PERCEPTION OF CIRCULAR VECTION UNDER DIFFERENT VIEWING CONITIONS

By DU BO

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ABSTRACT

Visually induced circular vection (CV) has been the subject of many functional brain studies and behavioral studies. Unfortunately, participants in functional brain studies were in supine position while participants for behavioral studies were in upright positions. Consequently, their findings are confounded with viewing positions and there is no reported study comparing the effects of upright and supine positions on CV perception. This thesis examines the effects of viewing positions and their interactions with different angular velocity of the stimuli (2, 4, 8, 16, 32, 64 degree/second). Experiment 1 started with a rotating color dot pattern commonly used to provoke CV in functional brain studies. Effects of replacing the color dots with gray and black dots were investigated with different rotating velocities. Experiment 2 investigated the interacting effects of velocity and viewing position (upright and supine position) on CV. Results showed that red, gray, and black dots provoked similar levels of CV. Results also indicated that CV with the longest accumulated and average duration occurred at 32 deg/sec for supine position and at 8, 16 and 32 deg/sec for upright position. In addition, at slow velocities (2, 4 and 8 deg/sec), subjects perceived CV with longer accumulated and average duration when they were sitting in an upright position than lying in a supine position. Original data on accumulated and average CV duration under different velocities and body positions provide a vital link between findings of functional brain studies and behavioral studies. The findings that different CV are generated from supine and upright positions need to be further explored in the future.

CHAPTER 1: INTRODUCTION

1.1 Self-motion illusions (Vection) and its general characteristics

Term of vection is used to describe the phenomenon where a compelling self-motion illusion is experienced without physically moving. It is primarily induced by a large field-of-view stimulus pattern (Dischagans & Brandt, 1978), but it can also be elicited at a small field-of-view stimulus pattern (Andersen & Braunstein, 1985). Many readers might have experienced vection under natural conditions. Take the famous 'train illusion' as an example, when we sit in a stationary train and see another train move in the neighbouring track. We often get the compelling sensation that the train we are sitting in is moving in the opposite direction of neighbouring train while the neighbouring train seems to be stationary.

The researchers have studied vection for more than one century in the laboratories. Vision is the most common tool to elicit vection for vection study (So H.Y. and Lo W. T. et al., 2001; Chen D.J. and Bao et al., 2015). In recent years, non-visual stimuli (e.g. auditory cues, haptokinetic cues, arthrokinetic cues and bio-mechanical cues) (Keshavarz et al., 2014; Murata et al., 2014; Riecke et al., 2011) have been used to induce different kinds of non-visual vection.

According to the directions of visual motion stimulus, human normally experience vection as linear vection, circular vection and the combination of them termed as curve-linear vection. Specifically, linear vection can be forward-backward translation (Chen, D.J. and Bao, B. et al., 2015; Ji TT and So H. Y. et al., 2009), leftward-rightward translation and upward-downward translation. Circular vection can occur as roll, yaw and pitch vection along the three rotation directions (Figure 1.1). The perceived direction of vection is opposite to the direction of stimulus motion. In this dissertation, our study will focus on visually induced circular vection (CV).

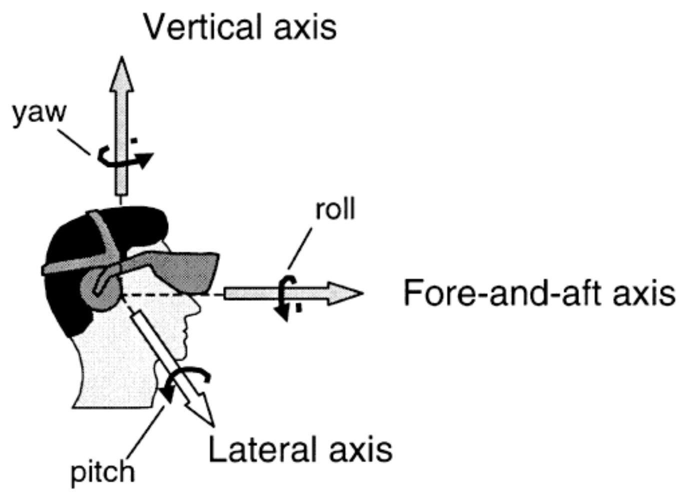


Figure 1.1 Linear and circular vection along three translational and rotating body-centric axes: roll, pitch and yaw axes (So H.Y. and Lo W.T., 2001).

1.1.1 Hypothetical time course of vection

Normally when presenting a large field-of-view visual moving stimuli pattern to subjects, they initially experience object motion at the first few seconds after the motion starts, following is an apparent body acceleration within 3-4 seconds whose rotating direction is opposite to object motion. During this transient period, subjects perceive a mixed object and self-motion with increasing vection intensity simultaneously. After an average of 8-12 seconds, subjects will perceive a steady state of rotation with strongest vection intensity. In this period, some observers may perceive only self-motion and earth-stationary, while some others may perceive both object and self-motion. Finally, vection may disappear due to a sudden eye blink or terminative stimulus (Brandt et al., 1973). Figure 1.2 illustrated hypothetical time course for vection.

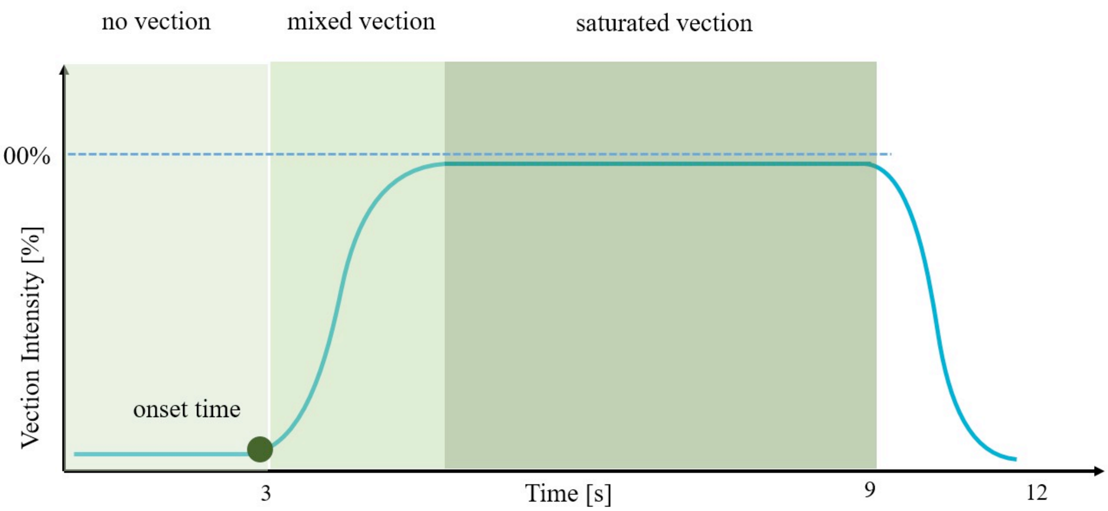


Figure 1.2 Hypothetical time course of vection (BE. Riecke et al., 2009)

1.1.2 The stimulus factors affecting visually induced CV

Most psychophysiology researchers studied vection by the means of behavior methods and they have investigated many factors affecting the visually induced CV. Such as, stimulus velocity (Brandt et a., 1973; Allison et al., 1999; Held et al., 1974; Ujike et al., 2004), field-of-view of stimulus (Brandt et al., 1973; Held et al., 1974; Anderson and Braunstein, 1985), central or peripheral vision (Brandt et al., 1973; Held et al., 1974; Nakamura, 2008), spatial frequency of the stimulus content (Palmisano and Gillam., 1998; Brandt et al., 1975), mono or multi colored stimulus (Bonato and Bubka, 2006; and Seno et al., 2010) and body position (Ujike et al., 2004). In this dissertation, angular velocity of stimulus, color and body position will be of particular interest to study.

1.2 Motivation to study visually induced vection

Nowadays, virtual reality stimulations combining immersive audio, vision, touch and feelings can recreate compelling sensory experiences to the audience. More recently, the development of graphics hardware and head-mounted displays (e.g. Oculus Rift) significantly popularize the virtual reality. Vection is a sharp and valid tool which can be utilized to provide more intriguing and compelling experiences to the audience. If researchers can find the ways to facilitate vection significantly, then IMAX theatres, large-screen theme parks and hemispheric dome displays can commercially utilize vection to better design the virtual system.

In addition of commercial use of vection, the understanding of how we experience vection, how different sensory is functionally modulating and working during vection can help us have a better understanding of the working mechanism of our brain.

1.3 Thesis outline

In this dissertation, the effects of color, velocity and body position on visually induced circular vection with variables of interests of vection duration, intensity were examined. Following is the summarized outline for each chapter.

Chapter 1 is a brief introduction of general characteristics of vection.

Chapter 2 will demonstrate the apparatus we used in three experiments in details, which includes visual stimulus generator, eye tracking system and the other experimental equipment. In addition, Chapter will describe some experimental parameters of measurement.

Chapter 3 is a comprehensive presentation of Experiment 1. Experiment 1 investigated the effects of color and angular velocity of visual motion stimulation with upright position on CV. In this chapter, literature review, research gaps, experimental design, procedures and data analysis will be shown. Chapter 4 discusses Experiment 2 in details. Two factors of body position and angular velocity of visual motion stimulation upon CV will be demonstrated in Chapter 4.

Ultimately, Chapter 6 will show major findings, conclusions, limitations of the experiments and future directions.

CHAPTER 2: APPARATUS AND MEASUREMENTS IN THE EXPERIMENTS

2.1 Apparatus in Experiment 1

The apparatus used in Experiment 1 contained two PCs, a Sony LCD, a chinrest, a keyboard and an eye tracker. One PC connected with LCD was used to generate the visual motion stimuli. Eye tracking system was installed in another PC to track eye motion of subjects during the experiments. Chinrest was standing at the edge of table to limit subject's head movement. Its height can be adjusted by subjects so that they can stare at the center of the screen at a distance of 50cm. A keyboard was placed close to subjects in which only '1' (labelled 'a') and '2' (''labelled 'b') in Number Pad area was left and the other keys were manually removed so that subjects could not mistakenly press the other keys during stimulus presentation. To avoid external light disturbance, a black-shading curtain was built beyond the LCD and chinrest to restrict field-of-view of subjects. Meanwhile, black cloth fully covered the table to prevent light reflection. Figure 2.1 demonstrates apparatus in Experiment 1 with notation.

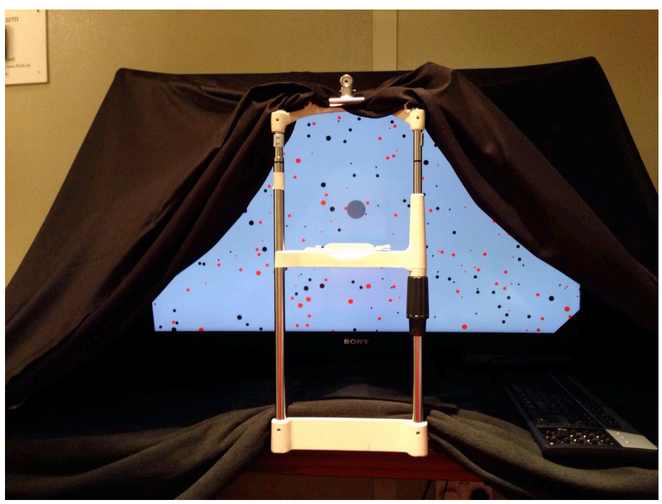


Figure 2.1 (a) Schematic illustration of the apparatus used in Experiment 1

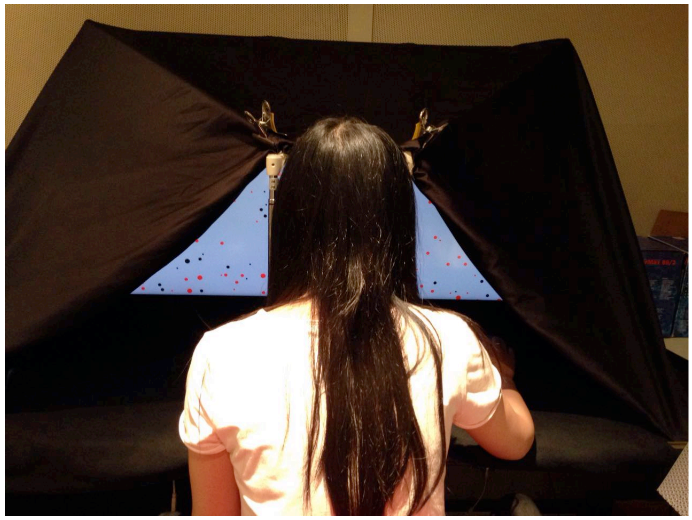


Figure 2.1 (b) Photograph of the apparatus when running an experiment. A partial view through subject's back is shown (the light will be off in the formal experiment).

