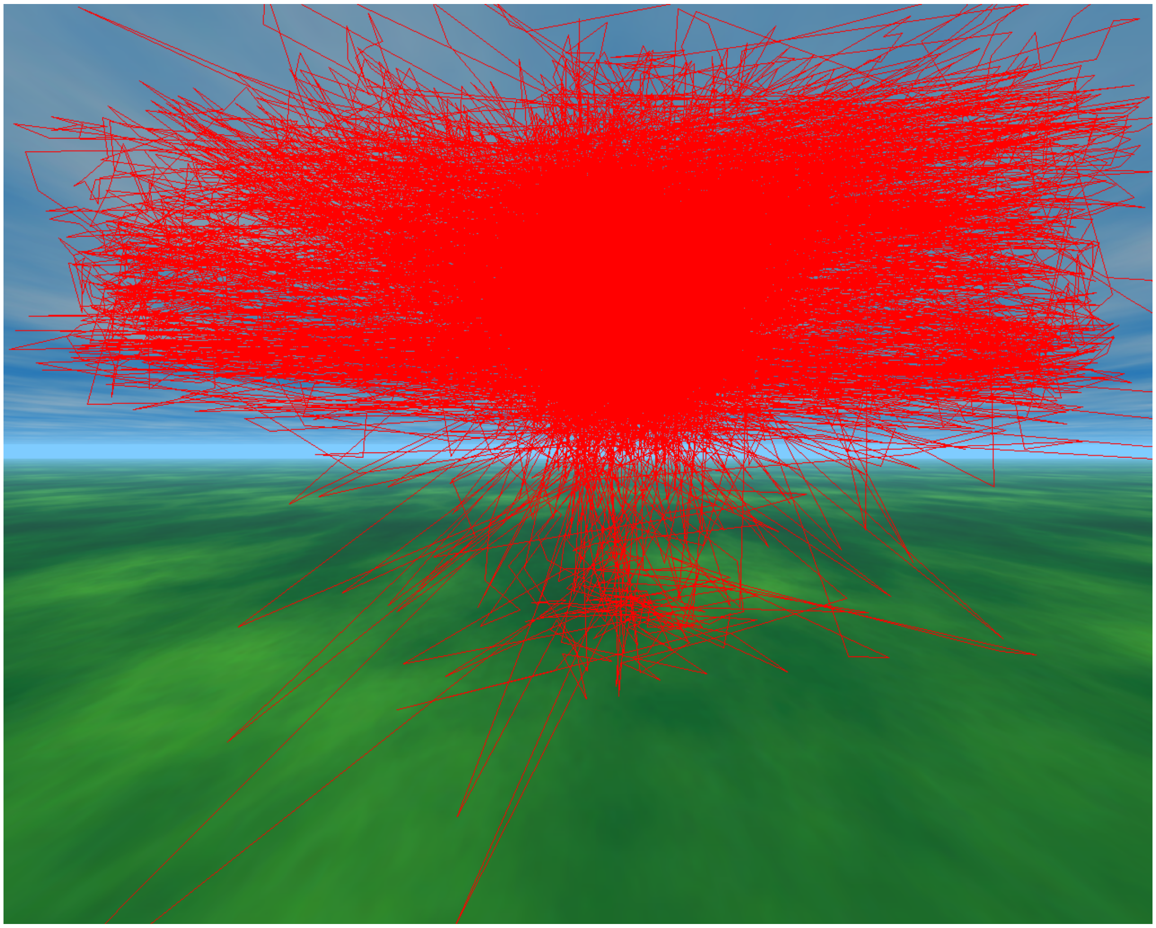


Figure 10. Experiment 1 fixation sequences for all participants in the attend-up condition. The red lines represent changes in eye position, and the vertexes represent fixations.

