Fall 2016

Effects of Auditory Vection Speed and Directional Congruence on Perceptions of Visual Vection

Isabella Alexis Gagliano
Old Dominion University

EFFECTS OF AUDITORY VECTION SPEED AND DIRECTIONAL CONGRUENCE ON PERCEPTIONS OF VISUAL VECTION

by

Isabella Alexis Gagliano
A.S. May 2011, Northern Virginia Community College
B.S. May 2012, Old Dominion University

A Thesis Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

PSYCHOLOGY

OLD DOMINION UNIVERSITY
DECEMBER 2016

Approved by:

J. Christopher Brill (Director)

Mark Scerbo (Member)

James Paulson (Member)

ABSTRACT

EFFECTS OF AUDITORY VECTION SPEED AND DIRECTIONAL CONGRUENCE ON PERCEPTIONS OF VISUAL VECTION

Isabella Alexis Gagliano
Old Dominion University, 2016
Director: Dr. J. Christopher Brill

Spatial disorientation is a major contributor to aircraft mishaps. One potential contributing factor is vection, an illusion of self-motion. Although vection is commonly thought of as a visual illusion, it can also be produced through audition. The purpose of the current experiment was to explore interactions between conflicting visual and auditory vection cues, specifically with regard to the speed and direction of rotation. The ultimate goal was to explore the extent to which aural vection could diminish or enhance the perception of visual vection. The study used a 3 × 2 within-groups factorial design. Participants were exposed to three levels of aural rotation velocity (slower, matched, and faster, relative to visual rotation speed) and two levels of aural rotational congruence (congruent or incongruent rotation) including two control conditions (visual and aural-only). Dependent measures included vection onset time, vection direction judgements, subjective vection strength ratings, vection speed ratings, and horizontal nystagmus frequency. Subjective responses to motion were assessed pre and post treatment, and oculomotor responses were assessed before, during, and following exposure to circular vection. The results revealed a significant effect of stimulus condition on vection strength. Specifically, directionally-congruent aural-visual vection resulted in significantly stronger vection than visual and aural vection alone. Perceptions of directionally-congruent aural-visual vection were slightly stronger vection than directionally-incongruent aural-visual vection, but not significantly so. No significant effects of aural rotation velocity on vection strength were observed. The results suggest directionally-incongruent aural vection could be used as a countermeasure for visual vection and directionally-congruent aural vection could be used to improve vection in virtual environments, provided further research is done.

Keywords: self-motion, circular vection, motion perception, illusions

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Spatial disorientation is a serious problem for aviation, and is the single most common cause of human-related aircraft mishaps. Between 1990 and 1999, the United States Air Force reported 36 spatial disorientation-related mishaps, resulting in the loss of 44 aircrew and a cost of $557 million (Heinle & Ercoline, 2003). Spatial disorientation is a major contributor to 25-33% of all aircraft mishaps, and of those, the fatality rate is close to 100% (Gibb, Ercoline, & Scharff, 2011).

One cause of spatial disorientation is vection, the illusion of self-motion in the direction opposite the motion of a visual scene or stimulus (Riecke, Väljamäe, & Schulte-Pelkum, 2009). A common example of vection is the false perception of rolling backwards at a stoplight, when in reality the adjacent car has edged forward while your car has remained stationary. This illusion could be dangerous, for example, when it causes an individual to make incorrect control inputs, resulting in an accident.

Vection can also be created by auditory stimuli, although the illusion tends to be weaker than visually-induced vection (Riecke, Schulte-Pelkum, Caniard, & Bülthoff, 2005a). However, relatively little is known about aurally-induced vection, and studies of the interactions between visually-induced and aurally-induced vection are scarce (Keshavarz, Hettinger, Vena, & Campos, 2014). Consequently, the purpose of the current experiment was to explore interactions between congruent and incongruent visual and auditory vection cues, specifically with regard to velocity and direction of rotation.

Vection and Spatial Disorientation

Vection occurs in aviation, for example during formation flight, when a pilot is unsure whether it was his or her own aircraft or the lead aircraft that was responsible for relative movements (Gillingham & Previc, 1993), possibly resulting in the pilot making incorrect control inputs and misjudging his or her velocity (Previc & Ercoline, 2004). Among helicopter pilots, vection occurs most frequently when hovering over open water, particularly at night in rough sea states (Ungs, 1989). At the altitudes at which helicopters operate, the surface of the ocean presents a wide, stable visual field in the pilot's periphery, while limiting the cues for central vision. As a result of this deprived visual scene characterized by few visual cues, helicopter pilots often experience vection. Rough sea states can also enhance the likelihood of vection occurrence due to the disorganized visual scene created by rough water and the increased motion in the visual scene from the waves. An aircraft's rotor wash creates concentric circles of outward moving waves when hovering over water. The rotor wash, combined with the rough sea motion, enhances the vection illusion (Ungs, 1989).

Vection can also occur when helicopter pilots initiate a low hover over loose surface material, (e.g., sand or snow; Cardullo, Zaychik, & Miura, 2012). Dust clouds kicked up by a helicopter's rotor downwash can degrade a pilot's view, resulting in a brownout. Brownout is the loss of outside spatial references and vection-induced spatial disorientation resulting from such degraded visual conditions (Patterson & York, 2009). Similarly, the visual field is usually dark and void at night, apart from the small space covered by the aircraft lights. This intensifies vection because the peripheral visual field is occupied by a large and indistinct space, and only a small area of central vision is illuminated (Anderson, 1986).

Pilots may respond to the illusion by employing inappropriate aircraft control movements, compromising flight safety. Additionally, pilots have reported that, in an attempt to maintain a stable hover, they moved the aircraft forward for several instants before realizing they had reacted to the vection illusion (Ungs, 1989). It only takes about 6 s for pilots to get into an unrecoverable state leading to an accident (Meuleau, Neukom, Plaunt, Smith, & Smith, 2011; Silva & Hansman, 2015). Ungs (1989) observed that over 90% of United States Coast Guard helicopter pilots had experienced vection.

Vection can also contribute to spatial disorientation when operating a craft extraterrestrially. Astronauts have reported vection when seated in the cockpit as little ice crystals stream past the spacecraft or while being moved by a robot arm during extravehicular activity (Previc & Ercoline, 2004). On Earth, the otolith organs of the vestibular system influence visual cues for spatial orientation, producing information about linear accelerations and head and body positions relative to gravity. The influence of the otolith organs is minimized in space, making vection particularly strong. Specifically, in microgravity vection can be enhanced by the dominance of visual cues and lack of body position validation by the otolith organs (Clément & Reschke, 2008; Young, 1993).

Influence of Velocity and Direction on Vection

Stimulus velocity also affects the perception of vection. Keshavarz et al. (2014) discovered that a simulated visual rotation velocity of 90 deg/s (15 rpm) produced a stronger perception of vection and shorter onset time than 60 deg/s (10 rpm). Similarly, Kennedy, Hettinger, Harm, Ordy, and Dunlap (1996) found that vection onset time was reduced when the rotation velocity was increased up to, but not faster than, 130 deg/s (21.67 rpm). They also discovered that perceived rotation velocity increased linearly with stimulus velocity, although actual velocities below 150 deg/s tended to be underestimated. Further, Riecke et al. (2004)

observed that a 40 deg/s velocity induced a stronger perception of vection than 20 deg/s. Similarly, perceived speed of vection increases with velocities up to 120 deg/s (Brandt, Dichgans, & Koenig, 1973).

Vection is commonly experienced in one of two planes of motion. Circular (or angular) vection involves perceived self-rotation around a pitch, roll, or yaw axis (Gillingham & Previc, 1993; Howard, Cheung, & Landolt, 1987). Linear vection refers to the perceived self-motion along a horizontal linear or vertical linear axis. The present investigation was restricted to circular vection.

Auditory Vection

Aurally-induced vection tends to be weaker and less compelling than visually-induced vection, which can be difficult to distinguish from actual motion (Brandt et al., 1973; Riecke et al., 2005a). Auditory cues alone are inadequate to reliably produce a strong perception of vection and aural vection only occurs in 25-60% of participants (Riecke et al., 2005a).

Lackner (1977) discovered that auditory vection and nystagmus (involuntary eye movements; Walls, 1962) could be produced when external sound sources were rotated around a blindfolded person. Additionally, he found that auditory vection could also be produced using stereo headphones. Knowledge concerning auditory vection can offer important contributions to many areas, including navigation in unfamiliar gravitoinertial environments (e.g., air or space), non-visual piloting, and auditory localization during flight, as well as multisensory incorporation of self-motion indications (Väljamäe, 2009).

Auditory vection rotation velocity has also been investigated. A stimulus velocity of 60 deg/s (10 rpm) can successfully produce auditory vection (Keshavarz et al., 2014; Lackner, 1977; Martens, 2004). Keshavarz et al. (2014) failed to find an increase in the intensity of vection with increases in rotation velocity (60 deg/s to 90 deg/s). Unfortunately, an analysis of a large range of rotational velocities is still absent from the literature for informing auditory vection research (Keshavarz et al., 2014).

Audiovisual Vection

Presenting information through single modalities provides an incomplete or unclear representation of the natural environment. To better understand the environment, humans integrate cues from all of their senses (Wuerger, Hofbauer, & Meyer, 2003). For objects in motion, both visual and auditory motion signals are correlated and supply information about an object's direction and velocity (Gibson, 1957). Generally, congruent stimulation from multiple modalities enhances our ability to correctly judge self-motion components, such as direction and speed during real or virtual locomotion (Butler, Campos, Bülthoff, & Smith, 2011; Durgin et al., 2005; Mohler, Thompson, Creem-Regehr, Pick, & Warren, 2007; Sun, Lee, Campos, Chan, & Zhang, 2003). In everyday life, humans integrate cues from multiple senses, including both visual and aural sources of vection. Väljamäe (2009) mentioned that directional congruence between a moving sound and a moving visual environment may be an important factor in correctly perceiving motion, but that any interaction between modalities that could have an effect on basic perception is not fully understood.

In the laboratory, Riecke et al. (2009) examined the interaction between auditory and visual vection in virtual reality, finding that auditory signals could facilitate the perception of visual vection by enhancing the strength and convincingness of vection through reduced vection onset time. In one study on auditory-vestibular sources of vection (i.e., physical rotation of a chair in darkness with simultaneous auditory stimulus rotation), Marme-Karelse and Bles (1977) discovered that incongruent auditory and vestibular cues produce a directionally unstable sensation of vection. Similarly, Schinauer, Hellmann, and Höger (1993) examined auditory-vestibular interactions by presenting congruent and incongruent rotating auditory stimuli (i.e., water splashes, stereophonic music, and a typewriter) during physical rotation. They determined that vection intensity ratings were significantly greater during the presentation of directionally-congruent stimuli, as compared to stationary or directionally-incongruent stimuli.

Although a few studies have assessed the multisensory interaction of visual and aural vection, there is still minimal research on the effects of audiovisual incongruence on vection. Past investigations have typically sought to facilitate vection rather than diminish it. For example, McAnally and Martin (2008) assessed sound localization during visual vection using auditory 3D displays in an attempt to improve spatial information provided to pilots. They found that auditory location information about a source was integrated with visual information about head motion to determine the perceived location of the source. Their results supported the application of 3D audio displays in dynamic visual environments (e.g., an aircraft), suggesting that 3D auditory displays can aid performance in these environments by providing additional spatial information. Other researchers found the addition of congruent auditory cues matched for velocity could increase the strength of vection (Keshavarz et al., 2014). During fore-and-aft movements, the perception of vection was facilitated when corresponding sounds were included to supplement the visual environment (Seno, Hasuo, Ito, & Nakakima, 2012).

When assessing whether suprathreshold auditory motion biased perceptions in a visual motion detection task, Meyer and Wuerger (2001) observed biased responses in the perceived direction of visual motion that was in the same direction as auditory motion. This bias occurred even if the auditory and visual motion stimuli moved at different velocities or came from different locations. This finding demonstrates that auditory motion cues can influence the perceived direction of visual motion. Additionally, Riecke, Feuereissen, and Rieser (2008) studied the effects of vestibular stimuli representing actual motion (i.e., vibrations) on the perception of auditory circular vection. They found that mean perceived vection velocity estimates were lower than the actual stimulus velocity. Thus, participants' perceptions of velocity did not match actual stimulus velocity, a finding consistent with previous research on visual circular vection (e.g., Riecke, Heyde, & Bülthoff, 2005).

Benefits of Facilitating Vection

Although vection can contribute to spatial disorientation, there are some circumstances in which facilitating vection could be beneficial. Vection is a common feature in optokinetic drums, widescreen movies (e.g., IMAX), and vehicle simulators, as well as other virtual environments (Bubka & Bonato, 2010). Enhancing vection in virtual reality can improve the realism of simulations by improving the convincingness of simulations and increasing overall simulation effectiveness. Adding auditory cues to simulations can further enhance realism in simulations (particularly in driving and flight simulators) because whenever real world situations would include corresponding sounds, one would also expect to hear those sounds in virtual reality simulations, so the simulation would be more realistic (Riecke et al., 2009).

Additionally, adding aural vection cues in the same locations as visual landmarks using head-related transfer functions can enhance virtual reality simulations. Specifically, Riecke et al. (2005a) found that adding spatialized auditory cues to a naturalistic visual stimulus (a virtual market) could enhance vection, as well as overall sense of presence in a virtual environment. Further, improving vection may help users navigate in a virtual environment (Lowther, 1998). Audiovisual vection research is still in its early stages, and there is considerable information to gain concerning the different aspects of the aural-visual vection relationship. Väljamäe (2009) has expressed the need for more methodical studies on the influence of sound on circular and linear vection.