2.2 Apparatus in Experiment 2

Apparatus in Experiment 1 were also used in Experiment 2. Additionally, the visual stimulus generator used in Experiment 2 contained a PC with two-screen display: a Sony LCD and a PC monitor. Other apparatus contained a sports mat, a keyboard and an infrared camera. The PC, Sony LCD and the keyboard were identical to Experiment 1. During the experiment, experimenter operated PC and monitor near the table to show visual stimulus, subjects could see the same stimulus pattern from Sony LCD simultaneously.

A cubic frame made of aluminium alloy was built in order to put LCD over table. Right below the LCD, a purple soft sports mat on the table was used to make subjects feel flat and comfortable. An infrared camera with black body was fixed in the top left corner of cubic frame to record the video during the experiment. The keyboard was put around the right hand of subjects when they lay down on the sports mat. A black crossing was labelled on the sports mat to locate the position of subjects. Figure 2.2 demonstrates the setup in Experiment 2.

Figure 2.2 (a) Schematic illustration of the apparatus used in Experiment 2

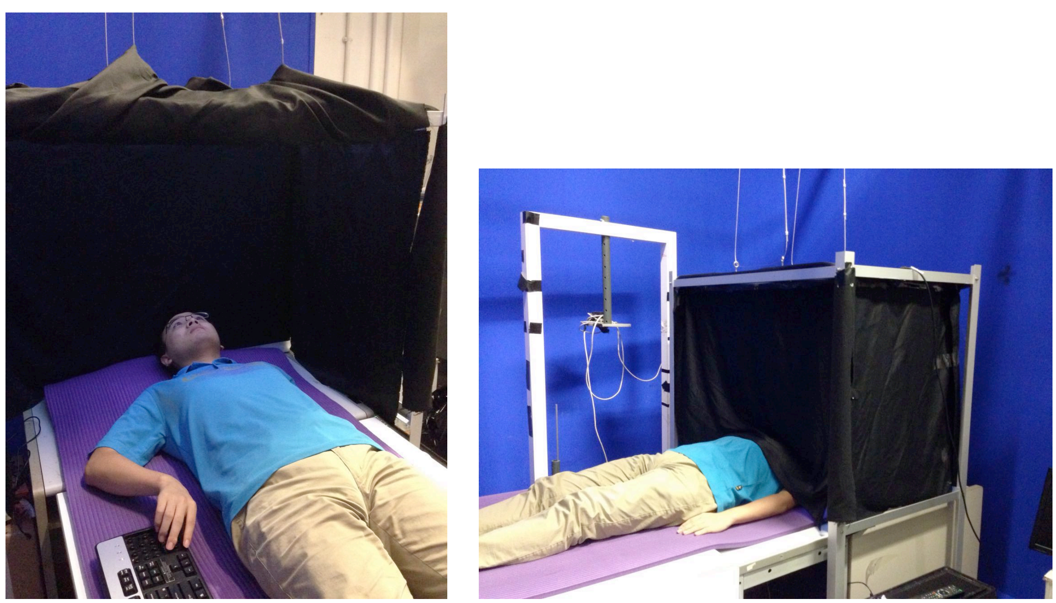


Figure 2.2 (b) Schematic illustration of the apparatus used in Experiment 2. (left) a partial view in front of experimental table shows the perspective inside cube with open front black curtain;

(right) a partial view from subject's lateral position shows setup during the experiment (the light will be off in the formal experiment).

2.3 Introduction for research equipment

2.3.1 Visual stimuli generator

The visual motion stimulus in Experiment 1 and 2 were programmed by OpenGL and presented by a Sony LCD with resolution of 1920 × 1080 pixels. Full field of view for LCD is 92 × 60 degree in horizontal and vertical directions. Table 2.1 shows related specifications of PC and table 2.2 shows specifications of Sony LCD.

Table 2.1 Specifications of PC generating visual motion stimuli

System	Windows 7 Enterprise
Processor	Inter(R) Core(TM) i7-2600 CPU @3.40GHz
Installed memory (RAM)	16.0GB (3.22GB usable)

Table 2.2 Specifications of Sony LCD

Screen Size (measured diagonally)	46" (16:9)
Viewing Angle (Right/Left)	178°
Display Resolution	Full HD 1080 (1920 ×1080)

2.3.2 Eye tracking system and infrared camera

The model of eye tracking system used in Experiment 1 and 2 is EyeTech TM3 and produced by EyeTech Digital Systems. Figure 2.3 (a) shows the appearance of eye tracker and table 2.3 lists part of its related specifications.

Figure 2.4 shows the configuration of the Eye tracker in experiments. Before running the eye tracker system, a calibration procedure is required to measure user's eye shapes, light refraction and reflection. Those characteristics of measurements can then be used to calculate the gaze data. During the calibration procedure, subjects need to look at the calibration dot whose inner green dot is flashing on the screen (Figure 2.5). After the procedure finishes successfully, the calibration scores will be shown in the screen. And then eye tracking system is ready for recording.

Table 2.3 Specifications of Sony LCD

Methods	Video, dark pupil, infrared illumination
Other features	Remote
Spatial resolution	1 degree (approximate)
Temporal resolution	Adjustable, 15-55 samples per second
Tolerance to eye glasses and contact lenses	Works well in most cases.
Accommodation to human eye variations (iris	Works most in all cases
Freedom of head movements	25 X 16 X19 cm

Figure 2.4 shows the configuration of the Eye tracker in experiments. Before running the eye tracker system, a calibration procedure is required to measure user's eye shapes, light refraction and reflection. Those characteristics of measurements can then be used to calculate the gaze data. During the calibration procedure, subjects need to look at the calibration dot whose inner green dot is flashing on the screen (Figure 2.5). After the procedure finishes successfully, the calibration scores will be shown in the screen. And then eye tracking system is ready for recording.

The model of infrared camera used in Experiment 2 is Vehicle Blackbox DVR which features high definition and support night vision. Figure 2.3 (b) shows its appearance.

2.4 Measurements and parameters in the experiments

2.4.1 Visual acuity

To make sure subjects' vision or corrected-to-normal vision are normal, vision tester model 2000 from Stero Optical Corporation was used to measure visual acuity of subjects. Each subject's nearsightedness for both eyes was tested.

When subjects' forehead touched and pressed upper part of the tester, the target pattern (see Figure 2.6) appeared through two ocular lens. Each pattern included 3 broken rings and an unbroken ring, subjects need to verbally report the position of unbroken one (bottom, top, left, right) when the experimenter asked the target number sequentially. The final score will be the last correct answer after two consecutive misses. A visual score no less than 20/22 (20/20 feet scale) in the Snellen Equivalents can be referred to the normal vision according to the stereo optical industrial vision tester record form (see Appendix 2.4 and 2.5). All subjects passed the eyesight test.

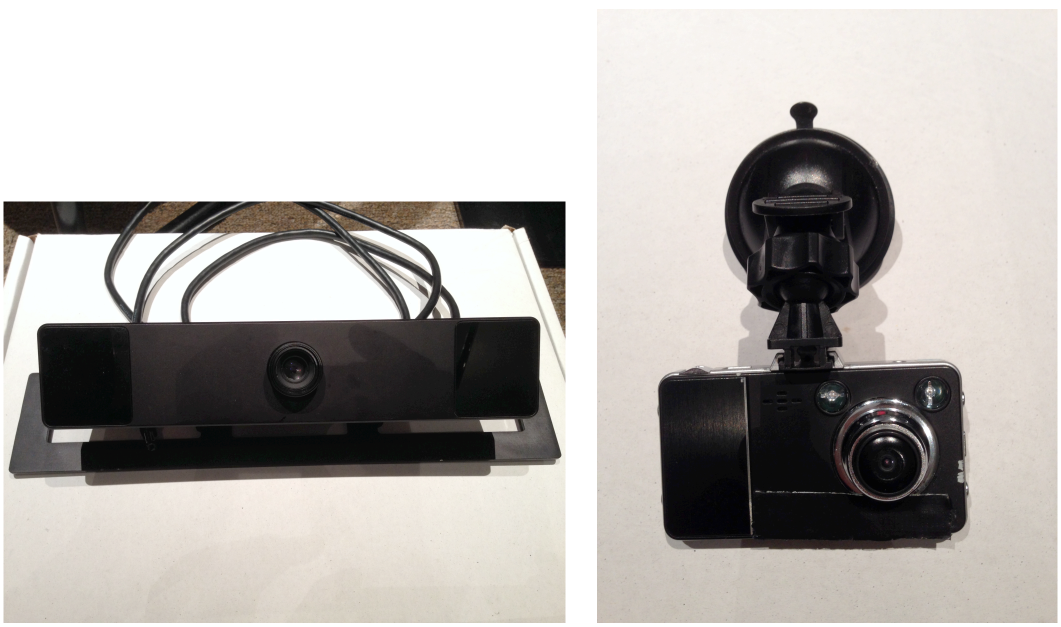


Figure 2.3 (left) Eye tracker used in Experiment 1 and 2; (right) infrared camera used in Experiment 2

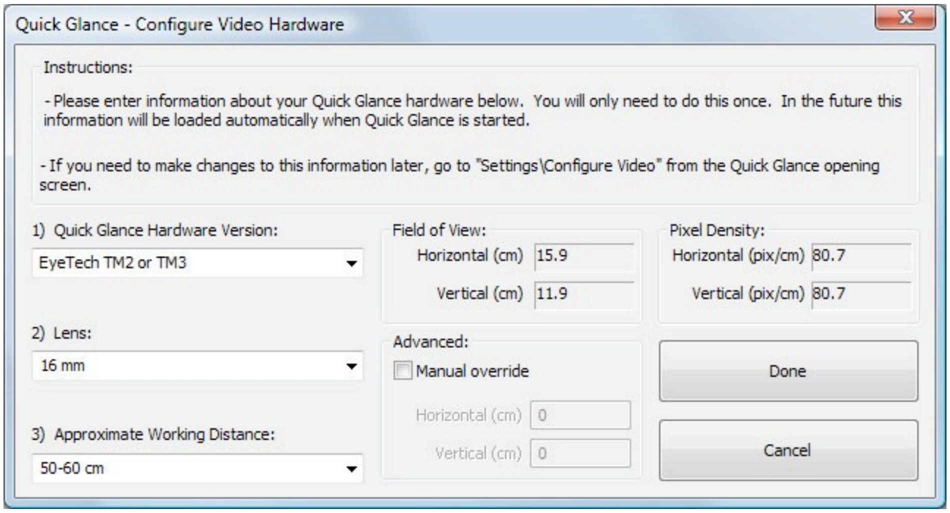


Figure 2.4 Configuration of eye tracker

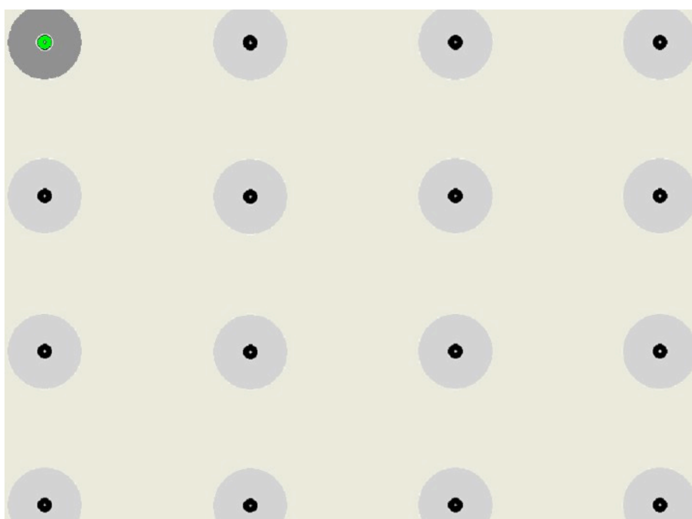


Figure 2.5 Interface of calibration procedure for eye tracker. Subjects need to stare at the flashing green dot at calibration procedure.