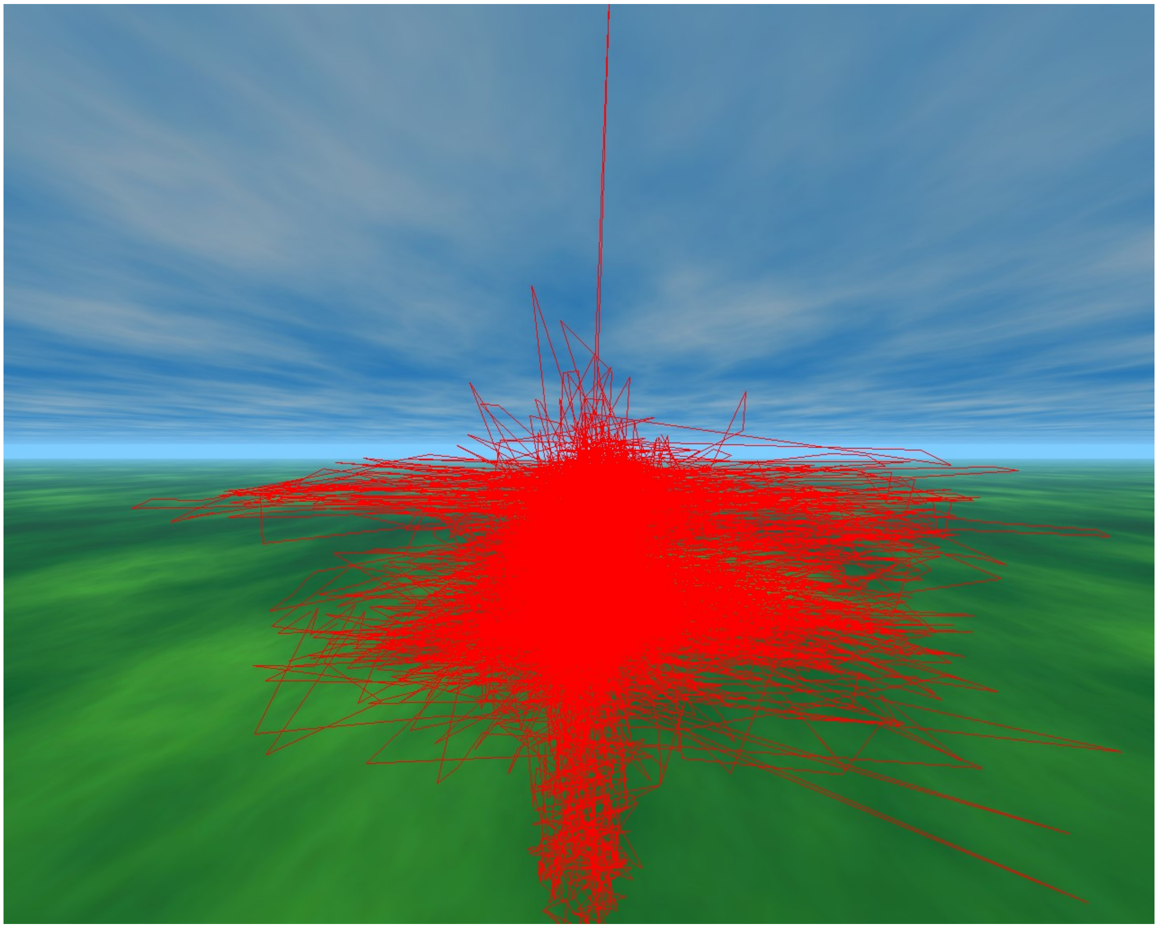


Figure 11. Experiment 2 fixation sequences for all participants in the attend-down condition. The red lines represent changes in eye position, and the vertexes represent fixations.