Vection and Nystagmus

The vestibulo-ocular reflex (VOR) stabilizes retinal images during head and body movements (Naito et al., 2003; Raphan & Cohen, 2002). Nystagmus, involuntary eye movements comprised in the VOR (Cohen & Raphan, 2004; Walls, 1962), is a physiological correlate of vection. Nystagmoid eye movements include two distinct mechanisms: a delayed, compensatory period in the direction to the reverse of head motion (smooth pursuit eye movements), and a rapid, restorative phase (saccadic eye movements). Rotating visual stimuli can produce optokinetic nystagmus (Cohen & Raphan, 2004), while rotating auditory stimuli can produce audiokinetic nystagmus (Dodge, 1923; Hennebert, 1960; Lackner, 1977).

Even though vection frequently generates nystagmus, vection can be experienced in the absence of nystagmoid eye movements (Brandt et al., 1973). Additionally, Ji, So, and Cheung (2009) discovered that, as the velocity of a rotating pattern increases, the velocity of the slow-phase mechanism of optokinetic nystagmus increases. Researchers have also found a positive correlation between the frequency of nystagmus and subjective ratings of vection magnitude (Hu & Stern, 1998).

Current Study

Little research has been conducted to investigate the many ways in which visual and aural vection stimuli can interact, including the effects of velocity and directional incongruence. As a result, the goal of this research is to examine the effects of aural congruence on the perception of circular visual vection. Incongruence was achieved by presenting incongruent direction and velocity aural vection cues presented during visual vection through headphones. Based on the previous literature on visual and auditory vection, I hypothesize the following:

Hypothesis one: *Presenting directionally-congruent aural vection during constant-velocity visual vection will increase vection strength, relative to incongruent aural vection or visual vection alone.* This hypothesis is based upon findings that auditory signals enhance the perception of visual vection by reducing the vection onset time (Riecke et al., 2009). Likewise, there is a negative correlation between vection onset time and subjective vection strength (Väljamäe, Larsson, Västfjäll, & Kleiner, 2009), so vection strength should also increase. Additionally, Schinauer et al. (1993) found that vection intensity ratings were significantly higher during the presence of directionally-congruent auditory-vestibular stimuli than stationary or incongruent auditory stimuli. Congruent stimulation from additional modalities compared to a single modality generally improves the ability to accurately evaluate direction and speed during real or virtual locomotion (Butler et al., 2011; Durgin et al., 2005; Mohler et al., 2007; Sun et al., 2003).

Hypothesis two: *Presenting incongruent aural vection during constant-velocity visual vection will reverse the perceived direction of visually-induced vection, irrespective of velocity.* This hypothesis is based on evidence suggesting that auditory motion cues can influence the perceived direction of visual motion, thus, producing a bias in the perceived direction of visual motion consistent with the direction of auditory motion, regardless of the speed and location of the visual and auditory motion stimuli (Meyer & Wuerger, 2001). Conversely, Schinauer et al. (1993) found that vection intensity ratings were higher during the presence of directionally-congruent auditory-vestibular stimuli than incongruent auditory stimuli.

Hypothesis three: *Presenting directionally-congruent aural vection during constant-velocity visual vection will increase nystagmus frequency, relative to incongruent aural vection or visual vection alone, but only for matched aural-visual vection velocities.* Seno and Sato (2006) found that nystagmus strength was positively correlated with vection strength. As congruent auditory signals can enhance the perception of visual vection (Riecke et al., 2009), nystagmus strength should also increase. Velocity congruence is required because performance tends to decline with incongruent motion stimuli of other modalities (Craig, 2005; Soto-Faraco, Lyons, Gazzaniga, Spence, & Kingstone, 2002), which may reduce nystagmus frequency.

Hypothesis four: *Presenting velocity-matched aural vection during constant-velocity visual vection will increase vection strength, relative to velocity mismatched aural vection, but only if aural-visual vection is directionally-congruent.* This is based on findings that auditory signals can enhance the perception of visual vection by reducing the vection onset time (Riecke et al., 2009). Moreover, findings from Keshavarz et al. (2014) show that adding velocity congruent auditory cues to visual vection increased vection strength. Directional congruence is necessary because performance declines with incongruent motion stimuli of other modalities (Craig, 2005; Soto-Faraco et al., 2002).

Hypothesis five: *Presenting velocity mismatched aural vection during constant-velocity visual vection will alter perceptions of vection velocity.* Specifically, faster or slower aural vection will result in increased or decreased perceptions of vection speed, respectively, but only for directionally-congruent stimuli. This hypothesis is based on findings from Kennedy et al. (1996) that perceived circular vection velocity in an optokinetic drum increases linearly with the actual drum velocity, although there was a tendency to underestimate actual velocity. No investigations of a wide range of auditory rotational velocities have been completed for producing aural vection (Keshavarz et al., 2014), or for investigating interactions between ranges of visual and aural vection velocities. This hypothesis depends on directional congruence because incongruent motion stimuli of other modalities tend to reduce performance in judging aspects of motion (Craig, 2005; Soto-Faraco et al., 2002).

Hypothesis six: *Presenting velocity-matched aural vection during constant-velocity visual vection will increase nystagmus frequency, relative to velocity mismatched stimuli or visual vection alone, but only if vection is directionally-congruent.* Results from Keshavarz et al. (2014) suggest that adding velocity congruent auditory cues to visual vection increased the overall strength of vection. Additionally, there is a positive correlation between the frequency of nystagmus and subjective ratings of vection magnitude (Hu & Stern, 1998). Directional congruence is important because incongruent motion stimuli of other modalities tend to reduce performance and the ability to correctly assess self-motion aspects (Craig, 2005; Soto-Faraco et al., 2002), which may reduce nystagmus frequency.

CHAPTER 2

METHOD

Experimental Design

A 3 (velocity) × 2 (rotational congruence) within-groups factorial design was used for the current study. The independent variables were relative aural rotation velocity (slower at 5 rpm, matched at 10 rpm, and faster at 15 rpm) and rotational congruence (congruent versus incongruent). Two control conditions were also incorporated into the study (auditory only and one visual only), which yielded a total of eight within-groups conditions in the experiment. Table 1 shows all of the experimental conditions. The dependent variables were vection onset time, judgments of vection direction (CW or CCW rotation), perceived vection strength, perceived vection speed, and horizontal nystagmus from EOG.

Table 1

Experimental Conditions Including Visual and Auditory Only Controls

		Directional Congruence		
		Congruent	Incongruent	
Velocity	Slower	Congruent/Slower	Incongruent/Slower	
	Matched	Congruent/Matched	Incongruent/Matched	
	Faster	Congruent/Faster	Incongruent/Faster	
Controls				Visual Only
				Auditory Only

Participants

A power analysis using G*Power 3 for a repeated-measures model ANOVA with eight within-groups conditions produced a sample size of 24. The power analysis calculation assumed a small-medium effect size of $f = 0.25$, a power of .80, α of .05, a correlation between repeated measurements of 0.5, eight conditions, and 32 measurements. The number of randomized trials per participant (32) was determined using the number of trials in similar experimental designs (e.g., Riecke et al., 2009). A sample of $N = 25$ college students were recruited for study participation: 14 were female and 11 were male. The sample was made of up Old Dominion University students recruited from ODU Psychology Department's research participation system and compensated with research credit for their participation. Participant ages ranged from 18 to

25 years old (*M* = 19.7, *SD* = 2.2 years). Forty-eight percent of participants described themselves as White/Caucasian, 32% described themselves as Black or African-American, 8% as Asian, 8% as Hispanic or Latino, and 4% as Western Indian. Two participants failed to complete the full experiment and were excluded from analyses.

In order to be eligible for study participation, participants had to be enrolled in a psychology course at ODU and be at least 18 years old. Additionally, participants were required to complete an online questionnaire to prescreen for eligibility based on age, medical conditions, and visually-induced motion sickness symptoms. Exclusionary criteria included scoring above six on the simulator sickness questionnaire pretest, and having reported vestibular disorders, epilepsy, or a history of seizures, as these conditions have the potential to skew the results of the study and can affect physiological activity. Participants were also required to have normal to corrected vision and good hearing in both ears. A total of *N* = 360 participants were screened prior to study participation and *N* = 193 were eligible and invited to participate. Aural vection occurs in only a relatively small percentage of people, so all participants were screened for their ability to perceive aural vection prior to participation in the full experiment (Riecke, Feuereissen, Rieser, & McNamara, 2011). A sample of *N* = 27 college students were screened for aural vection prior to participation.

Stimuli and Apparatus

Aural Vection Stimuli. Three evenly-spaced sound sources (crickets, river sounds, and frogs) were used to create the auditory circular vection stimuli. Naturalistic auditory landmarks were used because they are more effective at generating auditory circular vection than artificial sounds (e.g., pink noise) (Larsson, Västfjäll, & Kleiner, 2004; Riecke, Västfjäll, Larsson, & Schulte-Pelkum, 2005). The aural vection velocities that were used were 5 rpm (30 deg/s; 50%

slower), 10 rpm (60 deg/s; matched), and 15 rpm (90 deg/s; 50% faster). A velocity of 60 deg/s can successfully produce aural vection (Keshavarz et al., 2014; Lackner, 1977; Martens, 2004). Additionally, an increase in the simulated rotation speed from 60 to 90 deg/s does not increase the intensity of aural vection (Keshavarz et al., 2014). The velocities selected for the aural vection stimuli were chosen because they are equal distances apart and an investigation of a wide range of auditory rotation speeds has not been completed for producing aural vection (Keshavarz et al., 2014). NASA Sound Lab 5.8 (SLAB) was used to render and synthesize the spatial audio stimuli for this study using head-related transfer functions. Aural vection stimuli created with NASA SLAB were presented to the participant using headphones (Sennheiser HD 280 Pro).

Optokinetic Drum (OKD). The OKD (see Figure 1) was used to present circular visual vection for this study. The OKD is a 4' diameter circular chamber that rotates around a seated participant. The chamber is constructed of white fabric wrapped around a steel wire frame. The interior walls of the device are white with a random black polka dot pattern (dot size = 56.74 cm^2) subtending visual angles ranging from 4.58 to 5.17 deg (to the full range of dots around the OKD). The visual angle for the current study was 5.17 deg. The OKD velocity was controlled using a wall-mounted dimmer switch with a range of 10-25 rpm (0.17 to 0.42 Hz). The OKD chamber contains an adjustable-height stylist chair with a hydraulic mechanism for standardizing eye height across participants.

The OKD was operated at 10 rpm (60 deg/s) for the current study, a velocity sufficient for inducing vection (Brandt et al., 1973; Kowalski, Rapps, & Enck, 2006). OKD direction was not manipulated as a between-groups variable because the direction of the vection-inducing stimulus has only been shown to be valid for inducing vection in vestibular vection cases (Lepecq, Waele, Mertz-Josse, Teyssèdre, Huy, Baudonnière, & Vidal, 2006). OKD direction was not used as a within-groups variable because changing the direction of rotation in one trial has been found to accelerate the onset of motion sickness (Bonato, Bubka, & Story, 2005).

Figure 1. The Optokinetic Drum.

BioNomadix Physiological Recording System. The EOG module of the BioNomadix physiological recording system (model BN-EOG2; BioPac Systems, Inc., Goleta, CA) was used to measure the frequency of horizontal nystagmus (slow, compensatory phase velocity). The BioNomadix EOG device consisted of a two-channel transmitter and receiver module. The transmitter is battery-operated and worn by the participant to amplify and send the data. The transmitter batteries are designed to provide continuous operation for up to 72 hr. Each transmitter is 6 cm wide × 4 cm high × 2 cm thick and weighs about 54 grams.

The receiver module sent data to a desktop computer where it could be monitored and recorded. The entire system was wireless. Acq*Knowledge* 4.2 for Windows (BioPac Systems, Incorporated, Goleta, CA) was used to produce an overall metric for horizontal nystagmus frequency (mHz).

SuperLab. SuperLab 5.0.1 for Windows is a program used to present various types of multimedia stimuli and record participant responses (Cedrus Corporation, San Pedro, CA). It was used for the presentation of aural vection stimuli and the acquisition of participant responses. It was also be used to play pre-recorded auditory instructions to participants throughout the experiment over connected headphones due to the visual nature of the optokinetic stimuli and because participants would be unable to focus on the stimuli if they were viewing written instructions.

Cedrus Response Pad. The Cedrus RB Series Desktop Response Pad (model RB-530), a USB-based device, was used to register participant responses in each trial (Cedrus Corporation, San Pedro, CA). It contains five keys with four rectangular buttons arranged around a centered circular button. The participants used the response pad, placed on their laps, by pressing any button to indicate when they experienced a perception of vection to provide a measure of vection onset time.

Subjective Measures

Medical Status Questionnaire. The medical status questionnaire (see Appendix A) was be used to determine prospective participants' eligibility for the study and to obtain demographic information from participants. This information was also used to eliminate prospective participants with potentially confounding conditions on the day of their study participation.

Some exclusionary conditions included having an ear infection, recently consumed alcohol, and any other visual or hearing impairment.