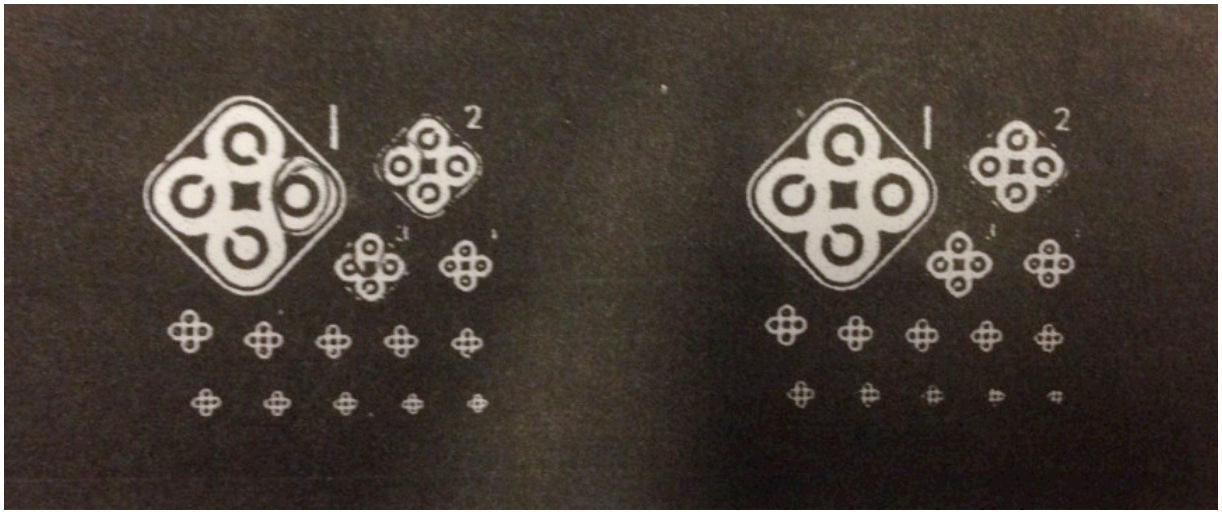


Figure 2.6 Task illustration for both eyes during the vision test.

2.4.2 Vection metrics: 5-point vection intensity rating

Normally for vection experiments, subjects need to give their perceived subjective judgement to the experimenter. The judgement variables include vection onset time, the perceived velocity or the perceived magnitude of vection, the perceived intensity of vection or the vection convincingness and vection duration. Two kinds of methodologies for vection study have been widely adopted. The first method named magnitude estimation is the most commonly used method for vection intensity and magnitude rating (Stevens, 1957). In this method, a standard stimulus is regarded as modulus and will be presented once at the beginning of the experiment. Concurrently, an arbitrary value of 10 will be assigned to subjects. During the experiment, subjects need to compare the vection intensity or perceived velocity of current visual stimuli and indicate the compared ratio. While the other researcher measure vection through comparison between object and self-motion. In this method, subjects are required to indicate vection intensity with a five-level scales (Webb and Griffin, 2003). Table 2.4 lists scaling of five-level metrics. The levels can be verbally reported or by the means of key pressing. Both of the methods have been approved to be useful and reliable for vection metrics.

Table 2.4 Scaling of 5-level vection rating

Perception of self-motion (vection)	Subjects report:
You feel like you are stationary and it is the dots which appear to be moving only.	1
You feel like you are moving a bit, but the dots are moving more.	2
You feel like you are moving at the same speed as the dots.	3
You feel like you are moving a lot and the dots are moving a bit.	4
You feel like you are moving and the dots appear stationary.	5

2.4.3 Introduction of full-vection, partial-vection, vection onset time, average duration, frequency of coming in and out of CV sensation

As hypothetical time course of vection and 5-level vection metrics introduced earlier, subjects need to verbally report the vection intensity ranging from level 1 to 5 according to its intensity level. In the first level, subjects perceive only object motion while themselves stationary. Thereafter, both object and self-motion can be experienced from second to fourth level, which is noted as partial vection in the following chapters. Vection onset time is noted when subjects perceive vection at the first time. Up to the maximum level of vection intensity, subjects perceive only self-motion and earth stationary, vection in this period is defined as full-vection.

When visual motion is the only informative cue for the perception of self-motion, a perceptual conflict will emerge and the intermittent self-motion illusion arises in one period due to cognitive and physiological factors (Dichgans and Brandt, 1978). Accumulated vection duration is calculated as addition of all intermittent duration in a period. Similarly, Frequency of coming in and out of CV sensation refers to the frequency of experienced vection times in a period. Therefore, average vection duration can be calculated by accumulated vection duration over frequency of coming in and out of CV sensation. Namely, Accumulated CV duration = Average duration * Frequency of coming in and out of CV sensation.

For the design of experiments in this dissertation, all parameters including full-vection, partial-vection, vection onset time, vection duration, average duration and frequency of coming in and out of CV sensation are designed as dependent variables.

In vection studies, participants are normally required to give subjective rating about perceived self-motion. The variables of interest and most frequently used in the experiments are CV onset time, CV intensity or perceived velocity of vection. While accumulated CV duration, average CV duration and frequency of coming in and out of CV sensation are rarely investigated in the experiments. The stronger vection we normally mentioned indicates that shorter vection onset time, higher vection intensity, longer duration and less frequency of coming in and out (keypress frequency).

2.4.4 Pre- and Post-Simulator Sickness Questionnaires (SSQ)

Simulator Sickness Questionnaires (SSQ) forms are used in two experiments to evaluate levels of simulator sickness. Kennedy developed the forms in 1993 after analyzing 1000 sets of previous data and a list of 27 symptoms are included in the pre- and post-SSQ forms respectively (Kennedy et al., 1993). Subjects rate each item with a scale of four levels symptom: none, slight, moderate and severe. Four representative scores including Nausea-related subscore (N), Ocularmotor-related subscore (O), Disorientation-related subscore (D) can be achieved after calculation from weights of symptoms form provided by Kennedy. Total Score (TS) is the sum obtained by adding all the symptoms scores and it represents the overall severity of motion sickness (see Appendix 2.3). Subjects need to fill in pre-SSQ form and post-SSQ form respectively before and after the experiment (see Appendix 2.1 and 2.2).

2.4.5 Eye movements

Literatures have revealed that adding a fixation point amid experiments can extremely enhance vection strength in comparison with the absence of fixation point. Accordingly, it is essential to record eye movements of subjects during the experiments and subjects were required to stare at the fixation point without attempting to follow any other object motion for the duration of stimuli presentation in Experiment 1 and 2. An infrared camera was used in Experiment 2 instead of eye tracker due to the limitation of experimental setup and safety consideration.

CHAPTER 3 EXPERIMENT 1: EFFECTS OF VELOCITY AND COLOR ON VISUALLY INDUCED CIRCULAR VECTION

3.1 Literature review and research gaps

3.1.1 Literature review for velocity

In order to enhance more compelling embodied sensations of self-motion in virtual reality and other immersive media, most of vection researchers focused on the effect of stimulus parameters on vection strength during the past 150 years. Following are the literature reviews related to the effect of velocity on CV.

Brandt et al. (1973) investigated effects of velocity, central and peripheral vision of stimuli on perceived velocity and intensity of CV. They used a closed cylindrical drum whose inner wall painted with alternating vertical and white stripes to induce yaw vection. Onset time, intensity and perceived velocity of CV by means of magnitude estimation were examined at different angular velocities 10, 30, 60, 90, 120, 180, 240, 300, 360 deg/sec. Results showed that perceived velocity of CV for subjects matched stimulus velocity up to 90-120 deg/sec. Beyond this velocity, subjects perceived CV velocity less than stimulus velocity and resulted in additional object motion. Additionally, Brandt concluded that CV latency were independent of stimulus velocity.

Similarly, Held et al. (1976) explored the effects of angular velocity and stimulus field on magnitude of tilt. A rotating disk randomly distributed with spots of various sizes was used to induce roll vection. During the experiment, angular velocity of stimulus varied among 5, 10, 20, 30, 40, 60, 80, 130 deg/sec. Finally, Held et al. concluded that magnitude of tilt saturated at an angular velocity of rotation between 30 and 40 deg/sec. With higher velocities, magnitude of tilt declined.

Ujike et al. (2004) investigated the effects of velocity, stimuli type and rotation axis (roll, yaw and pitch) on CV intensity and visually induced motion sickness (VIMS). The results finally suggested that subjective VIMS score produced by the roll motion were highest regardless of different types of visual image and velocity of stimuli rotation among three rotation axes. In addition, Ujike et al. (2004) reported the highest CV intensity score when subjects viewed the stimuli rotating around the roll axis.

As mentioned previously, both Brandt and Held studied perceived intensity or magnitude. Nonetheless, they did not measure and report accumulated and average CV duration at different velocities. In recent years, functional magnetic resonance (fMRI) and Positron emission tomography (PET) scanner are frequently used to measure brain activity through human blood flow as the rapid development of neuroimaging techniques. Those scanners are gradually used to detect which cortical areas are responsive to different stimulus type and their sensitivity. For instance, Brandt et al. (1998) conducted a PET study to investigate involved cortical areas during visual stimulus with CV comparing with those without CV (stimulus with randomly moving dots). Kleinschmidt et al. (2002) used the same visual motion stimulus to yield both object and self-motion, then compared the cerebral cortical areas between them by fMRI and identified how human brain processed two percepts under the same stimulus. Cardin et al. (2012) conducted an fMRI experiment in which subjects viewed different visual motion stimuli with and without CV to encode functional characteristics of human V6.

In terms of functional brain study associate with CV, its duration are also highly critical criterions in addition to CV intensity and magnitude in order to guarantee a stronger vection. In recent functional brain study or behavior study related to CV, normally a specific velocity (e.g. 30, 40, 45, 60 deg/sec) was selected to induce CV regardless of its accumulated and average duration. Adopting a stimulus velocity without optimal duration may impair the representation of experimental results to some extent.

3.1.2 Literature review for color

Brandt et al. (1998) elicited a new functional interpretation: theory of visual-vestibular reciprocal inhibition. It showed that visual motion stimulation with CV not only activates a medial parieto-occipital visual cortex, but also deactivates the parieto-insullar vestibular cortex and the theory has been widely used to interpret multisensory mechanism for self-motion perception (Brandt et al., 1998). In Brandt's experiment, subjects viewed four conditions of visual stimulation. Condition A was composed of of a light grey background with a central dot with darker grey. The background and central dot of Condition B were identical to Condition A, but beyond the stimulus contained a total of 190 red and black dots of various sizes ranging from 1/40 to 1/100 of the screen size and was randomly distributed in the screen. Condition C and Condition D were identical to condition B but with the difference that all dots rotated counter-clockwise and clockwise at a constant angular velocity of 40 deg/sec.

Brandt et al. (1998) employed stimuli with black and red dots. However, in almost all of previous vection study, researchers normally use achromatic stimuli to induce vection except for the research from Seno, Bonato and Bubka in recent years. Seno et al. (2010) investigated the effects of colors on vection latency, duration and magnitude with expanding optical flows. They conducted seven experiments to control different effects of luminance, luminance artifact, interaction between color, effective luminance contrast between the dots of background and differences in perceived speeds, visibilities of dots and vividness of motion. Finally, the results concluded that vection was weakened by red visual stimuli when it was employed as visual background or moving dots. And Seno et al. (2010) interpreted the conclusion as red visual fields have inhibition effect of magnocellular pathway or motion pathway. However, mono colored stimulus was used through his seven experiments.

Apart from research from Seno et al. (2010), Bonato and Bubka (2006) used a large optokinetic drum whose inner stipes painted with six different colors including black and white to induce CV. The results revealed that stimulus with six colors facilitate vection than black and white stripes. They concluded that a multicolored stimulus induced stronger vection than a mono colored stimulus. In comparison with the experiment of Seno et al., inhibition effect of red component was not applicable in all conditions. In this context, it remains to be demonstrated that the visual stimulus with combination of red/black dots employed by Brandt et al. (1998) to induce CV will inhibit vection or not. And it should be particularly avoided in functional brain study by means of fMRI and PET scanner.