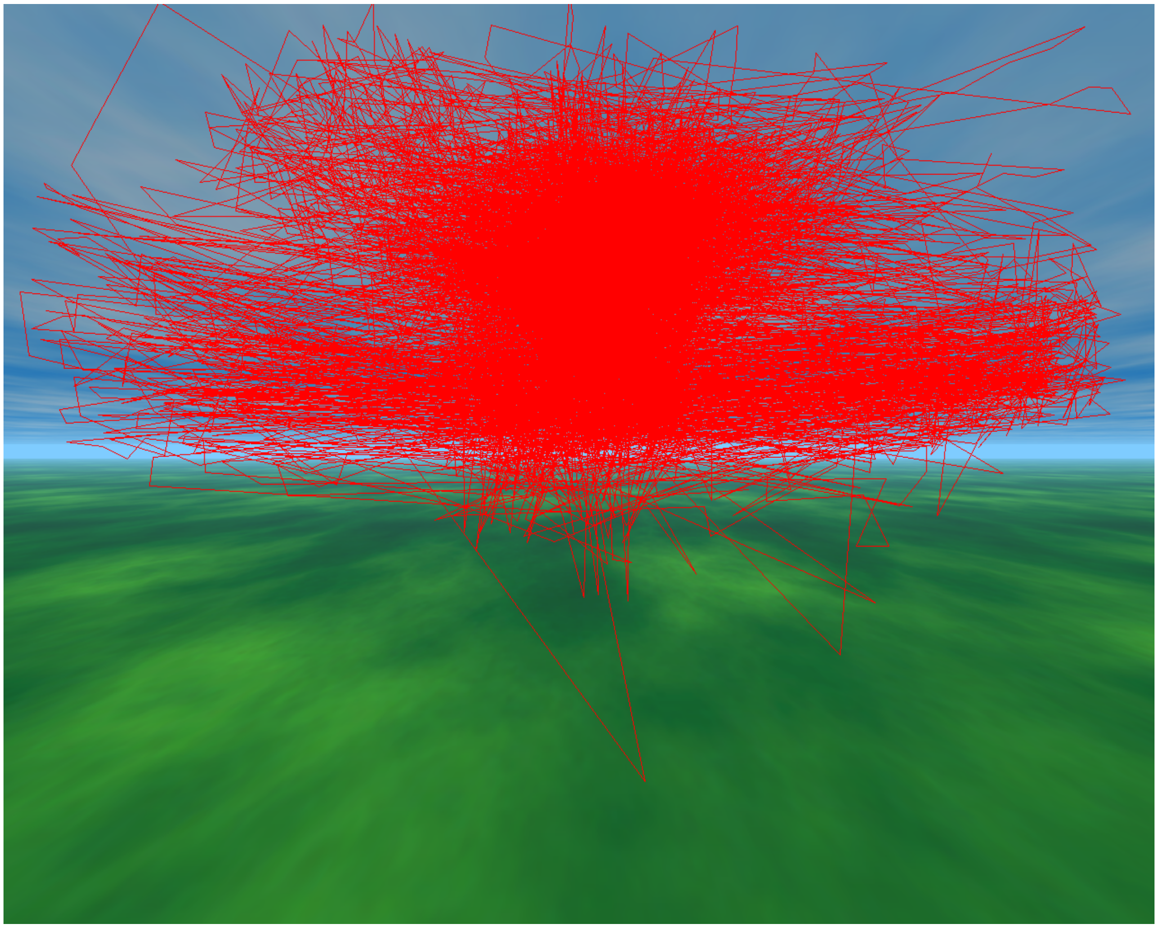


Figure 12. Experiment 2 fixation sequences for all participants in the attend-up condition. The red lines represent changes in eye position, and the vertexes represent fixations.