Vection Strength and Direction Scale. The vection strength scale was adapted from McAnally and Martin (2005) and Webb and Griffin (2003) to measure vection strength using the method of magnitude estimation. It consists of eleven items scored on an 11-point Likert-type scale in terms of the severity of vection (0 = *no vection* to 10 = *strongest feeling of vection*). Similar subjective vection strength rating scales were successfully administered in a number of other vection experiments (e.g., Ash, Palmisano, Govan, & Kim, 2011; Ito & Shibao, 1999; Kim, Palmisano, & Bonato, 2012; Nakamura & Shimojo, 1998; Palmisano, Bonato, Bubka, & Folder, 2007; Seno, 2013). Additionally, Palmisano et al. (2007) found that vection strength ratings are significantly related to simulator sickness symptoms. Vection direction was rated alongside vection strength in a scale adapted from Tanahashi, Ashihara, and Ujike (2015). It consists of 21 items in terms of the perceived direction and strength of vection (-10 to 0 to +10; positive numbers = *CW rotation* and negative numbers = *CCW rotation*).

Physiological Measure

Electro-oculography (EOG). EOG is a psychophysiological measurement technique for recording the resting potential of the retina in the human eye (Reilly & Lee, 2010). EOG was used to record participants' eye movements, specifically to assess horizontal nystagmoid eye movements, during the experiment. EOG data was recorded using disposable adhesive-backed electrodes from sites lateral, superior, and inferior to the eyes. A ground electrode was placed in the center of the forehead. Data analysis software, Acq*Knowledge* 4.2, was used to analyze and record EOG data. Frequencies of horizontal eye movements were analyzed for the full experiment. The mean slow-phase velocity of horizontal nystagmus (mHz) per participant was also calculated for each trial (45 s) (Kavanagh & Babin, 1986). Horizontal nystagmus frequency (mHz) was averaged for the visual-only trials and compared to the mean horizontal nystagmus frequency (mHz) at the onset of aural vection when both the visual and auditory stimuli were being presented simultaneously.

Procedure

This study was conducted in the Applied Sensory Psychology Laboratory at Old Dominion University. Upon arrival at the laboratory, the participant was given an overview of the study, and written informed consent was obtained from volunteers choosing to participate. The participant was initially screened for his or her ability to perceive aural vection. If the participant qualified for the experiment according to the aural vection screening, he or she completed the Medical Status Questionnaire. If the participant self-reported a disqualifying medical condition, he or she would be dismissed from the study (e.g., having an ear infection or having recently consumed alcohol). All eligible participants were then outfitted with electrodes for recording EOG. A small wireless transmitter connected to the electrodes was attached to the head using a Coban™ self-adhesive wrap and worn much like a headband. In some instances, medical tape was used to ensure that the transmitter was securely attached to the participant.

The participant was then seated in an adjustable stylist chair in the center of the OKD and given headphones (Sennheiser HD 280 Pro) and the Cedrus response pad for use for the duration of the experiment. The adjustable stylist chair was used because it includes a hydraulic mechanism to standardize eye heights across participants. The headphones were used to present auditory signals and pre-recorded instructions from the researcher. The Cedrus response pad was used to record participant responses for vection onset time.

The room was dimly lit to make the floor difficult to view, which could otherwise disrupt the illusion. Dim lighting is also desirable, as Lackner (1977) found that auditory stimuli were less successful in eliciting vection or nystagmus when participants were seated in a fully-illuminated visual environment. Baseline EOG recordings were taken for 2 min with the eyes open and not fixating on a particular point. No fixation point was used for the duration of the experiment because fixation on a central target greatly decreases nystagmus and marginally decreases vection (Stern, Hu, Anderson, Leibowitz, & Koch, 1990).

Before the experimental trials, the participant was presented with two practice trials to familiarize him or her with the experimental procedure. If the participant did not have any questions, the researcher would proceed with the full experiment. For the full experiment, the participant was asked to close his or her eyes and the OKD began rotating. Once the OKD reached the target velocity (10 rpm), the participant was asked to open his or her eyes on the count of three and view the visual vection stimulus from the OKD for 10 s. Participants observed the visual vection stimulus for 10 s because it takes several seconds from the start of the visual motion before participants typically perceive self-motion (2-30 s; Riecke, Schulte-Pelkum, Avraamides, Heyde, & Bülthoff, 2006). Before the participant opened their eyes, he or she was instructed to press any button on the Cedrus Response Pad when they experienced an illusion of self-motion (vection). Rotation direction of the OKD was initially counterbalanced and randomized, with half of the participants receiving clockwise rotation and half receiving counterclockwise rotation for the entire experiment.

Following exposure to the visual vection stimulus on the OKD, an aural vection stimulus was presented for 45 s because aural vection is a weaker illusion compared with visual vection, so 45 s was used to provide participants with sufficient time to experience vection with rotating sounds. The participant was then instructed to first, verbally indicate the perceived strength on the vection strength scale and direction of self-rotation on a scale of -10 to 0 to +10 (0 = *no feeling of vection* to 10 = *strongest feeling of vection*; positive numbers = *CW direction*, negative numbers = *CCW direction*) after the auditory signal was presented. Then the participant was asked to verbally indicate the perceived speed of vection [1(slow) to 10 (fast)] after the auditory signal was presented. The researcher recorded the participant's verbal responses with the keyboard in Superlab.

The participant was then asked to close his or her eyes for approximately 15 s until presentation of the next trial. The 15 s break was necessary to decrease possible motion aftereffects between trials (Riecke et al., 2009), carry-over effects from previous trials, and to reduce possible motion sickness incidence (nausea can be suppressed and even eliminated completely when participants close their eyes; Muth, Stern, & Koch, 1998). The participant was exposed to a total of 32 randomized trials, with four trials per condition (including visual and aural only control conditions). Using four trials per condition, Riecke et al. (2009) observed a large effect when comparing a stationary sound source to a spatialized sound source for vection convincingness ratings and vection build-up time.

EOG was recorded continuously for the duration of the study. After the final trial, the OKD was stopped and a 2 min "eyes open" posttest EOG recordings was taken to facilitate making comparisons between pre and post exposure eye movements. Then the experimenter removed the EOG recording equipment and electrodes, debriefed, and excused the participant from the study. Total study duration per participant took approximately 1.5 hrs.

CHAPTER 3

RESULTS

All statistical analyses were performed using IBM SPSS 22.0 for Mac (IBM Corporation, Armonk, NY) and Microsoft Excel 2010 for Mac. An alpha level of .05 was used to designate statistical significance for the omnibus tests. A moderate alpha level of .05 was selected due to the critical nature of vection and the potential applications in creating a countermeasure for spatial disorientation-induced vection. The data were screened for outliers, missing data, and errors, and were checked for violations of ANOVA test assumptions. Outliers were checked using boxplots and Studentized Residuals. Histograms indicated that the variables were normally distributed. Bonferroni corrections were used for all post-hoc tests to control for familywise type one error (alpha) inflation.

Hypothesis one, that presenting directionally-congruent aural vection during visual vection would increase vection strength relative to incongruent aural vection or visual vection alone, was tested using a one-way repeated-measures ANOVA. The independent variable was the stimulus condition (congruent, incongruent, visual only, and aural only). The dependent variable used was the mean rating of vection strength (0-10). Mauchly's Test of Sphericity indicated that the ANOVA assumption of sphericity was violated for stimulus condition, $\chi^2(5) = 29.34$, $p < .001$. A Greenhouse-Geisser correction was used because the estimated epsilon (ε) was less than 0.75.

A main effect of stimulus condition on vection strength was observed, wherein directionally-congruent vection ($M = 5.78$, $SD = 1.76$) was significantly greater than directionally-incongruent vection ($M = 5.36$, $SD = 1.53$), visual vection strength ($M = 4.43$, $SD =$

2.26), and aural vection strength (*M* = 2.34, *SD* = 2.06), $F(1.69, 40.44) = 28.28$, $p < .001$, partial $\eta^2 = 0.54$, observed power = 1.00 (see Table 2 and Figure 2).

Table 2

Analysis of Variance for Effects of Stimulus Condition (including Visual and Aural only vection) on Vection Strength Ratings

Source	*SS*	*df*	*MS*	*F*	partial η^2
Condition	176.16	1.69	104.56	28.28**	0.54
Error	149.50	40.44	3.70		

$^{*}p < .05$. $^{**}p < .01$.

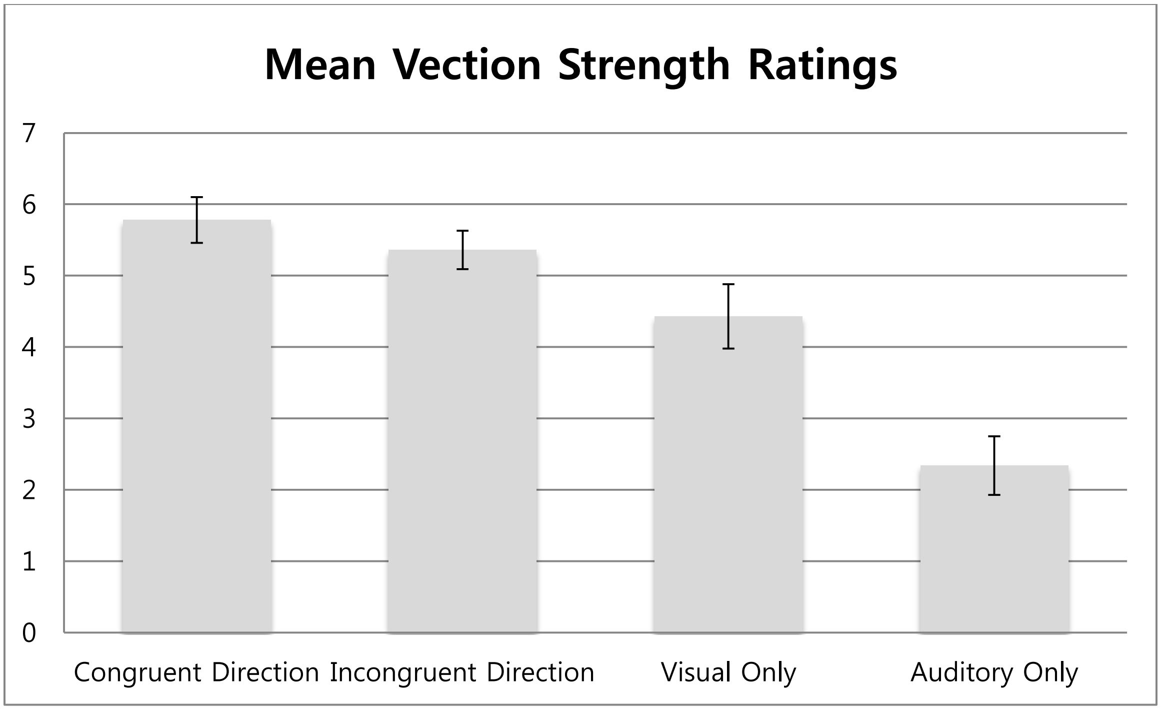

Figure 2. Mean Vection Strength Ratings for Congruent vs. Incongruent Aural Vection vs. Visual and Auditory-Only Baseline Conditions. Possible values were 0-10.

Post-hoc tests using the Bonferroni correction revealed that directionally-congruent vection strength was significantly greater than both visual vection ($M = 5.78$ vs. $M = 4.43$; $p = .002$) and aural vection strength ($M = 5.78$ vs. $M = 2.34$; $p < .001$). Directionally-incongruent vection strength was significantly greater than both visual ($M = 5.36$ vs. $M = 4.43$; $p = .028$) and aural vection strength ($M = 5.36$ vs. $M = 2.34$; $p < .001$). Additionally, vection strength following visual vection alone was significantly greater than that of auditory vection alone ($M = 4.43$ vs. $M = 2.34$; $p = .01$). Directionally-congruent vection strength was not significantly greater than directionally-incongruent vection strength ($M = 5.78$ vs. $M = 5.36$; $p = .35$).

A planned comparison showed that directionally-congruent vection strength ($M = 5.78$, *SD* = 1.76), was greater than visual vection alone (*M* = 4.43, *SD* = 2.26), $F(1, 24) = 18.20$, $p < .001$, partial $\eta^2 = 0.43$. Table 3 displays mean vection strength for the stimulus conditions by directional congruence including the visual and auditory control conditions.

Table 3

Descriptive Statistics for Vection Strength Ratings by Directional Congruence

		95% Confidence Intervals		
Condition	*Mean*	*Min*	*Max*	*SE*
Congruent	5.78	5.12	6.44	0.32
Incongruent	5.36	4.81	5.92	0.27
Visual Only	4.43	3.50	5.37	0.45
Auditory Only	2.34	1.49	3.19	0.41

A one-way repeated-measures ANOVA was used to test hypothesis two, that presenting directionally-incongruent aural vection during visual vection would reverse the perceived direction of visually-induced vection. The independent variable was directional congruence of aural vection (congruent and incongruent) and the dependent variable was mean vection direction judgements (-10 to 0 to +10; positive numbers = CW, negative numbers = CCW). This was adjusted for signage before analysis to compare both clockwise and counterclockwise OKD rotation directions. The effect of directional congruence on perceived vection direction approached significance, $F(1, 24) = 3.96$, $p = .058$, partial $\eta^2 = 0.14$, observed power = .48 (see Table 4). Judgments of vection direction were universally consistent with OKD direction (Table 5).