3.1.3 Research gaps and questions

As discussed above, two summarized research gaps and questions are as follows.

1. None of previous research investigated accumulated and average CV duration under different velocity. Then we propose the first research question that whether there exists an optimal velocity to induce the most durable and strongest CV.

2. Effect of color on vection has been scarcely explored in previous research. Then we propose the second research question that will stimulus with a combination of red/black dots inhibit CV comparing with the stimulus with black dots.

3.2 Methods

3.2.1 Participants

Twenty-one postgraduate students (6 females, 15 males) from Hong Kong University of Science and Technology (HKUST) with age between 22 to 26 years old (mean=23.8, SD=1.2) participated the experiment. All subjects had a normal or corrected-to-normal vison and no vestibular dysfunction and eye disease reported. All subjects were naïve to the purpose of the experiment. After the experiment, each subject was paid 50 HKD per hour according to the standard payment of human factor experiment in HKUST.

One subject is excluded because he cannot follow the instruction correctly. During the experiment, it is required for subjects to report CV intensity and indicate CV duration consistently. For example, if subjects experienced CV in a condition, they should verbally report CV intensity score higher than 1 and press any key to indicate CV duration amid this condition. The excluded subject reported this inconsistency in every trial with a total of 10 times while the other 20 subjects only reported 5 times in total through the entire experiment.

3.2.2 Visual motion stimulation

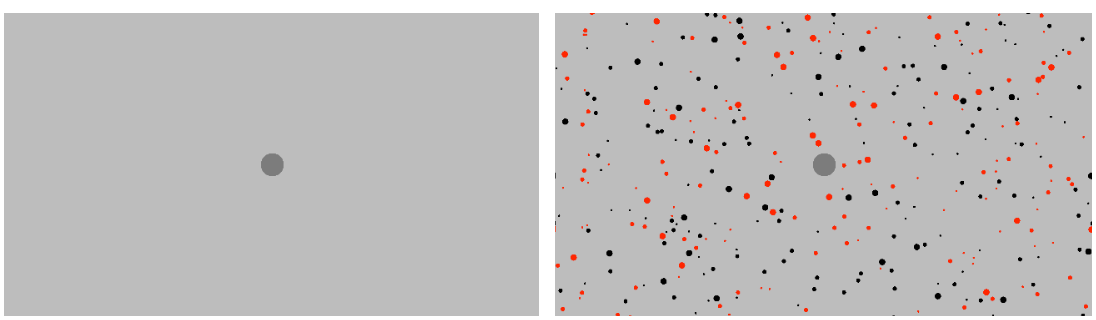
Experiment 1 contained four types of stimulus pattern to replicate the stimuli from Brandt et al. (1998). Type A consisted a light grey background with a central dot in a darker shade of grey.

Type B consisted a total of 839 black and red dots of various sizes ranging from approximately 0.6 to 1.6 degree in addition to the same background and central dot with type A. Type C was identical to type B but with the difference that half of the black dots were converted to red. A grey-shade condition was added as type D to avoid the luminance effect of red dots. The luminance value for grey dots in type D condition were matched as closely as possible with the luminance value in type B condition. The grayscale conversion algorithm is used by NTSC and JPEG for nonlinear data in a gamma working space employed by Gernot Hoffmann (Hoffmann, 2002). More detailed conversion algorithm can be found in Appendix 3.1.

During the visual motion stimulus presentation, all the dots were rotating around the central circle as direction of counter-clockwise. Table 3.1 listed parameters of visual motion stimulation and Figure 3.2 demonstrated four types of visual motion stimulation.

Table 3.1 parameters for visual motion stimulation

Total dots	839
Color of dots	black, red and grey
Size of each dot in degree	ranging from 0.6 to 1.5 degree
Angular velocity	2, 4, 8, 16, 32, 64 degree/second
Horizontal FOV	92 degree
Vertical FOV	60 degree
Distance between subjects and LCD	50 cm



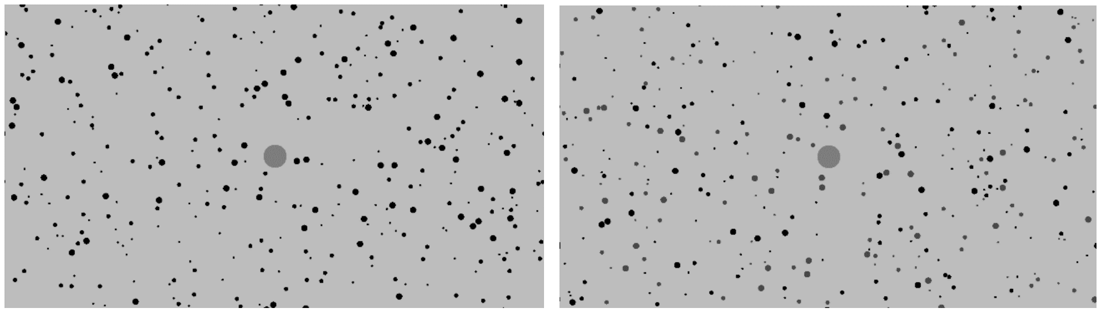


Figure 3.1 Four typoes of visual stimulus in experiment 1. (Top left) type A; 2. (top right) type B; 3. (bottom left) type C; 4.(bottom right) type D

3.2.3 Experimental Design

Independent variables

Independent variables (IV) for Experiment 1 includes color and velocity. The IV of color consists of three levels. The first level: all dots are black; the second level: half is black and half is red; the third level: half is black and half is grey. The IV of velocity consisted of six levels 2, 4, 8, 16, 32, 64 degree/sec.

Dependent variables

5-point intensity vection rating, accumulated duration of CV, CV onset time, average duration, CV frequency of coming in and out of CV sensation, full-vection and partial-vection are designed as dependent variables.

Control variables

- Eye motion for each subject was recorded by eye tracking system and subjects were required to stare at the fixation point during the experiment.
- The distance between subjects and screen was measured and adjusted to 50cm before experiment started.
- The background luminance of LCD was controlled through the entire experiment.

- subjects were exposed to a dim room with light off for more than 5 minutes for them to adapt the darkness before the experiment started.

Design of Experiment

The experimental design was a completely randomized design with two independent variables color and velocity therefore 18 conditions in total for each trial. Each condition contained 30-second stimulus presentation and 20-second rest. Each trial lasted about 15 minutes. The sequence of 18 conditions of each trial was randomized. Before the formal experiment, a training session for each subject was conducted so that they could follow the experimental instructions correctly. The formal experiment contained six trials, and experimenter could run a trial per day at most to avoid possible aftereffect and vection induced motion sickness (Lo,W.T. and So, R.H., 2001; Yang and Guo et al., 2011).

Procedures and measurements

Before the experiment, subjects were required to read the instruction carefully and sign the consent form (see Appendix III). Experimenter conducted a training session for subjects to make them acquainted with the instruction and experimental tasks. In the course of training, subjects could ask any unclear question to experimenter. The training session normally took 2 times for most subjects.

Once subjects finished the training session, they were allowed to commence the formal experiment. Subjects need to fill in consent form and pre-SSQ form before stimulus presentation. Subsequently calibration for eye tracker were conducted in the light-off condition. After calibration was done, subjects were ready to start the experiment.

During the stimuli presentation, subjects wore sponge earplugs (NRR value: 29dB) with two ears during the experiment to block out background noise. They also need to stare at the grey dot in the center from outset to the end and do not follow any moving dot. In the period of rotating dots, subjects need to press the keyboard 1 or 2 to give an assessment of vection intensity as soon as they experience any sensation of self-motion (see Table 3.2). In the period of stationary dot, only a grey dot appeared in the center of screen, subjects need to verbally report CV intensity to the experimenter using a scale from 1 to 5 (refer to Table 2.4, A complete and detailed experimental instruction can be found in Appendix I). After the experiment was completed subjects need to fill in post-SSQ form.

Table 3.2 Instruction of keypress task for subjects during stimulus presentation.

Perception of self-motion (vection)	Subjects Press:
You feel that you are stationary and only the dots are moving	Nothing
You feel that you are moving at the same time the dots are moving	a
You feel that you are moving and the dots stay stationary	b

3.3 Results

Twelve subjects participated vection experiment with sitting upright position. Considering that experimental data violated the normality (Shapiro-Wilk test, $p<0.05$), non-parametric statistical analysis were used in the following data analysis. More specifically, Friedman two-way ANOVA and Wilcoxon matched-pairs signed rank test were used. The data were analyzed using software IBM SPSS 23.

Although training session was conducted for all subjects to avoid apparent adaptation effect. We still checked the adaptation effect during upright position (see Figure 3.2). More specifically, the effects of repeats on each dependent variable for each combination of velocity and color were tested. And the results suggested there occurred significant adaptation for accumulated CV duration at 2 deg/sec (chi-square=13.673, p=0.018, Friedman), 4 deg/sec (chi-square=15.622, p=0.008, Friedman) and 32 deg/sec (chi-square=17.748, p=0.003, Friedman) and average CV duration at 2 deg/sec (chi-square=15.998, p=0.007, Friedman), 4 deg/sec (chi-square=14.556, p=0.012, Friedman) and 32 deg/sec (chi-square=14.410, p=0.013, Friedman).

After we removed the first two trials for accumulated CV duration at 2 and 4 deg/sec, and removed the first three trials at 32 deg/sec, the adaptation effect no longer existed (Accumulated CV duration at 2 deg/sec: chi-square=5.694, p=0.127, Friedman; 4 deg/sec: chi-square=4.295, p=0.231, Friedman; 32 deg/sec: chi-square=2.000, p=0.368, Friedman). Similarly, after we removed the first three trials for Average CV duration at 2 deg/sec and first two trials at 4 and 32 deg/sec, no adaptation effect was found (Average CV duration at 2 deg/sec: chi-square=3.323, p=0.19, Friedman; 4 deg/sec: chi-square=0.886, p=0.829, Friedman; 32 deg/sec: chi-square=5.694, p=0.365, Friedman). For each subject, data from the repeated trials or the remaining repeated trials collected from the same condition that are not significantly different were averaged to obtain better mean estimations. All remaining analyses of the main effects of color, velocities and gender used these mean data.

As mentioned in earlier section, main factors in Experiment 1 include velocity and color. Dependent variables consist of accumulated duration, intensity, onset time, frequency of coming in and out of CV sensation, average duration and accumulated duration for full-vection. Noted that if the subjects did not perceive vection in a condition, then onset time will be regarded as not applicable in the following data analysis.

For the main effect of velocity (see Figure 3.3), Friedman two-way ANOVA on the mean data showed a significant result for accumulated duration (chi-squared=21.501, p-value=0.001), CV intensity (chi-squared=29.025, p-value<0.001), CV onset time (chi-squared=38.586, p-value<0.001), frequency of coming in and out of CV sensation (chi-squared=10.077, p-value=0.073) and average duration of CV (chi-squared=19.092, p-value=0.002).

For the main effect of color (see Figure 3.4), Friedman test did not show any significant result for accumulated duration (chi-squared=3.100, p-value=0.212), intensity (chi-squared=1.787, p-value=0.409), onset time (chi-squared=0.700, p-value=0.705), frequency of coming in and out of CV sensation (chi-squared=0.105, p-value=0.949) and average duration (chi-squared=1.3, p-value=0.522).

As Friedman test showed significant results for velocity and all dependent variables, Post-hoc analysis were analyzed in the following part (p-value can be seen in Appendix 3.2).

3.3.1 Accumulated duration of CV

After pairwise analysis of Wilcoxon signed rank test, accumulated duration at 2 deg/sec was significantly shorter than at any other velocities and accumulated duration at 4 deg/sec was significant shorter than 16, 32 deg/sec. A marginal significant result was found between 32 and 64 deg/sec. In summary, accumulated duration at 8, 16, 32 deg/sec were higher than the other velocities. In those higher velocities, accumulated duration was around 20 seconds out of 30-second condition.

3.3.2 CV intensity

All pairwise comparisons showed significant difference except the pair between 2 deg/sec and 64 deg/sec and the pair between 4 deg/sec and 8 deg/sec. Therefore, the largest CV intensity was perceived at 4 and 8 deg/sec ($p<0.05$, Wilcoxon). In those velocities, CV intensity was over 3 in a scale range from 1 to 5.