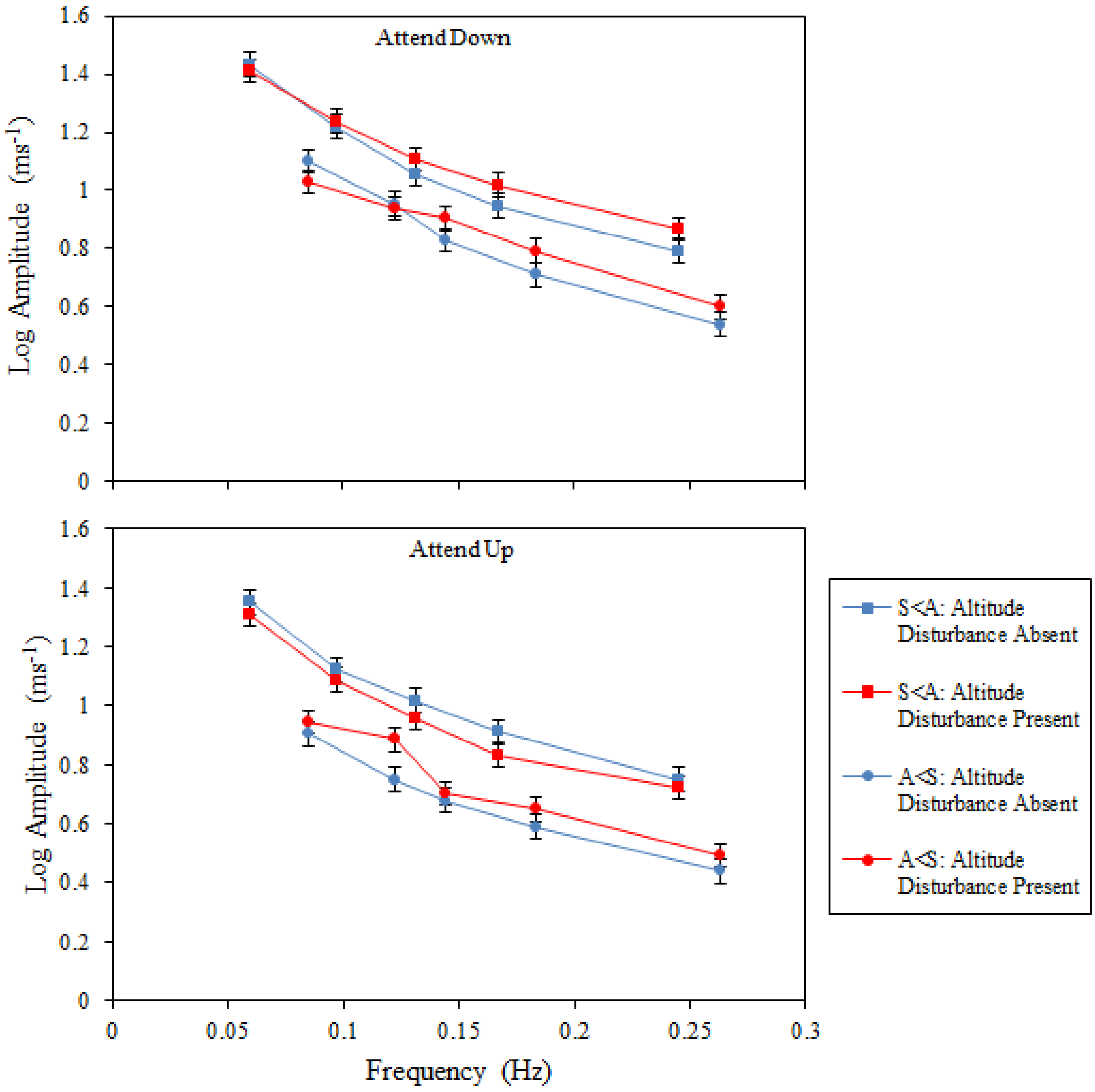


Figure 13. Combined Analysis: Log joystick amplitude at the altitude disturbance frequencies plotted by frequency, attention, frequency assignment, and altitude disturbance.