Table 4

Analysis of Variance for Effect of Directional Congruence on Vection Direction Judgements

Source	*SS*	*df*	*MS*	*F*	partial η^2
Congruence	5.12	1	5.12	1.69	.07
Error	72.88	24	3.04		

$^{*}p < .05$. $^{**}p < .01$.

Table 5

Descriptive Statistics for Vection Direction Judgments by Directional Congruence and OKD Direction

		95% Confidence Intervals		
Condition	*Mean*	*Min*	*Max*	*SE*
Congruent (Aural)				
Clockwise (Visual)	-3.75	-6.28	-1.22	1.15
Slower (Aural)	-3.71	-6.52	-0.90	1.28
Matched (Aural)	-3.48	-6.22	-0.74	1.24
Faster (Aural)	-3.96	-6.48	-1.44	1.15
Counterclockwise (Visual)	+3.85	+1.68	+6.01	0.99
Slower (Aural)	+4.60	+2.47	+6.72	0.98
Matched (Aural)	+3.88	+1.63	+6.13	1.03
Faster (Aural)	+3.12	+0.69	+5.54	1.11
Incongruent (Aural)				
Clockwise (Visual)	-2.75	-5.39	-0.11	1.20
Slower (Aural)	-3.23	-5.82	-0.64	1.18
Matched (Aural)	-2.50	-5.49	+0.49	1.36
Faster (Aural)	-2.40	-4.95	+0.16	1.16

Table 5 Continued

		95% Confidence Intervals		
Condition	*Mean*	*Min*	*Max*	*SE*
Incongruent (Aural)				
Counterclockwise (Visual)	+4.15	+2.64	+5.67	0.70
Slower (Aural)	+4.29	+2.55	+6.03	0.80
Matched (Aural)	+3.48	+1.39	+5.57	0.96
Faster (Aural)	+4.50	+3.23	+5.77	0.58

Note. Positive values correspond to perceived clockwise rotation (CW) and negative values correspond to perceptions of counterclockwise rotation (CCW).

A two-way repeated-measures ANOVA was used to test hypothesis three, that presenting directionally-congruent aural vection during visual vection would increase horizontal nystagmus frequency compared to incongruent aural vection or visual vection alone, but only for matched vection velocities. The independent variables were directional congruence of aural vection (congruent and incongruent) and aural vection velocity (slower, matched, and faster velocities, relative to visual rotation velocity). The dependent variable was mean horizontal nystagmus frequency from EOG (mHz). The interaction between directional congruence and aural vection velocity on horizontal nystagmus frequency was not significant, $F(2, 48) = 0.36$, $p = .70$. See

Table 6 for the results of the ANOVA.

Table 6

Analysis of Variance for Effects of Directional Congruence and Aural Vection Velocity on Horizontal Nystagmus Frequency from EOG

Source	*SS*	*df*	*MS*	*F*	partial η^2
Congruence	0.00	1	0.00	0.22	0.01
Error	0.10	24	0.00		
Velocity	0.02	2	213.18	2.65	0.10
Error	0.14	48	7.98		
Congruence × Velocity	0.00	2	0.00	0.36	0.02
Error	0.13	48	0.00		

$^{*}p < .05$. $^{**}p < .01$.

Two planned contrasts were completed. Mean horizontal nystagmus frequency during directionally-congruent and velocity-matched vection (M = 22.16, SD = 0.05) was significantly greater than that of visual vection alone (M = 22.12, SD = 0.07), $F(1, 24) = 10.99$, p =.003, partial $\eta^2 = 0.31$. Horizontal nystagmus frequency during directionally-congruent and velocity-matched vection (*M* = 22.16, *SD* = 0.05) was not significantly greater than that of directionally-incongruent velocity-matched vection (*M* = 22.17, *SD* = 0.05), $F(1, 24) = 0.30$, $p = .59$.

Hypothesis four, that presenting velocity-matched aural vection during constant-velocity visual vection would increase vection strength relative to velocity mismatched aural vection, but only if vection was directionally-congruent, was tested using a two-way repeated-measures ANOVA. The independent variables were directional congruence of aural vection (congruent and incongruent) and aural vection velocity (slower, matched, and faster velocities, relative to visual rotation velocity). The dependent variable was mean vection strength ratings (0-10).

The effect of directional congruence on vection strength approached significance, where directionally-congruent vection strength (*M* = 5.78, *SD* = 1.76) was greater than directionally-incongruent vection strength (*M* = 5.36, *SD* = 1.53), $F(1, 24) = 3.96$, $p = .058$, partial $\eta^2 = 0.14$, observed power = .48. An interaction between directional congruence and aural vection velocity on vection strength was not observed, $F(2, 48) = 0.36$, $p = .70$ (see Figure 3). Table 7 displays the results of this ANOVA test.

Vection strength consistently decreased for all directionally-congruent velocities, but the results were not significant. For directionally-incongruent vection, slower velocity vection strength (*M* = 5.42, *SD* = 1.68) was greater than that of matched velocity vection (*M* = 5.21, *SD* = 1.36), but not significantly so. Moreover, faster velocity vection strength (*M* = 5.45, *SD* = 1.59) was greater than that of matched velocity vection (*M* = 5.21, *SD* = 1.36), but not significant (see Figure 3). Vection strength was the lowest following directionally-incongruent and velocity-matched vection.

Additionally, vection onset time results were investigated because vection onset time has a negative correlation with vection strength. Moreover, participants were instructed to close their eyes as the OKD reached the target velocity (10 rpm), so vection onset time should be correlated with vection strength ratings. Post-hoc trend analyses of vection onset time approached significance, indicating that vection onset time increased linearly with directional congruence (congruent to incongruent) for all aural rotation velocities, $F(1, 24) = 3.08$, $p = .09$ (see Figures 4 and 5).

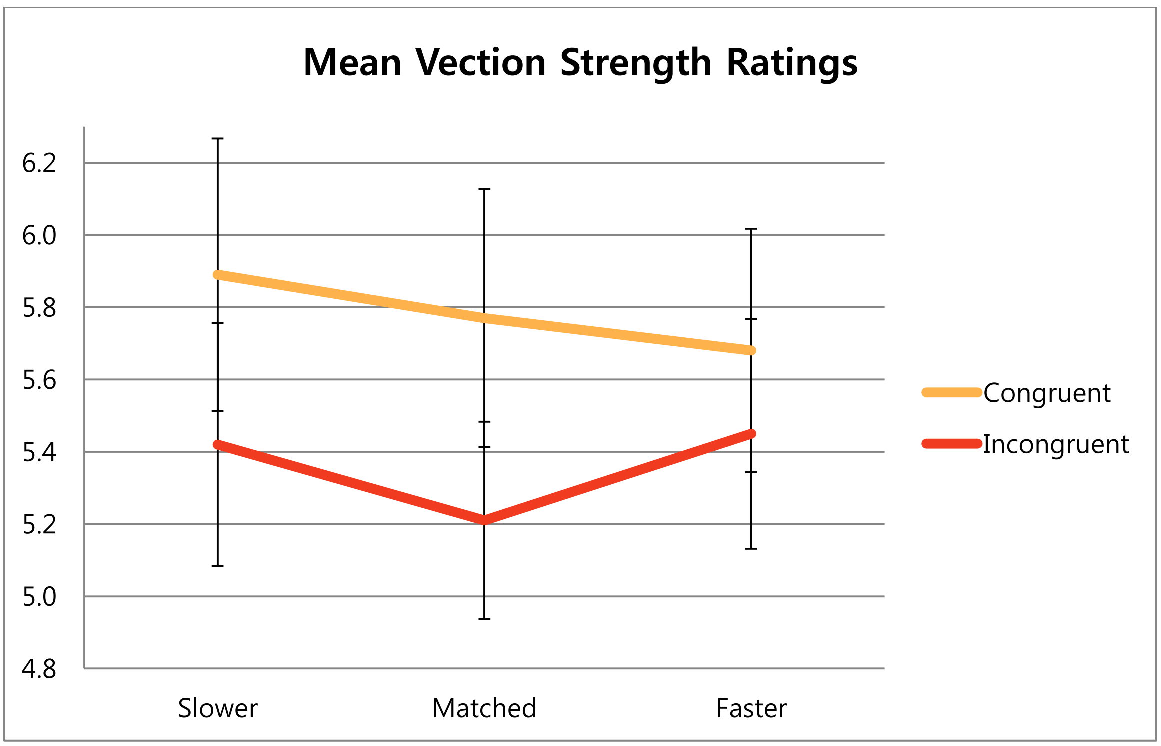

Figure 3. Mean Vection Strength Ratings for Rotation Directions and Velocities of Aural-Visual Vection. Possible values were 0-10.

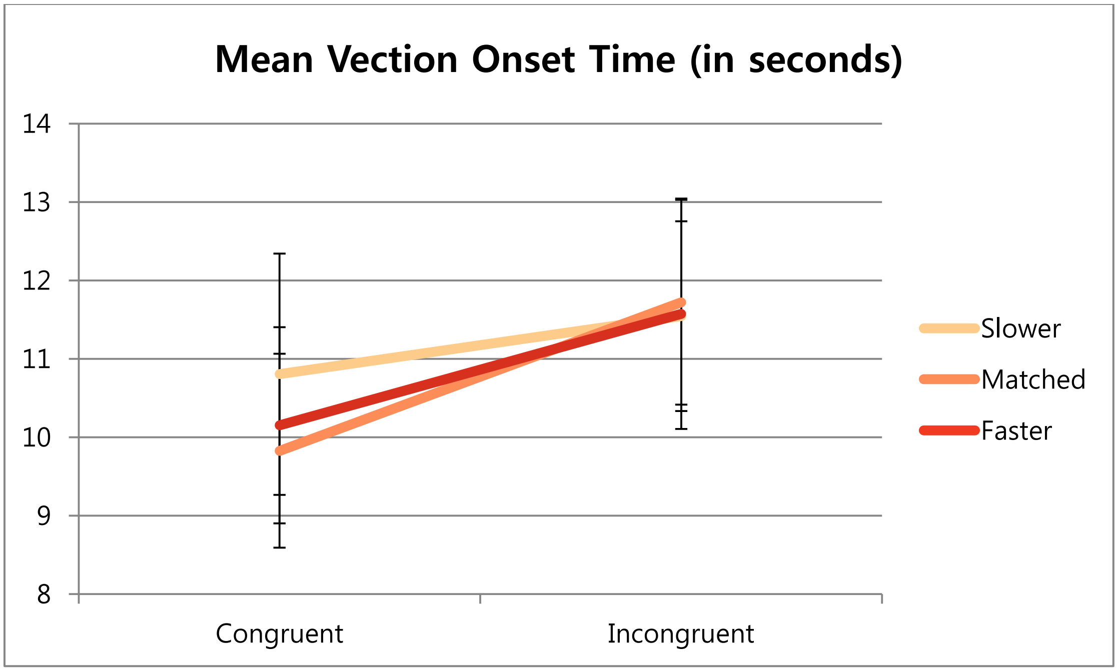

Figure 4. Mean Vection Onset Time for Rotation Directions and Aural Vection Velocities.

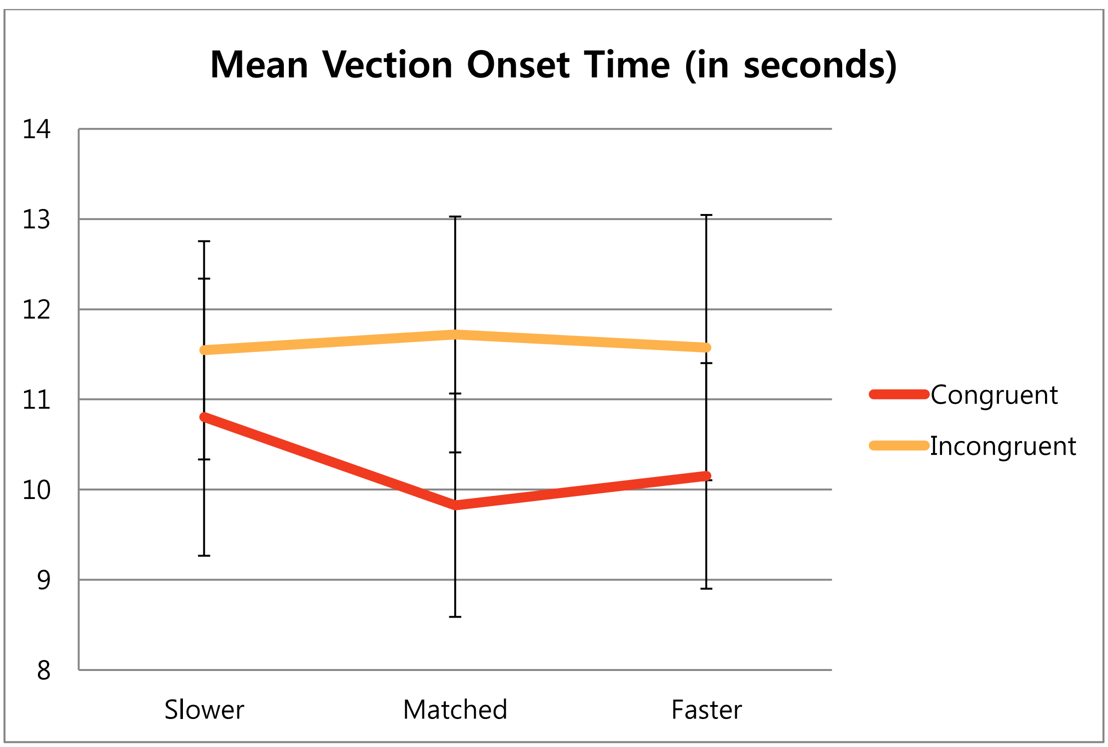

Figure 5. Mean Vection Onset Time for Aural Vection Velocities and Rotation Directions of Aural Vection.