3.3.3 CV Onset time

As Figure 3.2 showed that CV onset time declined with increasing velocities. Wilcoxon Rank test showed that the longest and shortest onset time occurred at 2 and 64 deg/sec respectively. At 64 deg/sec, CV onset time was approximately 5 seconds.

3.3.4 Frequency of coming in and out of CV sensation

The mean of frequency of coming in and out of CV sensation in different velocities were less than 2 in a condition. Wilcoxon rank test showed the there was less frequency of coming in and out of CV sensation at 8, 16 and 32 deg/sec than other velocities ($p<0.05$). Figure 3.4 represents frequency of coming in and out of CV sensation in different velocities with upright position. For the condition without CV, the bar charts illustrate that its highest frequency occurred at 4 deg/sec. For the condition that CV occurred once, it can be seen from the bar charts that CV occurred most frequently at 16 and 64 deg/sec.

Figure 3.2 Accumulated duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration in different trials for upright position. Abscissa axis represents different trials in sequence. The colored line in bottom right corner represents different velocities.

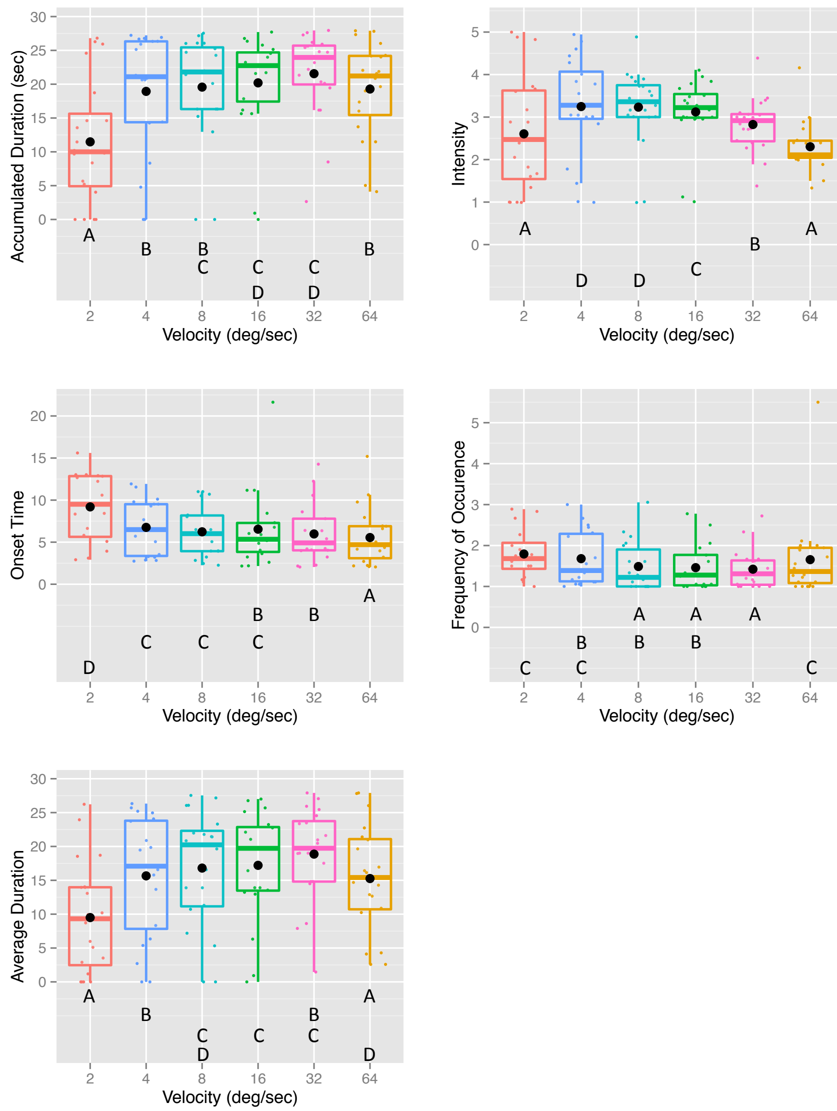


Figure 3.3 Measurements of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different velocities with upright position (median with inter-quartile range, IQR). Medians, inter-quartile ranges and ranges are

shown in the format of box-plots. Raw mean data of the 21 subjects are shown as colored dots and the black large dots were the average of the mean data. Data labeled with the same letter are not significantly different from each other at the 5% (p=0.05) level.

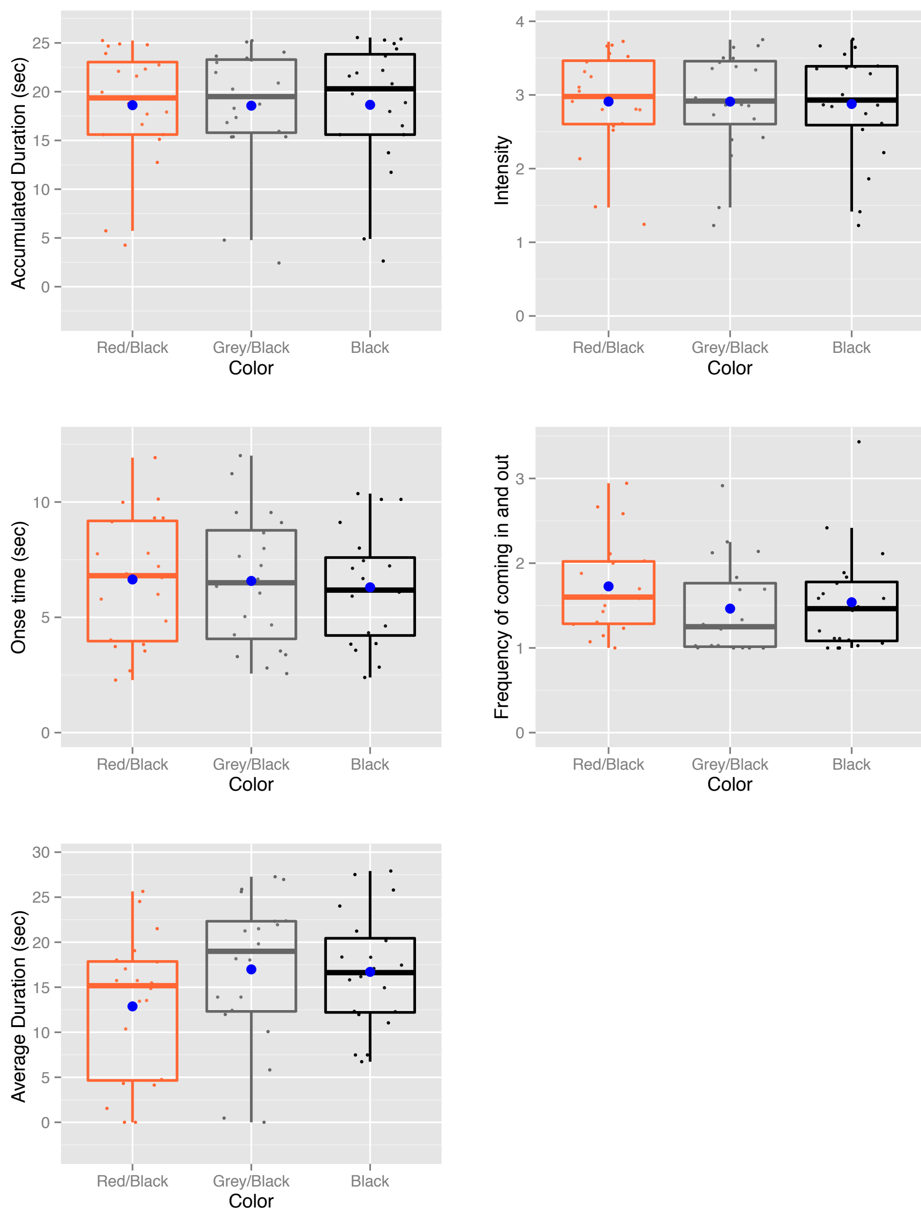


Figure 3.4 Measurements of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different color combination with upright position (median with inter-quartile range, IQR). (Red box: the stimulus with black and

red dots; black box: the stimulus with all black dots; grey box: the stimulus with black and grey dots). Medians, inter-quartile ranges and ranges are shown in the format of box-plots. Raw mean data of the 21 subjects are shown as colored dots and the blue large dots were the average of the mean data.

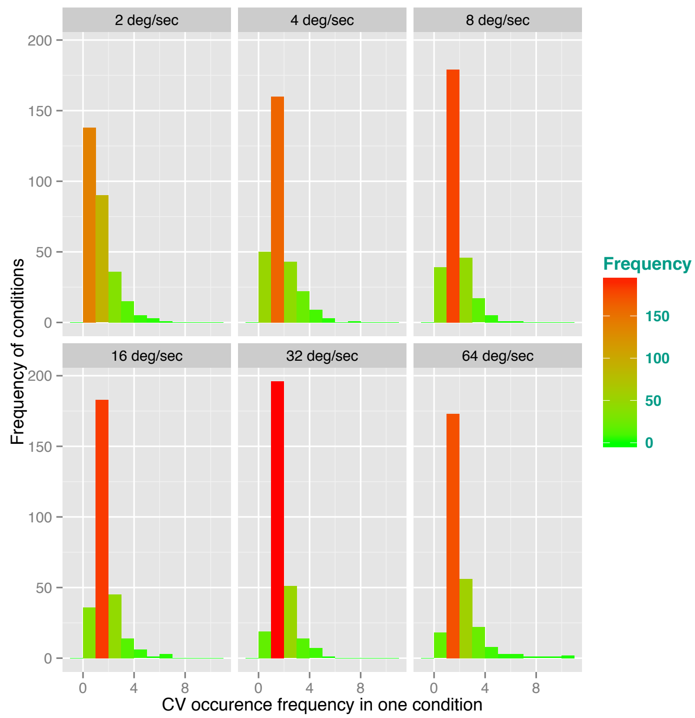


Figure 3.5 Frequency of coming in and out of CV sensation in different velocities. Abscissa axis represents different frequency of coming in and out of CV sensation in a condition and ordinate axis represents how many such conditions occur in a total of 360 conditions. The closer to red for each bar declares higher frequency of conditions.

3.3.5 Average duration for CV

Average duration Statistical results showed that average duration of CV at 8, 16 and 32 deg/sec were higher than the other velocities. In those velocities, the average duration was about 17 seconds for every CV interval.

3.4 Other analysis

3.4.1 Full vection analysis

Accumulated duration of full-vection under different velocities and body positions had been analyzed and plotted in Figure 3.5. Friedman test suggested that no significant difference for accumulated duration of full-vection in different color combinations (chi-square=0.029, p-value=0.9855).

As regarding full-vection of upright position, Friedman test suggested significant results for the upright position (chi-square=66.278, p-value=6.084e-13). Post-hoc analysis of pairwise Wilcoxon ranked test were conducted (see Table 3.3). As can be seen from the Table 3.3 that accumulated duration of full-vection at 2 and 4 deg/sec were significantly higher than the other velocities for upright position.

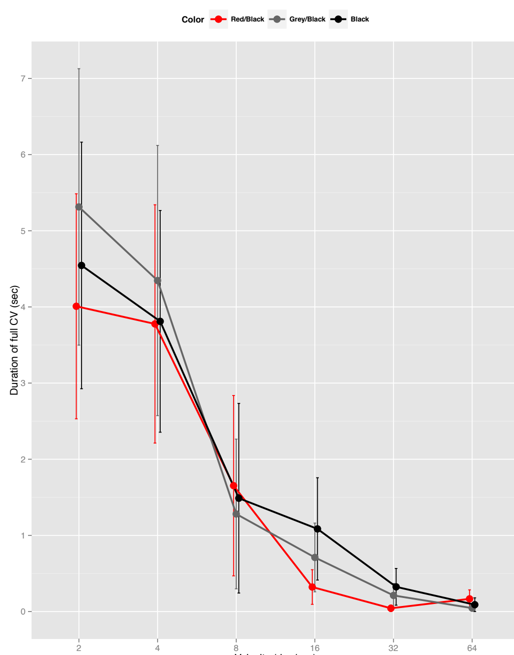


Figure 3.6 Mean with SEM plot of full-CV duration at different velocities with upright position. Colored line indicated different color combination; (right) full-CV duration with supine position.