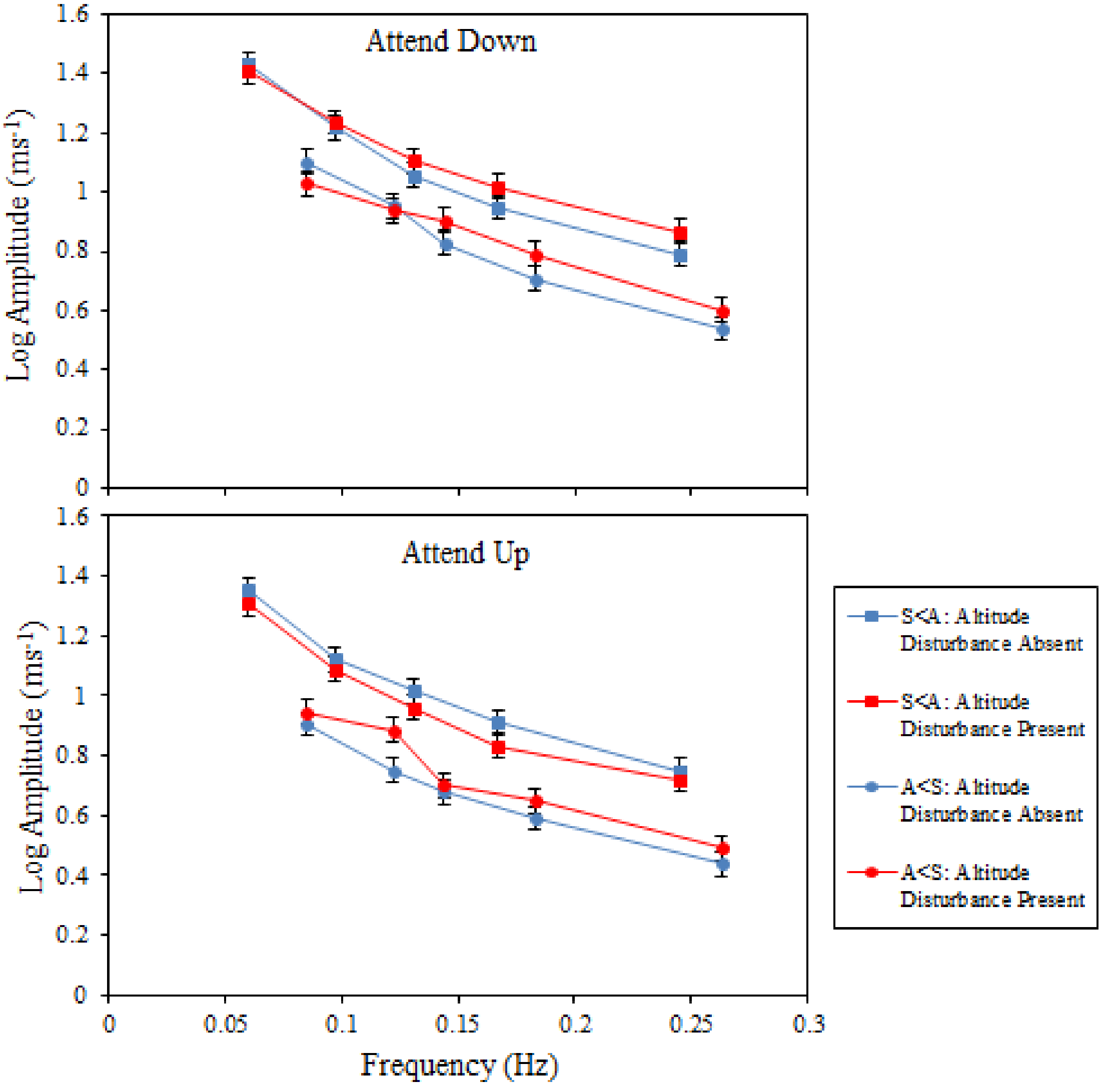


Figure 14. Combined Analysis: Log joystick amplitude at the speed disturbance frequencies plotted by attention, altitude disturbance, and frequency assignment.