Table 7

Analysis of Variance for Effects of Directional Congruence and Aural Vection Velocity on Vection Strength Ratings

Source	*SS*	*df*	*MS*	*F*	partial η^2
Congruence	6.62	1	6.62	3.96	0.14
Error	40.11	24	1.67		
Velocity	0.68	2	0.34	0.43	0.02
Error	38.53	48	0.80		
Congruence × Velocity	0.73	2	0.36	0.36	0.02
Error	48.36	48	1.02		

$^{*}p < .05$. $^{**}p < .01$.

A planned contrast comparison indicated that ratings of strength for velocity-matched and directionally-congruent vection ($M = 5.77$, $SD = 1.79$) were not significantly greater than for velocity-mismatched and directionally-congruent vection ($M_{slower} = 5.89$, $SD_{slower} = 1.88$, $M_{faster} = 5.68$, $SD_{faster} = 1.68$), $F(1, 24) = 0.004$, $p = .95$.

A two-way repeated-measures ANCOVA was used to test hypothesis five, that presenting velocity mismatched aural vection during constant-velocity visual vection would alter perceived vection speed, such that faster or slower aural vection would result in increased or decreased perceptions of vection speed, respectively, but only for directionally-congruent stimuli. The independent variables were directional congruence of aural vection (congruent and incongruent) and relative aural vection velocity (slower, matched, and faster velocities, relative to visual rotation velocity). The dependent variable was mean vection speed ratings (1-10). OKD direction was used as a covariate to determine its effect on perceived vection speed.

When controlling for OKD Direction, there was no significant interaction between relative aural vection velocity and directional congruence of aural-visual vection on perceived vection speed, $F(2, 46) = 1.18$, $p = .32$. However, there was a significant interaction between directional congruence and OKD direction on perceived vection speed, $F(1, 23) = 6.32$, $p = .019$, partial $\eta^2 = 0.22$, observed power = .67, wherein directionally-congruent vection speed perceptions ($M = 5.53$, $SD = 1.71$) were significantly greater than that of directionally-incongruent vection ($M = 5.44$, $SD = 1.59$). See Table 8 for the results of the ANOVA.

Table 8

Analysis of Covariance for Effects of Directional Congruence and Aural Vection Velocity on Vection Speed Ratings with OKD Direction as a covariate

Source	*SS*	*df*	*MS*	*F*	partial η^2
Congruence	4.81	1	4.81	4.90*	0.18
Congruence × OKD Direction	6.20	1	6.20	6.32*	0.22
Error	22.59	23	0.98		
Velocity	0.74	2	0.37	0.70	0.02
Velocity × OKD Direction	0.37	2	0.19	0.19	0.01
Error	12.84	48	0.27		
Congruence × Velocity	1.99	2	1.00	1.18	0.05
Congruence × Velocity × OKD Direction	0.93	2	0.47	0.55	0.02
Error	39.04	46	0.85		

$^{*}p < .05$. $^{**}p < .01$.

Post-hoc trend analyses indicated a slight, albeit not significant, linear trend for the aural vection velocity and directional congruence interaction on subjective vection speed, with mean vection speed increasing from directionally-congruent to directionally-incongruent aural vection and with increases in velocity, $F(1, 23) = 3.34$, $p = .08$.

Two planned contrasts were completed. Mean vection speed following faster velocity and directionally-congruent vection ($M = 5.47$, $SD = 1.90$) was not significantly faster than that of matched velocity and directionally-congruent vection ($M = 5.5$, $SD = 1.66$), $F(1, 24) = 0.01$, $p = .93$. Also, perceived vection speed following slower velocity and directionally-congruent vection ($M = 5.62$, $SD = 1.64$) was not significantly slower than matched velocity and directionally-congruent vection ($M = 5.5$, $SD = 1.66$), $F(1, 24) = 0.18$, $p = .67$.

During directionally-incongruent aural vection, mean vection speed increased with increases in aural vection velocity ($M_{\text{slower}} = 5.24$, $SD_{\text{slower}} = 1.79$, $M_{\text{matched}} = 5.36$, $SD_{\text{matched}} = 1.47$; $M_{\text{faster}} = 5.72$, $SD_{\text{faster}} = 1.53$), but not significantly so. During directionally-congruent aural vection, vection speed decreased with increases in aural vection velocity ($M_{\text{slower}} = 5.62$, $SD_{\text{slower}} = 1.64$, $M_{\text{matched}} = 5.5$, $SD_{\text{matched}} = 1.66$, $M_{\text{faster}} = 5.47$, $SD_{\text{faster}} = 1.90$), but not significantly. Figures 6 and 7 display the aural rotation velocity and directional congruence interaction on vection speed ratings.

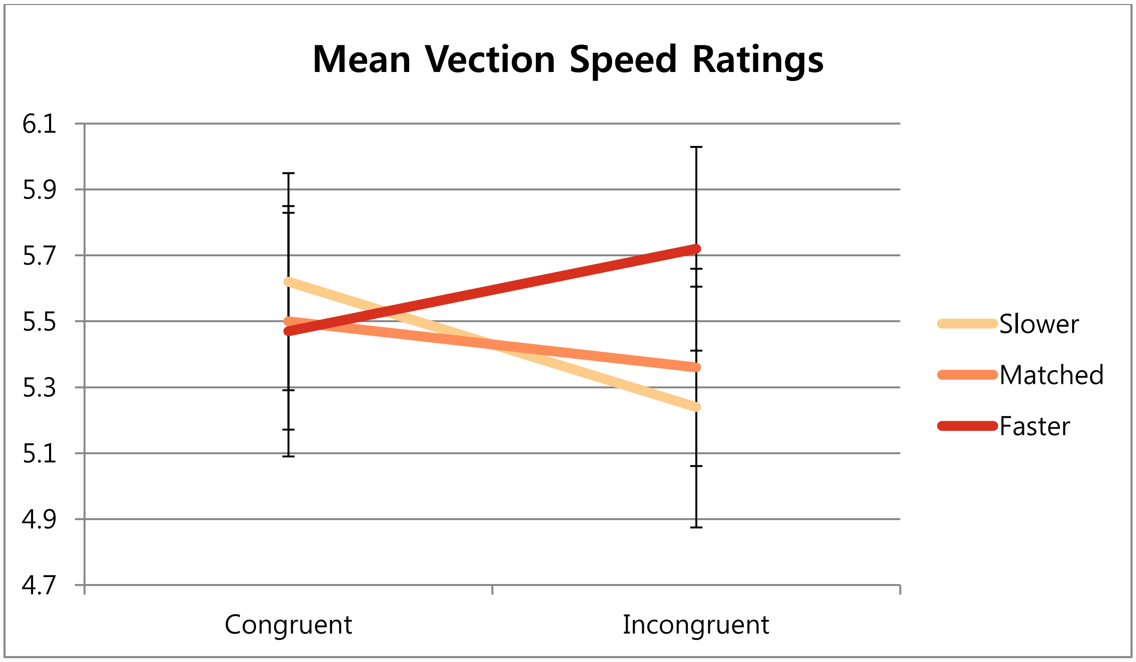

Figure 6. Mean Vection Speed Ratings for Aural Vection Rotation Direction by Aural Vection Velocity (Slower, Matched, and Faster). Possible values were 1-10.

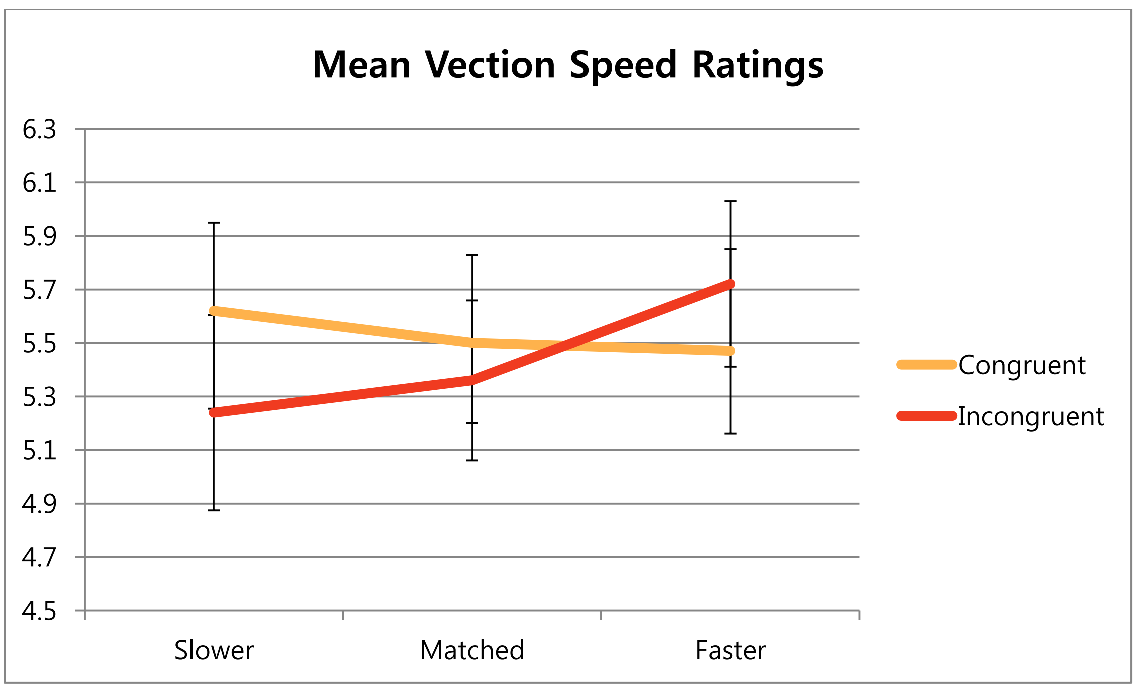

Figure 7. Mean Vection Speed Ratings for Aural Vection Velocity (Slower, Matched, and Faster) by Aural Vection Rotation Direction. Possible values were 1-10.

A two-way repeated-measures ANOVA was used to test hypothesis six, that presenting velocity-matched aural vection during constant-velocity visual vection would increase horizontal nystagmus frequency relative to velocity mismatched stimuli or visual vection alone, but only if vection was directionally-congruent. This was the same statistical test that was used to test hypothesis three, but with different planned comparisons. The independent variables were directional congruence of aural vection (congruent and incongruent) and aural vection velocity (slower, matched, and faster velocities, relative to visual rotation velocity). The dependent variable was mean horizontal nystagmus from frequency from EOG.

The interaction between directional congruence and aural vection velocity on horizontal nystagmus frequency was not significant, $F(2, 48) = 0.36$, $p = .70$. The effect of aural vection velocity on horizontal nystagmus frequency approached significance, wherein horizontal nystagmus frequency during slower velocity vection ($M = 22.15$, $SD = 0.06$) was not significantly less than that of matched velocity vection ($M = 22.17$, $SD = 0.05$) and faster velocity vection ($M = 22.17$, $SD = 0.06$), $F(2, 48) = 2.65$, $p = .08$. Table 6 shows the ANOVA results from hypotheses three and six.

Mean horizontal nystagmus frequency increased with aural rotation velocity. However, no pairwise comparisons of combinations of slower, matched, and faster aural vection velocities were significant (slower vs. matched, $M = 22.15$ vs. 22.17 mHz, $p = .35$; slower vs. faster, $M = 22.15$ vs. 22.17 mHz, $p = .18$; matched vs. faster, $M = 22.17$ vs. 22.17 mHz, $p = 1.00$). Moreover, post-hoc trend analyses indicated a near-significant linear trend for aural vection velocity on horizontal nystagmus frequency, $F(1, 24) = 3.91$, $p = .06$ (see Figure 8).