Table 3.3 P-value of full-CV duration at different velocities with upright position (by Wilcoxon rank test).

deg/sec	2	4	8	16	32
4	0.551	-	-	-	-
8	8.00E-05	0.0009	-	-	-
16	2.00E-05	0.0003	0.7745	-	-
32	3.00E-08	8.00E-07	0.0621	0.1003	-
64	3.00E-08	8.00E-07	0.0919	0.132	0.8298

CHAPTER 4 EXPERIMENT 2: EFFECTS OF ANGULAR VELOCITY AND BODY POSITION ON VISUALLY INDUCED CIRCULAR VECTION

4.1 Literature review

The mechanism of vection occurrence is normally interpreted as a result of the convergence of visual and vestibular neural processing (Brandt & Dichagans, 1978; Howard, 1982). The human vestibular system only works during head acceleration or deceleration and it will cease to work during constant velocity. When visual motion is the sole informative cue to induce vection a conflict between visual and vestibular information occurs. Most of earlier vection studies focused on visual information while neglecting vestibular information.

Palmisano et al. (2000) summarized theory of visual-vestibular conflict based on Zacharias and Yong's finding (1981): (1) visual-vestibular conflict (e.g. the absence of expected vestibular activity for a particular optic flow pattern) should always reduce or impair vection; (2) the degree of vection impairment should increase with the discrepancy between the actual and expected vestibular activity.

Viewing the stimulus with upright position to induce CV has been extensively used for functional brain study. However, accumulated and average when subjects lie down have not been investigated previously. Only rare research was conducted to study the role of postural components of CV so far.

Tanahashi et al. (2012) examined the visual-vestibular conflict theory of CV in different conditions. They used a visual stimulus that simulated a sphere with FOV of 83 × 93 degree in horizontal and vertical directions, three different axes (roll, yaw and pitch) and three different body positions (supine, left lateral recumbent and sitting upright) to induce CV at a constant angular velocity of 60 deg/sec. At last, Tahanashi et al. (2012) concluded that the strength of CV and magnitude of illusory body tilt were the highest when subjects kept the upright position and rotated along the roll axis.

4.2 Research gaps and questions

As stated in above section 4.1, both Ujike and Tanahashi's findings were highly consistent that the CV strength were larger when subjects kept the upright posture than supine posture. In accordance with visual-vestibular conflict theory, if subjects view the visual motion stimulation with supine position, a conflict between information from semicircular canal and visual system will arise during CV. While if subjects view the visual motion stimulation with upright position, a conflict between information from otolith and visual system will also appear in addition to a conflict between semicircular canal and visual system. Suppose the visual vestibular theory works for both upright and supine position, then accumulated and average duration for supine position should be larger than CV for upright position.

To sum up, research gaps and questions of Experiment 2 are as follows.

- It still remains unclear for accumulated and average CV duration in different velocity, and whether they are consistent with CV strength when subjects stay supine position.
- As aforementioned, both Ujike and Tanahashi's findings contradict with visual-vestibular conflict theory. Therefore, we propose the research questions that will CV duration with supine position be significantly different with the condition of upright position and whether they conform or contradict with visual-vestibular conflict theory?

4.3 Methods

4.3.1 Participants

Sixteen postgraduate students (5 females, 11 males) from HKUST with age between 22 to 26 years old (mean=24, SD=1.1) participated Experiment 2. All subjects had normal or corrected-to-normal vision and no vestibular dysfunction and eye disease reported. All subjects were naïve to the purpose of the experiment. After the experiment, each subject was paid 50 HKD per hour according to the standard payment of human factor experiment in HKUST.

4.3.2 Experimental design

4.3.2.1 Independent variables

Velocity and body position were independent variables of Experiment 2. The velocity consisted of six levels which were identical to Experiment 1: 2, 4, 8, 16, 32, 64 deg/sec. The influential of two body position including upright and supine position on CV were examined in Experiment 2.

4.3.2.2 Dependent variables

5-point intensity vection rating, accumulated duration, CV onset time, average duration, frequency of coming in and out of CV sensation, full-vection and partial-vection are designed as dependent variables.

4.3.2.3 Control Variables

- Infrared camera was used to record motion of subjects so that they would stare at the fixation point during the experiment.
- The distance between subjects and screen was fixed at 50 cm for experiments with upright and supine positions.
- The background luminance of LCD was controlled through the entire experiment.
- Subjects were exposed to a dim room with light off for more than 5 minutes for them to adapt the darkness before the experiment started.

4.3.2.4 Design of Experiment

Eight subjects participated vection experiment with upright position first and then supine position. While the other eight subjects participated vection experiment with supine position first and then upright position.

Visual motion stimulation with only black dots were presented to subjects in Experiment 2. Both of the experiment with upright and supine positions were completely randomized design with independent variable of velocity. It was designed for six trials in total and each trial contained six conditions. Each condition contained 30-second stimulus presentation and 20-second rest period. The sequence of six conditions in each trial was randomized. Before the formal experiment, a short training session was conducted so that subjects could follow the instructions correctly. The formal experiment contained six trials and experimenter conducted them in one day. To avoid eye fatigue, possible aftereffect and motion sickness, subjects were allowed to have a five-minute rest between trials.

4.3.2.5 Procedure

The procedure of Experiment 2 was identical to Experiment 1 with the only difference that Experiment 2 was conducted in one day (Instruction can be seen in Appendix II). Subjects were allowed to have a five-minute rest between trials, they could continue to lie down on the mat or come out from the cubic frame when they kept supine position. The light was off during the entire experiment. Subjects wore sponge earplugs (NRR value: 29dB) with two ears during the experiment to block out background noise.

4.4 Results for upright position

Sixteen subjects of Experiment 2 (5 females, 11 males) participated vection experiment with upright position. Since experimental data violated the normality, non-parametric statistical analyses were used in the following data analysis.

Although training session was conducted for all subjects to avoid apparent adaptation effect. We still checked the adaptation effect during upright position (see Figure 4.1). More specifically, the effects of repeats on each dependent variable for each velocity. And the results suggested there occurred significant adaptation for accumulated CV duration (chi-square=11.102, p=0.049, Friedman) and onset time (chi-square=11.416, p=0.044, Friedman) at 2 deg/sec. After we removed the first trial for accumulated CV duration and onset time at 2 deg/sec, the adaptation effect was no longer exist (accumulated CV duration at 2 deg/sec: chi-square=1.273, p=0.866, Friedman; CV onset time at 4 deg/sec: chi-square=4.314, p=0.365, Friedman). For each subject, data of the repeated trials that were not significantly different from each other were averaged to obtain better mean estimations. These mean data were used in the subsequent analyses of the main effects of velocity, viewing position and gender.

For the main effect of velocity (Figure 4.4), Friedman test showed a significant result for accumulated duration (chi-squared=10.926, p-value=0.053), CV intensity (chi-squared=16.315, p-value=0.006), CV onset time (chi-squared=24.741, p-value=0.0001), frequency of coming in and out of CV sensation (chi-squared=0.692, p-value=0.405), average duration (chi-squared=16.148, p-value=0.006).

As Friedman test showed significant results for all dependent variables except for frequency of coming in and out of CV sensation, Post-hoc analysis were analyzed in the following part (p-value can be seen in Appendix 4.1).

4.4.1 Accumulated duration

Wilcoxon rank test showed that duration at 2 deg/sec was significantly lower than the other velocities. While no significant difference was found for pairwise comparison among 4, 8, 16, 32 and 64 deg/sec.

4.4.2 CV intensity

CV intensity at 4, 8, 16 deg/sec were significant higher than the other velocities. The lowest intensity occurred at 2 and 64 deg/sec.

4.4.3 CV onset time

Wilcoxon rank test showed that the maximum onset time occurred at 2 or 4 deg/sec and the minimum occurred at 32 and 64 deg/sec. Figure 4.2 demonstrated that the mean for CV onset time ranged from 10 to 5 seconds when increasing the velocity from 2 deg/sec to 64 deg/sec.

4.4.5 Average duration for CV

The lowest mean for average duration of CV occurred at 2 deg/sec, which was significant lower than the other velocities ($p<0.05$, Wilcoxon). The mean of average duration ranged from about 7 to 17 seconds within 30-second condition.

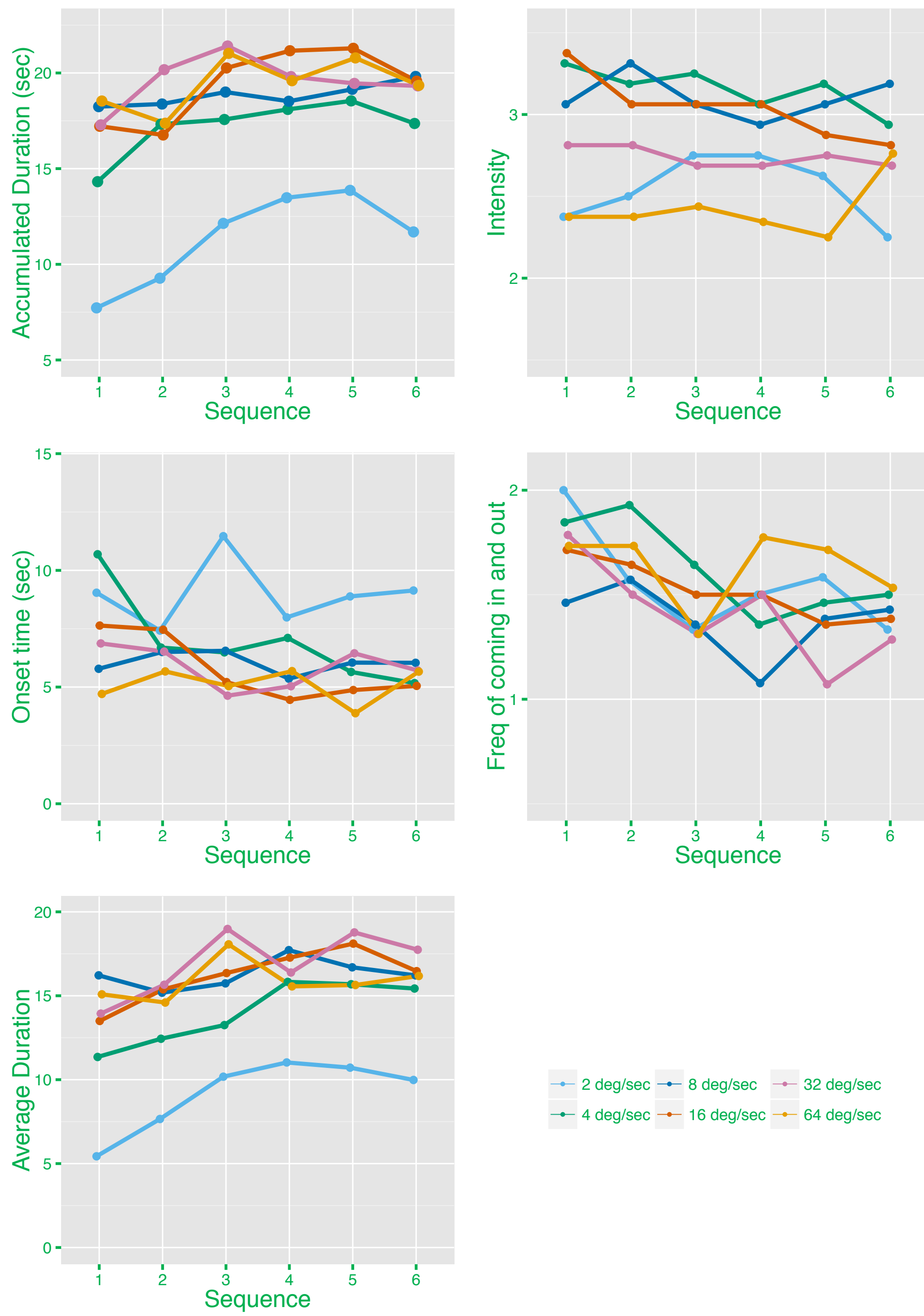


Figure 4.1 Accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration in different trials for upright position. Abscissa axis represents different trials in sequence. The colored line in bottom right corner represents different velocities.