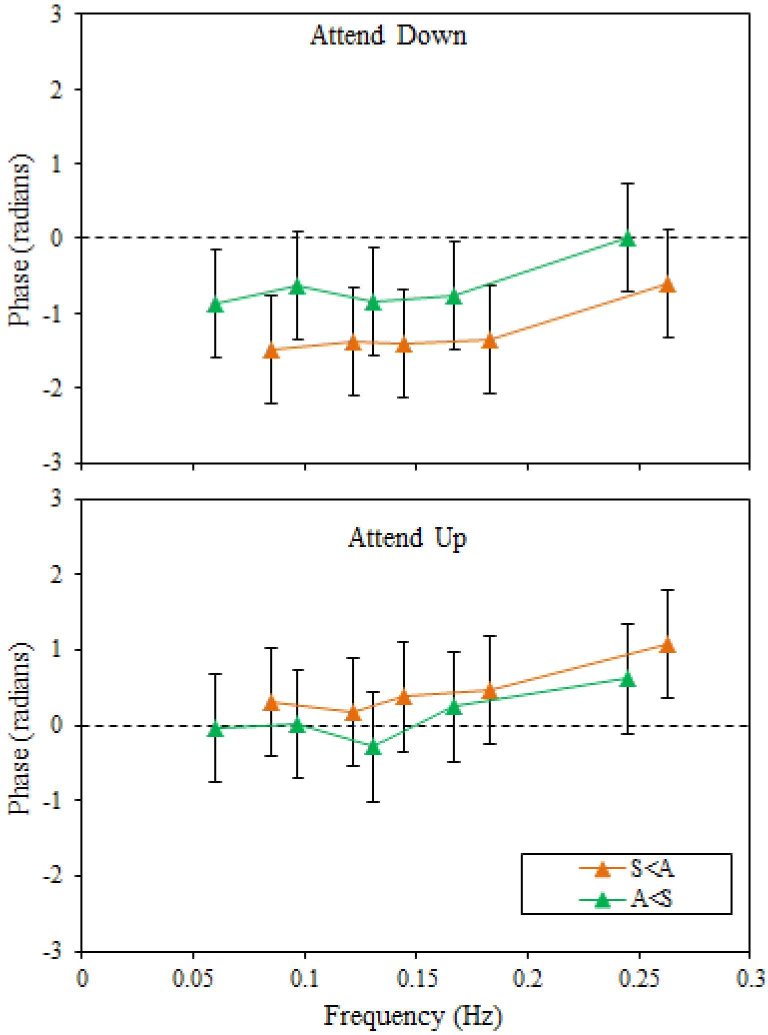


Figure 15. Combined Analysis: Joystick phase lag plotted by attention and frequency assignment at the altitude disturbance frequencies