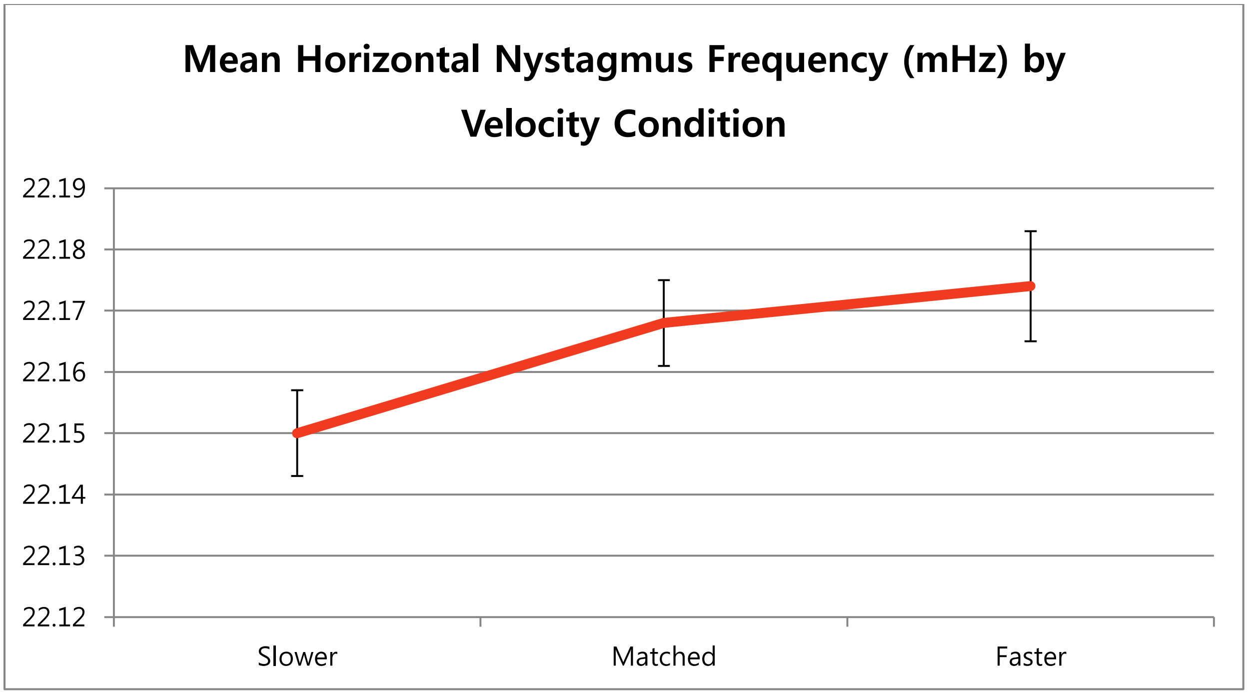

Figure 8. Mean Horizontal Nystagmus Frequency from EOG during Different Aural Vection Velocities (Slower, Matched, and Faster).

Two planned contrasts were completed. Mean horizontal nystagmus frequency during velocity-matched and directionally-congruent vection ($M = 22.16$, $SD = 0.05$) was significantly greater than that of visual vection alone ($M = 22.12$, $SD = 0.07$), $F(1, 24) = 10.99$, $p = .003$, partial $\eta^2 = 0.31$. There was no significant difference between horizontal nystagmus frequency during velocity-matched and directionally-congruent vection ($M = 22.16$, $SD = 0.05$) and velocity mismatched and directionally-congruent vection ($M_{slower} = 22.13$, $SD_{slower} = 0.04$, $M_{faster} = 22.17$, $SD_{faster} = 0.05$), $F(1, 24) = 0.09$, $p = .76$.

CHAPTER 4

DISCUSSION

The purpose of this experiment was to explore how visually and aurally-induced vection interact. I attempted this by using aural vection velocities faster and slower than visual vection and by reversing aural vection direction. The results suggested that hypothesis one was supported. Overall, directionally-congruent vection produced a stronger perceptual experience of vection than directionally-incongruent vection, visual, or aural vection alone. These results were consistent with findings from Riecke et al. (2009) that auditory signals enhanced the perception of visual vection. In another study, Keshavarz et al. (2014) found that the sensation of vection could be enhanced when visual and auditory signals were combined.

In accordance with the present study, Tanahashi et al. (2015) discovered that auditory cues alone produced a weaker perception of vection than that of visual cues alone. With regard to multimodal vection congruence, these results were consistent with previous research (Riecke et al., 2009; Seno et al., 2012). Their results indicated that auditory cues enhanced vection perception when the stimulus directions were congruent. Typically, congruent stimulation from multiple modalities, rather than one modality, can improve the ability to evaluate direction and speed during real or virtual locomotion (Butler et al., 2011; Durgin et al., 2005; Mohler et al., 2007; Sun et al., 2003).

Aural vection alone generated the weakest perception in the present study. Aural vection tends to be weaker than visual vection, with strong aural vection only occurring in a small number of people (Riecke et al., 2005a). Vection perception was only slightly weaker following directionally-incongruent vection than following directionally-congruent vection, and not significantly so. Previous investigations have found similar results. For example, Ash and Palmisano (2012) failed to find impaired vection strength with conflicting visual-vestibular sensory information. Past aural vection research has indicated that there was no difference in vection strength between aural rotation directions (CW and CCW, Väljamäe & Sell, 2014). Based on past literature, aural vection is weaker than visual vection, which explains why reversing the direction of aural vection rotation did not appear to have a large impact on overall vection perception in the current study.

Hypothesis two was not supported. Directionally-incongruent vection slightly reduced vection judgments, compared to congruent vection, but not significantly. Regardless of the direction of aural vection, vection direction perceptions were consistently opposite to the direction of the OKD (see Table 5). Again, this shows a consistent dominance of visual information on vection perception. Posner, Nissen, and Klein (1976) also found visual cues to be superior to auditory cues. Visual vection stimuli also tend to be stronger than aural vection stimuli (Riecke et al., 2005a). Generally, visual motion signals can also strongly affect the perception of auditory motion direction (Mays & Schirillo, 2005; Soto-Faraco, Spence, & Kingstone, 2004). The result of the current study is consistent with research by Kaliuzhna, Prsa, Gale, Lee, and Blanke (2015) involving conflicting directions of visual-vestibular vection. Their results indicated that the perceived direction of vection strongly depended on the visual stimulus direction. Additionally, in aural-visual vection research, Tanahashi et al. (2015) discovered that the perceived vection direction was determined by visual information when visual and auditory stimuli directions conflicted. Seno et al. (2012) also found that visual information dominates vection perception when visual and auditory motion cues conflict; vection strength and direction were similar to that of visual vection alone. Conversely, Meyer and Wuerger (2001) found that auditory motion cues could produce a bias in the perceived direction of visual motion consistent with the direction of auditory motion, regardless of the speed and location of the visual and auditory motion stimuli. However, those results did not involve vection perception.

Hypothesis three and hypothesis six were both partially supported. There was no significant interaction between directional congruence and aural rotation velocity on horizontal nystagmus frequency, as was hypothesized. Horizontal nystagmus increased with aural vection velocity, but directional congruence of vection did not have an effect on horizontal nystagmus frequency. Again, a potential reason for this result is visual dominance in vection perception (Posner et al., 1976); aural vection tends to be weaker than visual vection (Riecke et al., 2005a). The illusion produced by the visual cues used in this study may have been too compelling, as compared to the aural vection cues. Future investigations should attempt to strengthen aural vection or weaken visual vection before attempting more multimodal vection research involving aural vection. Reducing the velocity of the stimulus is one way to attempt to weaken visual vection (Keshavarz et al., 2014; Riecke et al., 2004). Aural vection can be strengthened with a naturalistic stationary sound source that matches a stationary object in the environment (Larsson at al., 2004; Riecke at al., 2005). Producing a more compelling aural vection stimulus may be more effective in weakening overall vection perception, and in turn, horizontal nystagmus, which a physiological correlate of vection.

The non-significant interaction between velocity and directional congruence of aural vection on horizontal nystagmus is inconsistent with previous results from Keshavarz et al. (2014). They found that adding velocity-matched auditory cues to visual vection increased vection strength. Additionally, as nystagmus frequency increases, subjective vection perception also typically increases (Hu & Stern, 1998); changes in eye movements over time also tend to increase as vection strength increases (Kim & Palmisano, 2010). That being said, adding velocity-matched and directionally-congruent auditory cues to visual vection stimuli should have increased overall vection perception, and in turn nystagmus frequency. Instead, as the aural rotation velocity increased, nystagmus frequency also increased, but not significantly so.

Additionally, horizontal nystagmus frequencies during slower aural vection velocities were not significantly lower than horizontal nystagmus during matched and faster velocities. This result is similar to findings from Cohen, Matsuo, and Raphan (1977), who found increases in peak optokinetic nystagmus as actual stimulus velocity increased up to 30 rpm. Furthermore, Ji et al. (2009) discovered that, as the velocity of a rotating pattern increased, the velocity of optokinetic nystagmus also increased. However, because the EOG frequencies for each stimulus condition were very similar, more research is needed to further test this hypothesis.

Results indicated that hypothesis four was not supported. The interaction between aural vection velocity and directional congruence on vection strength was not significant. Consistent with this result, Keshavarz et al. (2014) did not find increased aural vection intensity alongside increases in aural rotation velocity (10 rpm to 15 rpm). However, they found increased visual vection intensity as rotation velocity increased. The aural vection velocities used in this experiment may not have been fast or slow enough to detect a difference, or the range may have been too small to elicit this interaction on overall vection perception. Moreover, the OKD may have been too compelling, as compared to the aural vection stimuli. Currently, there are no studies investigating wide ranges of rotation velocities for producing aural vection (Keshavarz et al., 2014). Different aural vection velocities during visual vection could bring about the direction and velocity interaction on vection perception.

Additionally, the current study found that directionally-incongruent and matched velocities of aural vection produced the weakest vection perceptions. This is supported by findings from Keshavarz et al. (2014) that adding velocity congruent auditory cues to visual vection increased vection strength. Consequently, incongruent vection should weaken vection perception. Performance also tends to decline when the motion stimuli of other modalities are incongruent (Craig, 2005; Soto-Faraco et al., 2002), so vection perception should also weaken, respectively.

Hypothesis five was not supported. Changes in aural vection velocity did not significantly affect vection speed perceptions (for both directionally-congruent and incongruent directions of aural vection). However, during directionally-incongruent aural vection, increases in aural vection velocity increased vection speed perception. During directionally-congruent aural vection, perceived vection speed decreased as aural vection velocity increased. This result is in contrast to previous visual vection findings that perceived visual vection velocity increases linearly with actual stimulus velocity (Kennedy et al., 1996). Also, Brandt et al. (1973) found that perceived vection speed increases with stimulus velocities up to 20 rpm.

Keshavarz et al. (2014) did not find an increase in aural vection intensity as stimulus velocity increased (10 rpm to 15 rpm), which supports the present finding that directionally-congruent changes in aural rotation velocity do not increase vection speed perceptions. One possible reason why this hypothesis was not supported is that there are no investigations of wide ranges of auditory rotation velocities for producing aural vection (Keshavarz et al., 2014), or for investigating interactions between large ranges of visual and aural vection velocities. Likewise, only a small number of studies have investigated how auditory stimuli effect vection perception, and how it integrates with additional sensory cues. One explanation for this is the assumption that sound is less reliable than vision for spatial processing (Keshavarz et al., 2014).

Directional congruence of aural vection had a significant effect on perceived vection speed. This indicated that directionally-congruent vection produced faster perceived vection speeds than directionally-incongruent vection. This is supported by previous multisensory research findings. Congruent stimulation from multiple modalities compared to one modality typically improves the ability to judge direction and speed during real or perceived motion (Butler et al., 2011; Durgin et al., 2005; Mohler et al., 2007; Sun et al., 2003).

Out of the tested subjective vection measures, perceived vection strength and vection speed appeared to be the strongest subjective measures of vection when simultaneously altering the velocity and direction of aural vection. The other subjective vection measures (vection onset time and perceived vection direction) showed only small or non-significant effects.

Limitations and Future Directions

Due to the technical limitations of the OKD, the visual vection velocity could not be varied below 10 rpm. The OKD operates by a wall-mounted dimmer switch, which makes it difficult to reach a range of velocities. This could explain the failure to find significant effects of aural rotation velocity on overall vection perception. Different visual vection velocities may have better success in producing significant effects in combination with aural vection than just one velocity.

Moreover, it was difficult to equate the density of the dots on the OKD to the density of the aural vection stimuli due to the difference in modality and type of stimuli. Also, too many sounds rotating around a participant could have been confusing, potentially altering the results (Patterson & Mayfield, 1990). Ultimately, three sound sources were used to produce aural vection in this study. The number and type of sound sources should be altered in future investigations. Additionally, the naturalistic aural stimuli may have been more effective if it was paired with a naturalistic visual stimulus (e.g., a rotating image of a naturalistic scene). Likewise, sound sources usually associated with stationary visual landmarks are more effective in producing aural vection than artificial sounds or sounds that normally come from moving objects (Larsson at al., 2004; Riecke at al., 2005). This is thought to be due to participants' interpretations of the sound sources and the meaning they associated with a sound source, which suggests that top-down factors influence vection perception (Riecke et al., 2009). More research should also be completed in an effort to create a stronger aural vection stimulus to increase its effect on overall vection perception.

Due to the limited previous research on aural-visual vection, this research was exploratory. This research focused on the perception of circular aural-visual vection. Future research should explore the effect of linear aural-visual vection on vection strength. A wider variety of vection velocities should also be tested, both for visual and aural vection, as this experiment was restricted by the limitations of the OKD. Different combinations of vection modalities could also be used, such as incorporating tactile stimuli. Additionally, future investigations could use rotating external free-field sound sources from speakers rather than simulated head-related transfer functions through headphones to present aural vection, as this may create a stronger perception of vection.

The aural vection pre-screener may have been too easy to distinguish between stationary and rotating sounds, which could have limited the findings. All participants who were screened for aural vection passed the pre-screener. This is in in contrast to Riecke et al. (2005a) who found that 25-60% of participants experienced aural vection. Future investigations should use a more rigorous form of aural vection screening.

The population of participants in this study was restricted to college students. Although vection is a common perceptual phenomenon we experience daily, the participants in this study were naïve observers who had no previous experience with laboratory-induced vection or with making psychophysical judgments. Future research should assess the effects of direction and velocity of aural-visual vection on pilots or other trained observers who may experience vection in their professions in order to better apply the results in more real-world circumstances and improve the external validity of the present study.