4.4.4 Frequency of coming in and out of CV sensation

No significant results were found for frequency of coming in and out of CV sensation. Figure 4.2 represents frequency of coming in and out of CV sensation in different velocities with supine position. For the condition without CV, the bar charts illustrate that its highest frequency occurred at 2 deg/sec. For the condition that CV occurred once, it can be seen from the bar charts that its highest frequency occurred at 32 deg/sec.

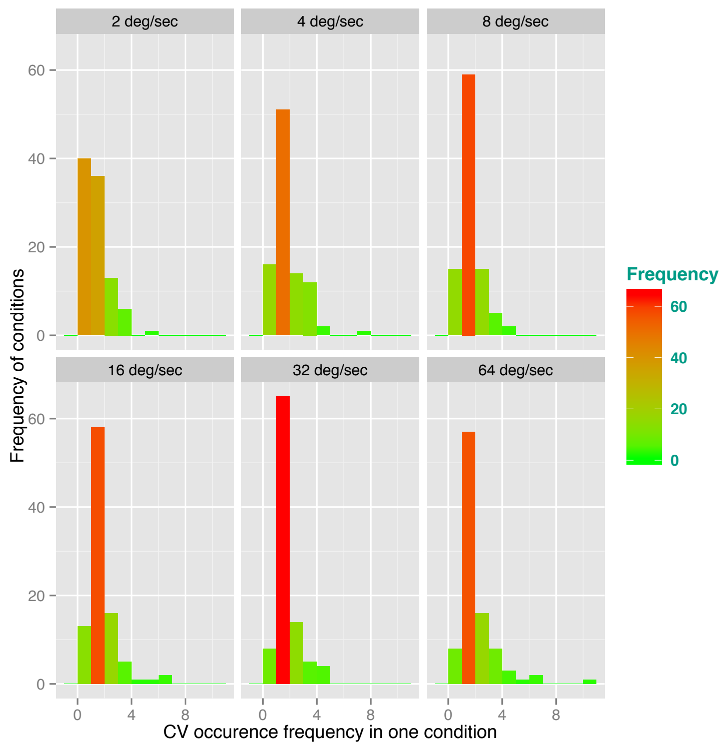


Figure 4.2 Frequency of coming in and out of CV sensation in different velocities. Abscissa axis represents different frequency of coming in and out of CV sensation in a condition and ordinate axis represents how many such conditions occur in a total of 96 conditions. The closer to red for each bar declares higher frequency of conditions.

4.5 Results for supine position

Sixteen subjects of Experiment 2 (5 females, 11 males) participated vection experiment with supine position. Since experimental data violated the normality, non-parametric statistical analysis were used in the following data analysis.

As aforementioned, main factor for Experiment 2 was velocity and dependent variables consisted of accumulated duration, intensity, onset time, frequency for coming in and out of CV sensation, average duration and full-vection. Noted that if subjects did not perceive CV in a condition, then onset time was regarded as not applicable in the data analysis.

We also checked the adaptation effect during supine position (see Figure 4.3). More specifically, the effects of repeats on each dependent variable for each velocity were tested. And the results suggested there occurred significant adaptation for accumulated and average and no adaptation effect was found.

For the main effect of velocity (Figure 4.6), Friedman test showed a significant result for accumulated duration (chi-squared=31.413, p-value=0.0001), CV intensity (chi-squared=17.246, p-value=0.004), CV onset time (chi-squared=24.741, p-value=0.0001), frequency of coming in and out of CV sensation (chi-squared=16.893, p-value=0.005), average duration (chi-squared=34.275, p-value=0.0001).

As Friedman test showed significant results for all dependent variables, Post-hoc analysis were analyzed in the following part (p-value can be seen in Appendix 4.2).

4.5.1 Accumulated duration

Wilcoxon rank test showed that duration at 2 deg/sec was significant lower than the other velocities. Duration at 4 deg/sec was significant lower than 8, 16, 32 deg/sec and marginally significant lower than 64 deg/sec. While no significant difference was found for pairwise comparison among 8, 16, 32 and 64 deg/sec.

Figure 4.3 Accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration in different trials for supine position. Abscissa axis represents different trials in sequence. The colored line in bottom right corner represents different velocities.

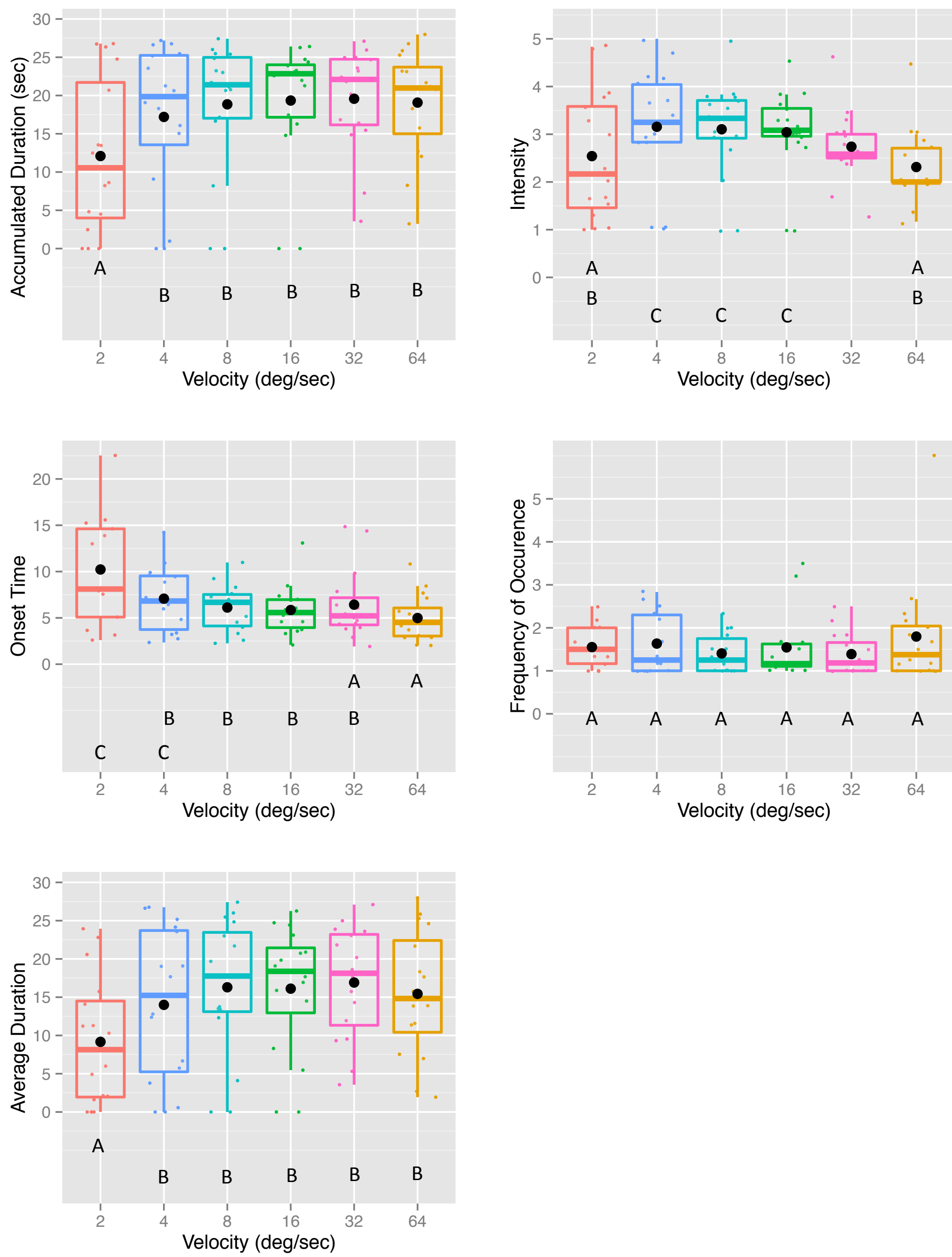


Figure 4.4 Measurements of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different velocities with upright position (median with inter-quartile range, IQR). Medians, inter-quartile ranges and ranges are

shown in the format of box-plots. Raw mean data of the 16 subjects are shown as colored dots and the black large dots were the average of the mean data. Data labeled with the same letter are not significantly different from each other at the 5% (p=0.05) level.

4.5.2 CV intensity

CV intensity at 4, 8, 16 deg/sec were significant higher than the other velocities. The lowest intensity occurred at 2 and 64 deg/sec. All results are tested to be significant at $p<0.05$ level with Wilcoxon tests.

4.5.3 CV onset time

Similar to the trend of onset time for upright position, CV onset time for supine position decreased as velocity increased. The statistical results showed that the maximum onset time occurred at 2 or 4 deg/sec and the minimum occurred at 64 deg/sec. Figure 4.4 demonstrated that the mean for CV onset time ranged from 10 to 5 seconds when increasing the velocity from 2 deg/sec to 64 deg/sec.

4.5.4 Frequency of coming in and out of CV sensation

Wilcoxon singed test showed that the lowest frequency of coming in and out of CV sensation appeared at 32 deg/sec and its mean was slightly lower than 1.5 times in a condition. Figure 4.5 represents frequency of coming in and out of CV sensation in different velocities with supine position. For the condition without CV, the bar charts illustrate that its highest frequency occurred at 2 deg/sec and 8 deg/sec. This suggests there are less frequency of coming in and out of CV sensation with 2 and 8 deg/sec conditions. For the condition that CV occurred once, most of them occurred at 32 deg/sec.

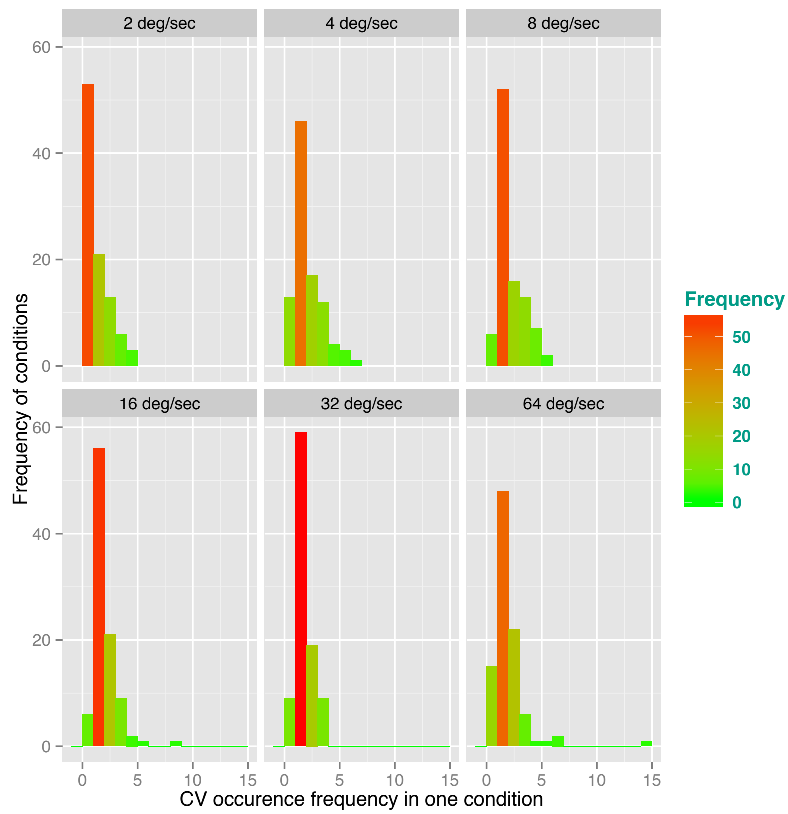


Figure 4.5 Frequency of coming in and out of CV sensation in different velocities. Abscissa axis represents different frequency of coming in and out of CV sensation in a condition and ordinate axis represents how many such conditions occur in a total of 96 conditions. The closer to red for each bar declares higher frequency of conditions.

4.5.5 Average duration for CV

Average CV duration at 4 deg/sec was also significant lower than the other higher velocities. While the highest average duration occurred at 16, 32 or 64 deg/sec.