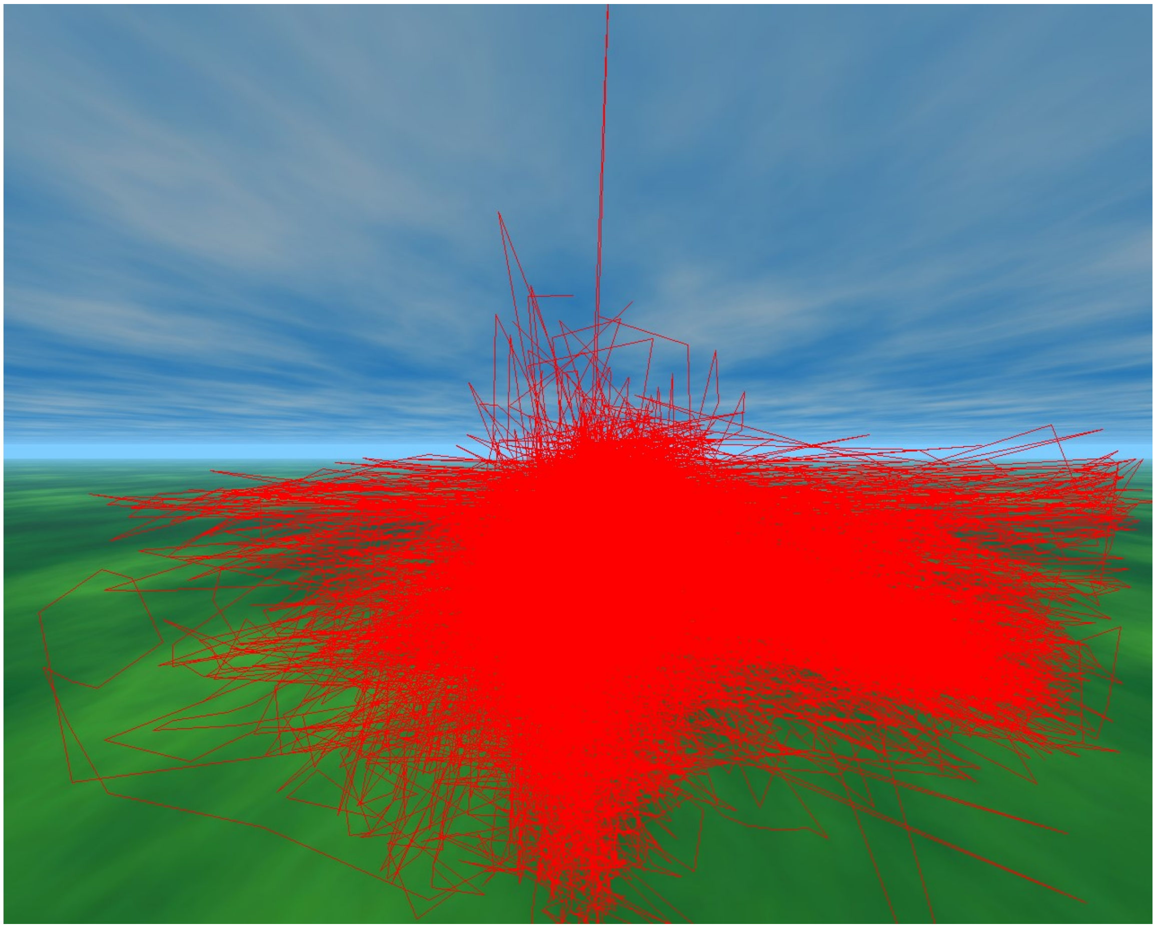


Figure 16. Combined Analysis: Fixation sequences for the attend-down condition. The red lines represent changes in eye position, and the vertexes represent fixations.