Further, the sample size of this study may have provided insufficient statistical power to detect more nuanced differences. Several statistical tests trended towards significance, suggesting a larger sample size would have facilitate hypothesis confirmation. Individual differences could have also contributed to the results, so a larger sample might enhance these findings. That said, I employed a within-groups design specifically to control for between-subjects variability. Having a age-restricted sample (as a function of using a college-aged convenience sample) may have also contributed to the failure to confirm some hypotheses. Older adults have been shown to be better at integrating multisensory cues (Ramkhalawansingh, Keshavarz, Haycock, Shahab, & Campos, 2016), which could explain some of the non-significant results of the present study with participant ages ranging from 18 to 25. Future investigations should assess the effects of reversing directions and changing velocities of aural-visual vection on a population of both younger and older adults.

Moreover, a different vection-inducing stimulus may have better external validity than the OKD and rotating sounds used in this study. For example, a driving or flight simulator could be used to produce a stronger perception of vection. A researcher could then attempt to manipulate the perception of vection with sounds. Furthermore, the impact of workload during vection could be evaluated in future research by giving participants secondary tasks to complete while operating a simulator and experiencing vection. This would show how vection affects a person during a real-world situation, which could provide valuable insight.

Implications

The findings from the present study provide a basis for further understanding the interaction between visual and aural vection, specifically in terms of direction and velocity. These results may prove beneficial when applied to a number of environments (aircraft, automobile, or spacecraft). The presentation of auditory cues simultaneously with visual vection could be used as a vection countermeasure, potentially preventing mishaps and accidents. Pilots and others who regularly experience vection could be presented with a vection countermeasure (e.g., using incongruent auditory signals), which could weaken the overall perception of vection.

Once more research is completed on a larger range of aural vection velocities; those results could be incorporated into a vection countermeasure involving aural vection cues. There has been minimal aural-visual vection research completed to date, specifically on incongruence, and more research with incongruent aural and visual vection stimuli is recommended. Conversely, strengthening the vection illusion using congruent auditory cues could be beneficial in enhancing realism in virtual environments, theme park designs, widescreen movies, and video games. Enhancing vection perception could also aid users in navigating a virtual environment (Lowther, 1998). In addition, increasing the realism of simulators is valuable, as improved realism helps strengthen the perception of vection.

CHAPTER 5

SUMMARY

One cause of spatial disorientation, a leading contributor to aircraft mishaps, is vection, the illusion of self-motion in the direction opposite to the motion of a visual scene. The purpose of the current experiment was to explore interactions between conflicting visual and aural vection cues, specifically with regard to direction and velocity. Although aural vection tends to be weaker and less convincing than visual vection, there is some benefit to implementing it alongside visual vection to weaken or strengthen the overall perception of vection.

The results of this experiment showed that there was an overall effect of stimulus condition on vection perception. Directionally-congruent vection produced stronger vection than directionally-incongruent vection, visual, and aural vection alone. Aural vection rotating in the same direction as visual vection resulted in slightly stronger vection than aural vection rotating in the opposite direction, but not significantly. Specifically, aural vection rotating in the opposite direction of visual vection and matched in velocity produced the weakest vection perception. Aural vection velocity did not have a significant effect on vection perception. Directionally-incongruent aural vection significantly decreased vection speed perceptions, as compared to directionally-congruent aural vection. This research provides evidence that directionally-incongruent aural vection could be used as a countermeasure for visual vection.

The results of this experiment have the potential to aid transportation operators who experience vection and spatial disorientation. A visual vection countermeasure could be developed using incongruent auditory cues, to help weaken vection perception in a critical environment (e.g., aircraft). Conversely, there are a number of benefits that aiding vection can provide. An enhanced sense of vection can improve the realism of virtual environment simulations (Riecke, Schulte-Pelkum, Canaird, & Bulthoff, 2005b).

Again, due to the limited previous research on aural-visual vection, this research was exploratory. These results suggest that there is a multimodal association between visual and aural vection, but more research is needed to discover its extent. Future research should investigate larger ranges of aural vection velocities and, potentially, different vection directions (e.g., using linear vection). Future investigations could also examine participants who are regularly exposed to vection. More research is important, but this is a good start in attempting to weaken vection in a critical environment, and with more research, to possibly prevent it entirely.

REFERENCES

AcqKnowledge Software for Windows (Version 4.2) [Computer software]. Goleta, CA: BioPac Systems Incorporated.

Andersen, G. J. (1986). Perception of self-motion: Psychophysical and computational approaches. *Psychological Bulletin, 99*, 52–65. doi:10.1037/0033-2909.99.1.52

Ash, A., Palmisano, S., Govan, D. G., & Kim, J. (2011). Display lag and gain effects on vection experienced by active observers. *Aviation, Space, and Environmental Medicine*, *82*(8), 763-769.

Ash, A., & Palmisano, S. (2012). Vection during conflicting multisensory information about the axis, magnitude and direction of self-motion. *Perception, 41*(3), 253–267. http://doi.org/10.1068/p7129

BioNomadix Wireless Amplifiers and MP150 Data Acquisition System [Measurement instrument]. Goleta, CA: BioPac Systems Incorporated.

Bonato, F., Bubka, A., & Story, M. (2005). Rotation direction change hastens motion sickness onset in an optokinetic drum. *Aviation, Space, and Environmental Medicine*, 76(9), 823–827.

Brandt, T., Dichgans, J., & Koenig, E. (1973). Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. *Experimental Brain Research*, *16*(5), 476-491. doi:10.1007/BF00234474

Bubka, A., & Bonato, F. (2010). Natural visual-field features enhance vection. *Perception, 39*(5), 627-635. doi:10.1068/p6315

Butler, J. S., Campos, J. L., Bülthoff, H. H., & Smith, S. T. (2011). The role of stereo vision in visual-vestibular integration. *Seeing and Perceiving*, *24*(5), 453-470. doi:10.1163/187847511X588070

Cardullo, F., Zaychik, K., & Miura, R. (2012). Visually induced self-motion illusion in a flight simulator: Does it exist? State of research. In *AIAA Modeling and Simulation Technologies Conference* (Vols. 1-0). American Institute of Aeronautics and Astronautics. Retrieved from http://dx.doi.org/10.2514/6.2012-4792

Cedrus Corporation (2014). SuperLab (Version 5) [Computer software]. San Pedro, CA. Retrieved January 28, 2014. Available from http://www.superlab.com/

Clément, G., & Reschke, M. F. (2008). *Neuroscience in space*. Springer.

Cohen, B., Matsuo, V., & Raphan, T. (1977). Quantitative analysis of the velocity characteristics of optokinetic nystagmus and optokinetic after-nystagmus. *The Journal of Physiology, 270*(2), 321–344. http://doi.org/10.1113/jphysiol.1977.sp011955

Cohen, B., & Raphan, T. (2004). The physiology of the vestibuloocular reflex (VOR). In S. Highstein, R. Fay, & A. Popper (Eds.), *The Vestibular System* (Vol. 19, pp. 235–285). Springer New York. Retrieved from http://dx.doi.org/10.1007/0-387-21567-0_6

Craig, J. C. (2005). Visual motion interferes with tactile motion perception. *Perception, 35*(3), 351-367.

Dodge, R. (1923). Thresholds of rotation. *Journal of Experimental Psychology*, *6*(2), 107–137. doi:10.1037/h0076105

Durgin, F. H., Pelah, A., Fox, L. F., Lewis, J., Kane, R., & Walley, K. A. (2005). Self-motion perception during locomotor recalibration: More than meets the eye. *Journal of*

Experimental Psychology: Human Perception and Performance, 31(3), 398-419. doi:10.1037/0096-1523.31.3.398

Flanagan, M. B., May, J. G., & Dobie, T. G. (2004). The role of vection, eye movements and postural instability in the etiology of motion sickness. *Journal of Vestibular Research*, *14*(4), 335–346.

Gibb, R., Ercoline, B., & Scharff, L. (2011). Spatial disorientation: Decades of pilot fatalities. *Aviation, Space, and Environmental Medicine*, *82*(7), 717–724. doi:10.3357/ASEM.3048.2011

Gibson, J. J. (1957). Optical motions and transformations as stimuli for visual perception. *Psychological Review*, *64*(5), 288–295. doi:10.1037/h0044277

Gillingham, K. K., & Previc, F. H. (1993). *Spatial orientation in flight* (No. ADA279306). Brooks Air Force Base, TX: Armstrong Laboratory (AFMC).

Heinle, T. E., & Ercoline, W. R. (2003). *Spatial disorientation: Causes, consequences and countermeasures for the USAF*. DTIC Document.

Hennebert, P. (1960). Audiokinetic nystagmus. *Acta Oto-Laryngologica*, *51*, 412–415.

Hettinger, L. J., Berbaum, K. S., Kennedy, R. S., Dunlap, W. P., & Nolan, M. D. (1990). Vection and simulator sickness. *Military Psychology*, *2*(3), 171–181. doi:10.1207/s15327876mp0203_4

Hettinger, L. J., & Riccio, G. E. (1992). Visually induced motion sickness in virtual environments. *Presence: Teleoperators and Virtual Environments*, *1*(3), 306–310.

Howard, I., Cheung, B., & Landolt, J. (1988). Influence of vection axis and body posture on visually-induced self-rotation and tilt. *AGARD, Motion Cues in Flight Simulation and Simulator Induced Sickness*, 15-1-15-8.

Hu, S., & Stern, R. M. (1998). Optokinetic nystagmus correlates with severity of vection-induced motion sickness and gastric tachyarrhythmia. *Aviation, Space, And Environmental Medicine*, *69*(12), 1162–1165.

IBM SPSS Statistics for Mac (Version 22.0) [Computer software]. Armonk, NY: IBM Corporation.

Ito, H., & Shibao, T. (1999). Motion direction distribution as a determinant of circular vection. *Perceptual and Motor Skills*, *89*(2), 564-570.

Ji, J. T. T., So, R. H. Y., & Cheung, R. T. F. (2009). Isolating the effects of vection and optokinetic nystagmus on optokinetic rotation-induced motion sickness. *Human Factors*, *51*(5), 739–751. doi:10.1177/0018720809349708

Kaliuzhna, M., Prsa, M., Gale, S., Lee, S. J., & Blanke, O. (2015). Learning to integrate contradictory multisensory self-motion cue pairings. *Journal of Vision*, *15*(1), 1–15. http://doi.org/10.1167/15.1.10

Kavanagh, K. T., & Babin, R. W. (1986). Definitions and types of nystagmus and calculations. *Ear and Hearing*, *7*(3), 157-166. doi:10.1097/00003446-198606000-00007

Kennedy, R. S., Hettinger, L. J., Harm, D. L., Ordy, J. M., & Dunlap, W. P. (1996). Psychophysical scaling of circular vection (CV) produced by optokinetic (OKN) motion: Individual differences and effects of practice. *Journal of Vestibular Research: Equilibrium & Orientation*, *6*(5), 331-341.

Keshavarz, B., & Hecht, H. (2012). Stereoscopic viewing enhances visually induced motion sickness but sound does not. *Presence: Teleoperators and Virtual Environments*, *21*(2), 213–228. doi:10.1162/PRES_a_00102

Keshavarz, B., Hettinger, L. J., Vena, D., & Campos, J. L. (2014). Combined effects of auditory and visual cues on the perception of vection. *Experimental brain research*, *232*(3), 827-836.

Kim, J., & Palmisano, S. (2010). Eccentric gaze dynamics enhance vection in depth. *Journal of Vision*, *10*(12), 1–11. http://doi.org/10.1167/10.12.7

Kim, J., Palmisano, S., & Bonato, F. (2012). Simulated angular head oscillation enhances vection in depth. *Perception*, *41*(4), 402.

Kowalski, A., Rapps, N., & Enck, P. (2006). Functional cortical imaging of nausea and vomiting: A possible approach. *Nausea and Vomiting: An Interdisciplinary Approach*, *129*(1–2), 28–35. doi:10.1016/j.autneu.2006.07.021

Lackner, J. R. (1977). Induction of illusory self-rotation and nystagmus by a rotating sound-field. *Aviation, Space, and Environmental Medicine*, *48*, 129–131.

Larsson, P., Västfjäll, D., & Kleiner, M. (2004). Perception of self-motion and presence in auditory virtual environments. In *Proceedings of 7th annual workshop of presence* (pp. 252-258).

Lepecq, J.-C., Waele, C. D., Mertz-Josse, S., Teyssèdre, C., Huy, P. T. B., Baudonnière, P.-M., & Vidal, P.-P. (2006). Galvanic Vestibular Stimulation Modifies Vection Paths in Healthy Subjects. *Journal of Neurophysiology*, 95(5), 3199–3207. http://doi.org/10.1152/jn.00478.2005

Lowther, K. L. (1998). *Vection in a large-screen virtual environment*. University of New Brunswick, Fredericton, N.B., Canada.

Marme-Karelse, A. M., & Bles, W. (1977). Circular vection and human posture, II. Does the auditory system play a role?. *Agressologie*, *18*(6), 329.

Martens, W. L. (2004). The importance of perceived self-motion in experiencing convincing virtual acoustic rendering. *The Journal of the Acoustical Society of America*, *115*(5), 2514-2514. doi: 10.1121/1.4783159

Mays, A., & Schirillo, J. (2005). Lights can reverse illusory directional hearing. *Neuroscience Letters*, *384*(3), 336–338. http://doi.org/10.1016/j.neulet.2005.05.021

McAnally, K. I., & Martin, R. L. (2008). Localization of sound presented via a spatial audio display during visually induced vection in pitch, roll, and yaw. *Aviation, Space, and Environmental Medicine*, *79*(6), 611–615. doi:10.3357/ASEM.2248.2008.

Meuleau, N. F., Neukom, C., Plaunt, C. J., Smith, D. E., & Smith, T. B. (2011). The emergency landing planner experiment. *ICAPS 2011*, 60.

Meyer, G. F., & Wuerger, S. (2001). Cross-modal integration of auditory and visual motion signals. *Neuroreport*, *12*(11), 2557–2560. doi:10.1097/00001756-200108080-00053

Mohler, B. J., Thompson, W. B., Creem-Regehr, S. H., Pick Jr, H. L., & Warren Jr, W. H. (2007). Visual flow influences gait transition speed and preferred walking speed. *Experimental Brain Research*, *181*(2), 221-228. doi:10.1007/s00221-007-0917-0

Muth, E. R., Stern, R. M., & Koch, K. L. (1998). A psychophysiological paradigm for the study of nausea: A rotating optokinetic drum, the electrogastrogram and the nausea profile. *Journal of Psychophysiology*, *12*, 56-63.

Naito, Y., Tateya, I., Hirano, S., Inoue, M., Funabiki, K., Toyoda, H., … Ito, J. (2003). Cortical correlates of vestibulo-ocular reflex modulation: a PET study. *Brain*, *126*(7), 1562–1578. http://doi.org/10.1093/brain/awg165

Nakamura, S., & Shimojo, S. (1998). Stimulus size and eccentricity in visually induced perception of horizontally translational self-motion. *Perceptual and Motor Skills*, *87*(2), 659-663.

Nichols, S., Haldane, C., & Wilson, J. R. (2000). Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies, 52*(3), 471–491. doi:10.1006/ijhc.1999.0343

Palmisano, S., Bonato, F., Bubka, A., & Folder, J. (2007). Vertical display oscillation effects on forward vection and simulator sickness. *Aviation, Space, and Environmental Medicine*, *78*(10), 951-956.

Patterson, R. D., & Mayfield, T. F. (1990). Auditory warning sounds in the work environment [and Discussion]. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *327*(1241), 485-492.

Patterson, F., & York, Y. (2009). *Vection and motion thresholds as a function of contrast* (No. NAMRL-09-32). Naval Aerospace Medical Research Lab, Pensacola, Florida.

Posner, M. I., Nissen, M. J., & Klein, R. M. (1976). Visual dominance: An information-processing account of its origins and significance. *Psychological Review*, *83*(2), 157–171. http://doi.org/10.1037/0033-295X.83.2.157

Previc, F. H., & Ercoline, W. R. (2004). *Spatial disorientation in aviation* (1st ed., Vol. 203). Reston, VA: AIAA.

Ramkhalawansingh, R., Keshavarz, B., Haycock, B., Shahab, S., & Campos, J. L. (2016). Age differences in visual-auditory self-motion perception during a simulated driving task. *Frontiers in Psychology, 7*, 1-12. doi: 10.3389/fpsyg.2016.00595

Raphan, T., & Cohen, B. (2002). The vestibulo-ocular reflex in three dimensions. *Experimental*

Brain Research, *145*(1), 1–27. http://doi.org/10.1007/s00221-002-1067-z

Reilly, R. B., & Lee, T. C. (2010). Electrograms (ECG, EEG, EMG, EOG). *Technology & Health Care*, *18*(6), 443–458.

Riecke, B. E., Heyde, M. V. D., & Bülthoff, H. H. (2005). Visual cues can be sufficient for triggering automatic, reflexlike spatial updating. *ACM Transactions on Applied Perception (TAP)*, *2*(3), 183–215. doi:10.1145/1077399.1077401

Riecke, B. E., Feuereissen, D., & Rieser, J. J. (2008). Auditory self-motion illusions (circular vection) can be facilitated by vibrations and the potential for actual motion. In *Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization* (pp. 147–154). New York, NY, USA: ACM. doi:10.1145/1394281.1394309

Riecke, B. E., Feuereissen, D., Rieser, J. J., & McNamara, T. P. (2011, May). Spatialized sound enhances biomechanically-induced self-motion illusion (vection). In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2799-2802). ACM.

Riecke, B. E., Schulte-Pelkum, J., Avraamides, M. N., Heyde, M. V. D., & Bülthoff, H. H. (2006). Cognitive factors can influence self-motion perception (vection) in virtual reality. *ACM Transactions on Applied Perception (TAP)*, *3*(3), 194-216. doi:10.1145/1166087.1166091

Riecke, B. E., Schulte-Pelkum, J., Caniard, F., & Bülthoff, H. H. (2005a). Influence of auditory cues on the visually-induced self-motion illusion (circular vection) in virtual reality. *PRESENCE 2005*, 49.

Riecke, B. E., Schulte-Pelkum, J., Caniard, F., & Bülthoff, H. H. (2005b). Towards lean and elegant self-motion simulation in virtual reality. *Virtual Reality, 2005. Proceedings. VR 2005. IEEE*, 131–138. doi:10.1109/VR.2005.1492765

Riecke, B. E., Väljamäe, A., & Schulte-Pelkum, J. (2009). Moving sounds enhance the visually induced self motion illusion (circular vection) in virtual reality. *ACM Transactions on Applied Perception*, *6*(2), doi:10.1145/1498700.1498701

Riecke, B. E., Västfjäll, D., Larsson, P., & Schulte-Pelkum, J. (2005, July). Top-down and multi-modal influences on self-motion perception in virtual reality. In *HCI International*.

Schinauer, T., Hellmann, A., & Höger, R. (1993). Dynamic acoustical stimulation affects self-motion perception (pp. 373–385). Presented at the Contributions to Psychological Acoustics. Results of the 6th Oldenburg Symposium on Psychological Acoustics, BIS, Oldenburg, Germany.

Seno, T., Hasuo, E., Ito, H., & Nakajima, Y. (2012). Perceptually plausible sounds facilitate visually induced self-motion perception (vection). *Perception-London*, *41*(5), 577. doi: 10.1068/p7184

Seno, T., & Sato, T. (2006). Temporonasal motion induces stronger vection. *Journal of Vision*, *6*(6), 148-148. doi:10.1167/6.6.148

Seno, T. (2013). Social inhibition of vection. *Psychology*, *4*, 619.

Silva, S. S., & Hansman, R. J. (2015). Divergence between flight crew mental model and aircraft system state in auto-throttle mode confusion accident and incident cases. *Journal of Cognitive Engineering and Decision Making*, 1555343415597344.

Smart, L. J., Stoffregen, T. A., & Bardy, B. G. (2002). Visually induced motion sickness predicted by postural instability. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44*(3), 451–465. doi:10.1518/0018720024497745

Soto-Faraco, S., Lyons, J., Gazzaniga, M., Spence, C., & Kingstone, A. (2002). The ventriloquist in motion: Illusory capture of dynamic information across sensory modalities. *Cognitive Brain Research, 14*(1), 139-146.

Soto-Faraco, S., Spence, C., & Kingstone, A. (2004). Cross-modal dynamic capture: congruency effects in the perception of motion across sensory modalities. *Journal of Experimental Psychology: Human Perception and Performance, 30*(2), 330.

Stern, R. M., Hu, S., Anderson, R. B., Leibowitz, H. W., & Koch, K. L. (1990). The effects of fixation and restricted visual field on vection-induced motion sickness. *Aviation, Space, and Environmental Medicine*, *61*(8), 712–715.

Sun, H. J., Lee, A. J., Campos, J. L., Chan, G. S., & Zhang, D. H. (2003). Multisensory integration in speed estimation during self-motion. *Cyber Psychology & Behavior*, *6*(5), 509-518. doi:10.1089/109493103769710532

Tanahashi, S., Ashihara, K., & Ujike, H. (2015). Effects of auditory information on self-motion perception during simultaneous presentation of visual shearing motion. *Frontiers in Psychology*, *6*. http://doi.org/10.3389/fpsyg.2015.00749

Ungs, T. J. (1989). The occurrence of the vection illusion among helicopter pilots while flying over water. *Aviation, Space, and Environmental Medicine*, *60*(11), 1099–1101.

Väljamäe, A. (2009). Auditorily-induced illusory self-motion: A review. *Brain Research Reviews*, *61*, 240–255.

Väljamäe, A., Larsson, P., Västfjäll, D., & Kleiner, M. (2009). Auditory landmarks enhance circular vection in multimodal virtual reality. *Journal of the Audio Engineering Society, 57*(3), 111-120.

Väljamäe, A., & Sell, S. (2014). The influence of imagery vividness on cognitive and perceptual cues in circular auditorily-induced vection. *Frontiers in Psychology*, *5*, 1–8. http://doi.org/10.3389/fpsyg.2014.01362

Walls, G. L. (1962). The evolutionary history of eye movements. *Vision Research*, *2*(1), 69–80. doi:10.1016/0042-6989(62)90064-0

Webb, N., & Griffin, M. (2002). Optokinetic stimuli: Motion sickness, visual acuity, and eye movements. *Aviation, Space, and Environmental Medicine*, *73*(4), 351–358.

Webb, N. A., & Griffin, M. J. (2003). Eye movement, vection, and motion sickness with foveal and peripheral vision. *Aviation, Space, and Environmental Medicine, 74*(6), 622-625.

Wenzel, E. M., Miller, J. D., & Abel, J. S. (2000). Sound Lab: A real-time, software-based system for the study of spatial hearing. Presented at the Audio Engineering Society Convention 108, Audio Engineering Society.

Wuerger, S. M., Hofbauer, M., & Meyer, G. F. (2003). The integration of auditory and visual motion signals at threshold. *Perception & Psychophysics*, *65*(8), 1188–1196. doi:10.3758/BF03194844

Young, L. (1993). Space and the vestibular system: What has been learned? *Journal of Vestibular Research : Equilibrium & Orientation*, *3*(3), 203–206.

APPENDIX A

MEDICAL STATUS QUESTIONNAIRE

Old Dominion University
Applied Sensory Psychology Lab
Current Medical Status Evaluation

Date: _______________ Participant ID: _____________

1. Are you currently taking any medication (prescription and/or over-the counter)? Yes / No

   If yes, please list all medications below:

   _________________________________ _________________________________

   _________________________________ _________________________________

   _________________________________ _________________________________

2. a) How many hours of sleep did you get last night? __________ hours

   b) Was this amount sufficient? Yes / No

   c) How much sleep do you normally get per night? __________ hours

3. Have you been ill in the past week? Yes / No

   a) If yes, please describe: ____

   ____

   b) If you've been sick, are you fully recovered? Yes / No

4. Have you engaged in any physical activity in the past 24 hours, beyond your normal routine? Yes / No

   If yes, what and for how long: ____

   ____

5. Have you consumed any alcohol in the <u>past 24 hours</u>? Yes / No

   If yes, please specify what and how much:____

____

6. Have you consumed any caffeine (including energy drinks) in the <u>past 24 hours</u>? Yes / No

If yes, please specify what and how much:____

____

7. Have you consumed any nicotine (e.g., cigarettes, gum) in the <u>past 24 hours</u>? Yes / No

If yes, please specify what form and about how much: ___________________________________

8. Have you eaten a full meal within the past hour? Yes / No

If yes, please specify exactly what you consumed and about how much: ____________________

____

VITA

Isabella Alexis Gagliano
Psychology Department
Old Dominion University
Norfolk, VA 23529

Currently a master's student in the Experimental Psychology program at ODU, I graduated from ODU in May 2012 with a B.S. in Psychology with honors. I also hold an A.S. in Social Sciences from Northern Virginia Community College. I am interested in psychophysiological measurement techniques. Ultimately, I hope to succeed in a position where I can utilize the human factors psychology research skills I have learned in academia to make a difference in safety, health, or usability in the industry.

EDUCATIONAL EXPERIENCE

Old Dominion University, Norfolk, VA
Master of Science (MS) in Psychology
Major: Psychology   Current Overall GPA: 3.57
December 2016 (Expected)
Presentations:

- Gagliano, I., & Brill, J. C. (October, 2013). *Effects of Frequency and Acceleration on the Physiological and Subjective Responses to Motion.* Presented at the 2013 International Annual Meeting of the Human Factors and Ergonomics Society. San Diego, CA.

Related Courses: Methods, Measures, Techniques, and Tools in Human Factors, Human Factors Psychology, Sensation and Perception, Human Cognition, Multimodal Displays
Professional Memberships:

- HFES National: Student Affiliate Member, Perception and Performance Technical Group Member
- HFES ODU Student Chapter: Secretary (Fall 2013 - Spring 2014)
- Phi Kappa Phi Honor Society: General Member
- Golden Key International Honor Society: General Member

Old Dominion University, Norfolk, VA
Bachelor of Science (BS) in Psychology
Major: Psychology   Minor: Business Administration
Magna Cum Laude   Overall GPA: 3.78; Psychology GPA: 3.92
May 2012

Northern Virginia Community College, Sterling, VA
Associate of Science (AS) in Social Sciences
Major: Social Sciences
May 2011

WORK EXPERIENCE

Transportation Research Center Inc., East Liberty, OH
Research Analyst (February 2015 - Present)
Old Dominion University, Norfolk, VA
Research Participation Advisor (May 2013 - August 2014)