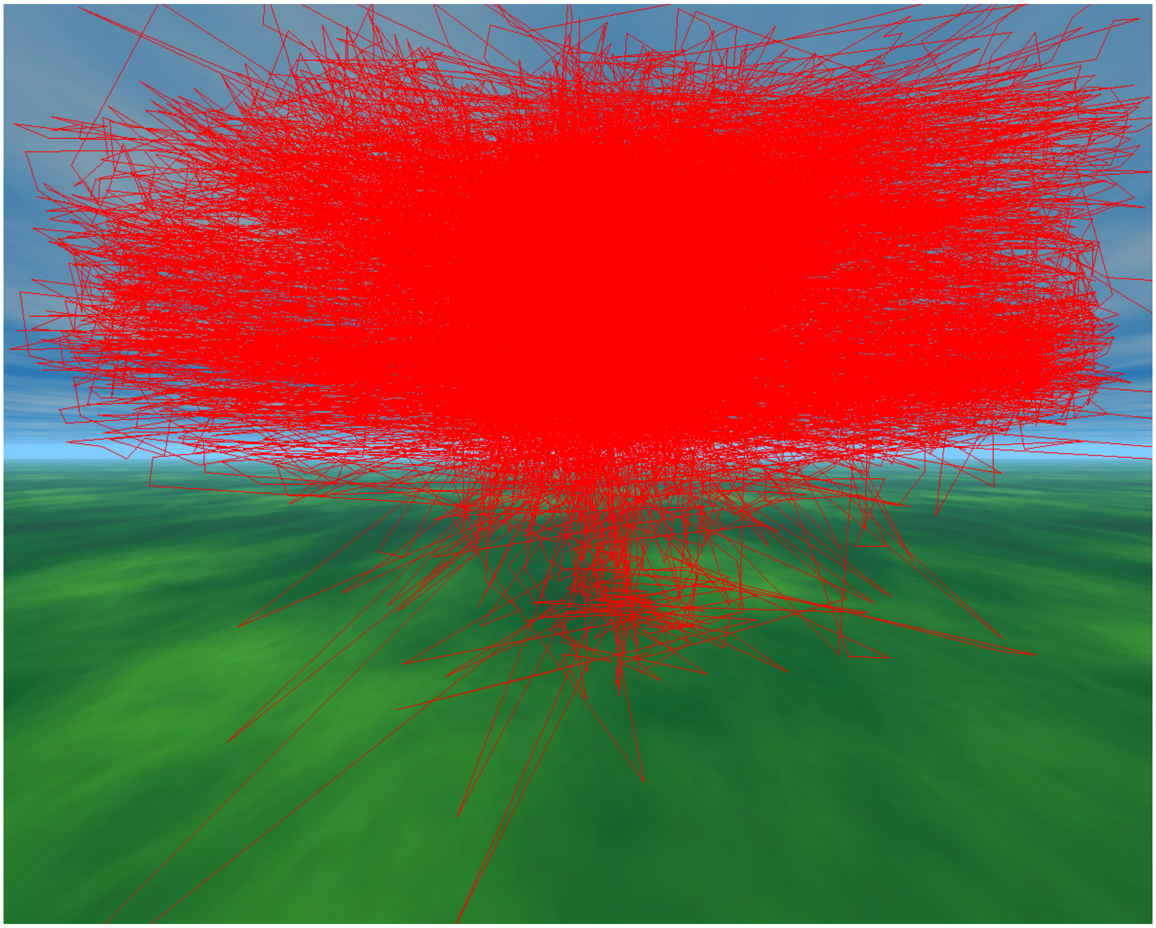


Figure 17. Combined Analysis: Fixation sequences for the attend-up condition. The red lines represent changes in eye position, and the vertexes represent fixations.

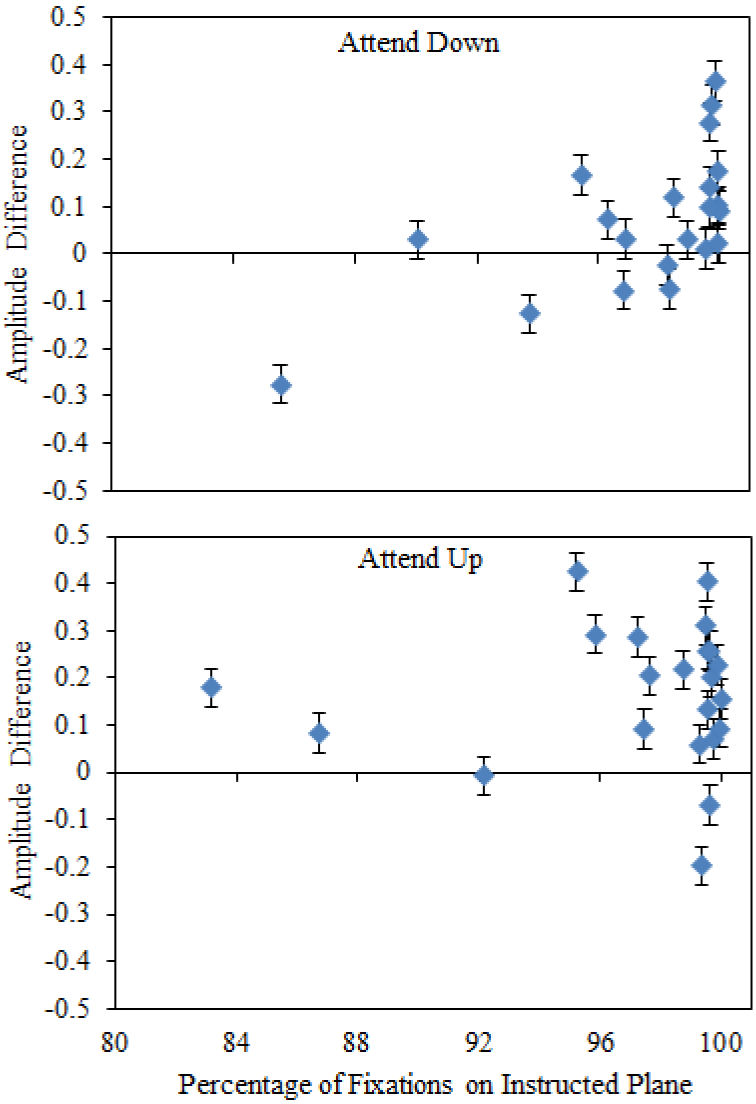


Figure 18. Combined Analysis: Scatterplot examining the relationship between the difference in joystick amplitude when the altitude disturbance was on versus when the disturbance was off, to the percentage of fixations on the instructed plane for each participant. Each blue diamond represents a data set for a participant.