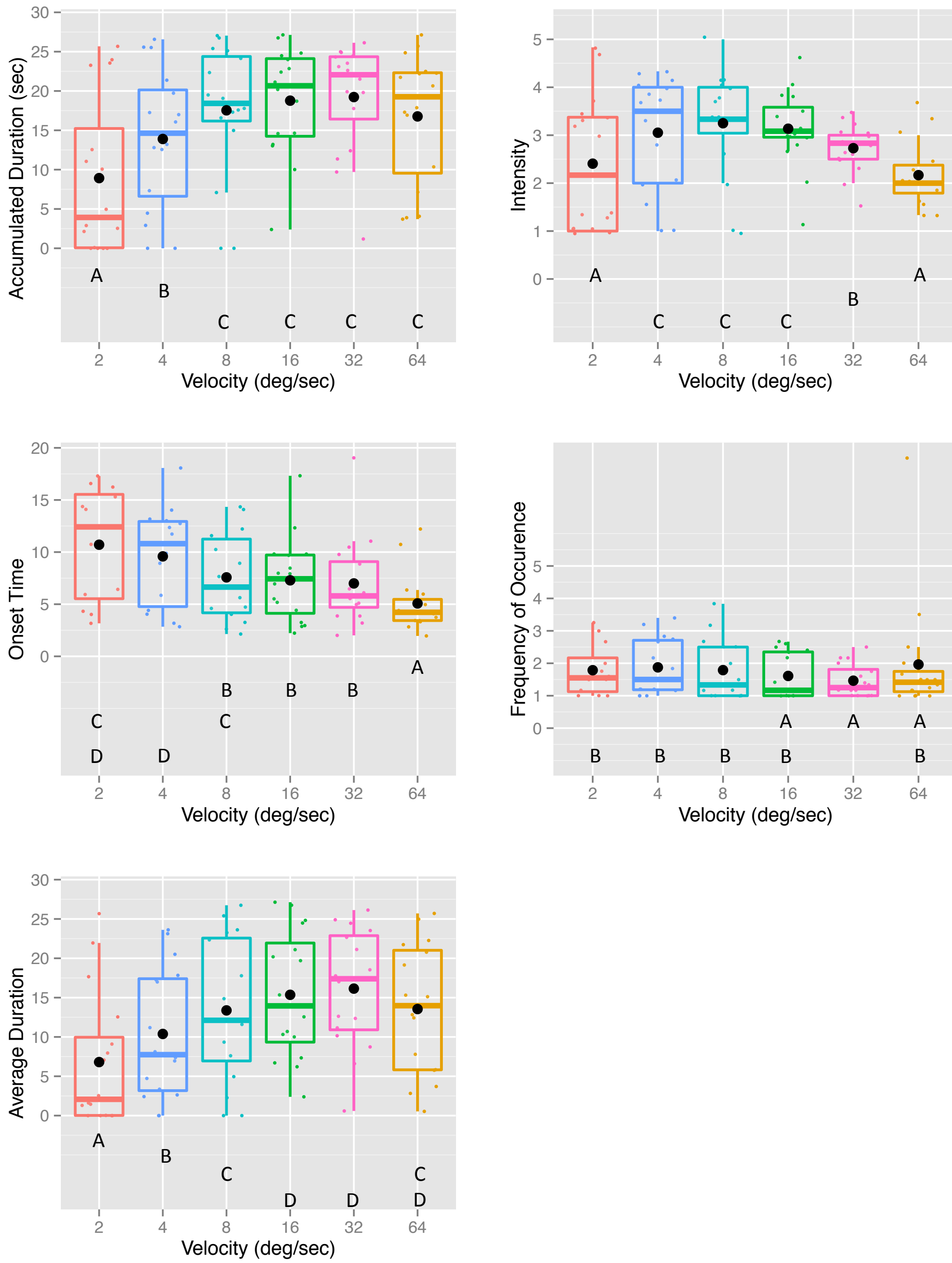


Figure 4.6 Measurements of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different velocities supine position (median with inter-quartile range, IQR). Medians, inter-quartile ranges and ranges are shown in

the format of box-plots. Raw mean data of the 16 subjects are shown as colored dots and the black large dots were the average of the mean data. Data labeled with the same letter are not significantly different from each other at the 5% (p=0.05) level.

4.6 CV comparison between upright and supine positions

Sixteen subjects (5 females, 11 males) participated vection experiment with both upright and supine positions. The order for upright and supine position was counterbalanced. Therefore, we conducted a comparison between two body positions in the following part.

Main factor for this comparison was body position and dependent variables included accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration. Noted that if subjects did not perceive any vection in a condition, then onset time was regarded as not applicable in the following data analysis.

After analysis of pairwise Wilcoxon singed rank test, the results suggested that accumulated CV duration and average duration at 2 deg/sec are marginally significantly different between upright and supine position. Accumulated CV duration at 64 deg/sec also were marginally significantly different between both positions. Frequency of coming in and out of CV sensation at 8 deg/sec showed significant difference. Average duration showed marginal significant difference between both positions. At 4 deg/sec, CV average duration, onset time and average duration all indicated significant difference for upright and supine positions. Moreover, all of above significant results showed stronger and longer CV for upright position than supine position. Table 4.1 showed p-value of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different velocities comparison for upright and supine position. CV comparison between two body position for each subject can be seen in Appendix 4.11-4.15.

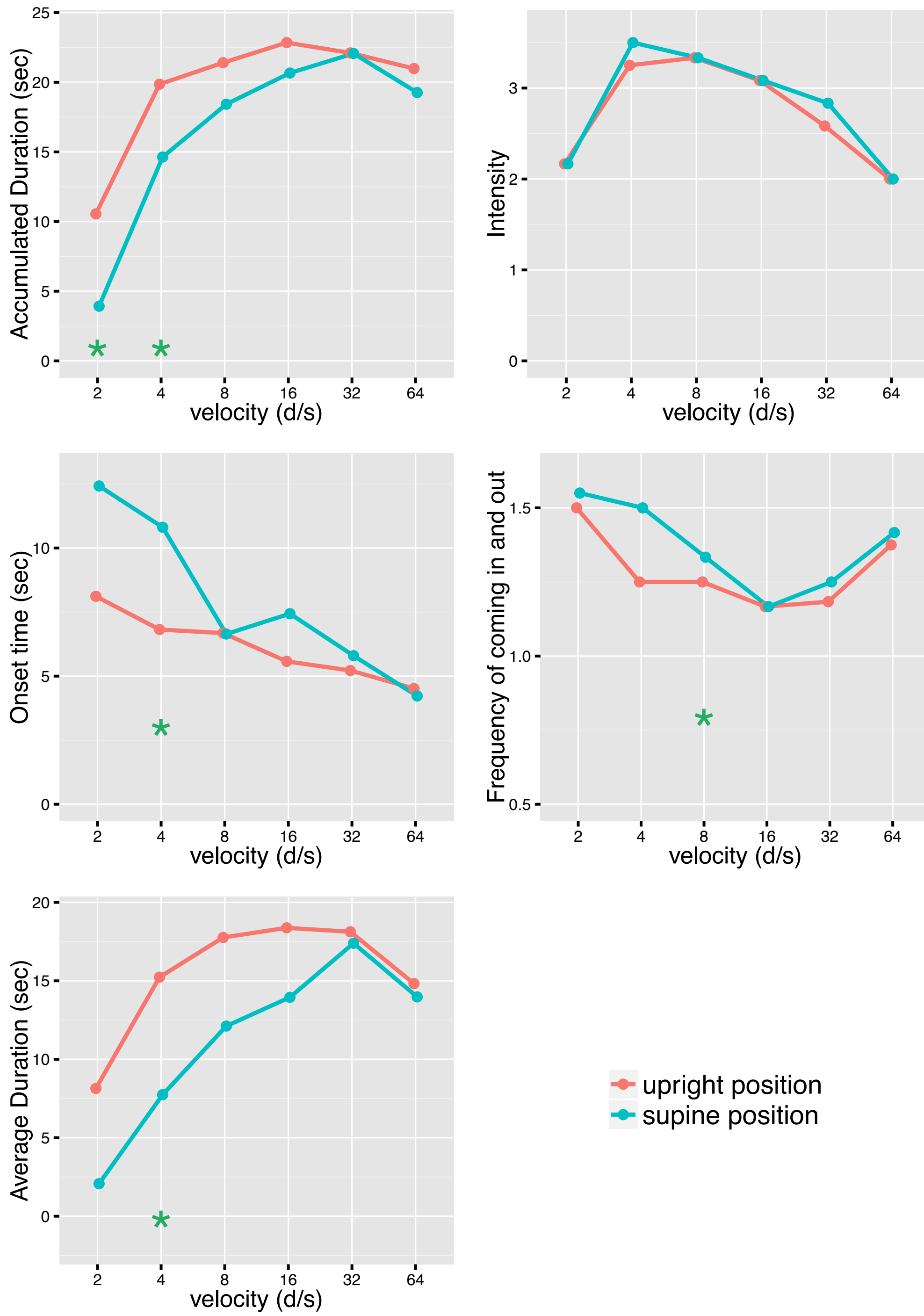


Figure 4.7 Body position comparison for the measurements of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration (green star indicated significant difference). Median data are used.

Table 4.1 P-value of accumulated CV duration, intensity, onset time, frequency of coming in and out of CV sensation and average duration at different velocities comparison for upright and supine position (by Wilcoxon signed rank test).

CV (deg/sec)	2	4	8	16	32	64
Duration	0.024	0.013	0.16	0.27	0.38	0.086
Intensity	0.53	0.67	0.3	0.46	0.88	0.23
Onset time	0.69	0.016	0.14	0.39	0.13	0.49
Frequency of coming in and out	0.11	0.23	0.015	0.3	0.48	0.66
Average duration	0.087	0.023	0.066	0.68	0.44	0.18

4.7 Other analysis

4.7.1 Pre and Post SSQ analysis

Increased SSQ with its four representative sub-scores for upright and supine positions were calculated and analyzed (see Figure 4.6). Statistical analysis did not show any significance for Nausea-related scores (Wilcoxon, p-value=0.6624), Oculormotor-related subscore (Wilcoxon, p-value=0.477), Disorientation-related score (Wilcoxon, p-value=0.1838) and Total Score (Wilcoxon, p-value=0.9741) between upright and supine positions.

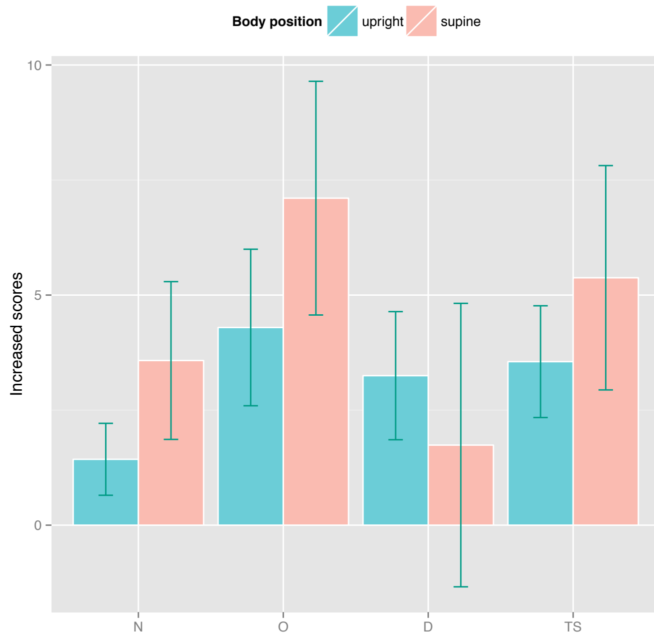


Figure 4.8 Four representative sub-scores of increased SSQ between upright and supine positions. N: Nausea-related scores; O: Oculormotor-related scores; D: Disorientation-related scores; TS: Total score; cyan bar indicates upright position and pink bar indicates supine position; green error bar indicates stand error of mean.

4.7.3 Full vection analysis

Duration of full-vection under different velocities with supine position had been analyzed and plotted in Figure 4.9, Friedman test suggested significant results for supine position (chi-square=13.37, p-value=0.02015). Post-hoc analysis of pairwise Wilcoxon test were conducted (see Table 4.2). As can be seen from the Table 4.2 that duration of full-vection at 2, 4 and 8 deg/sec were significantly higher than the other velocities.

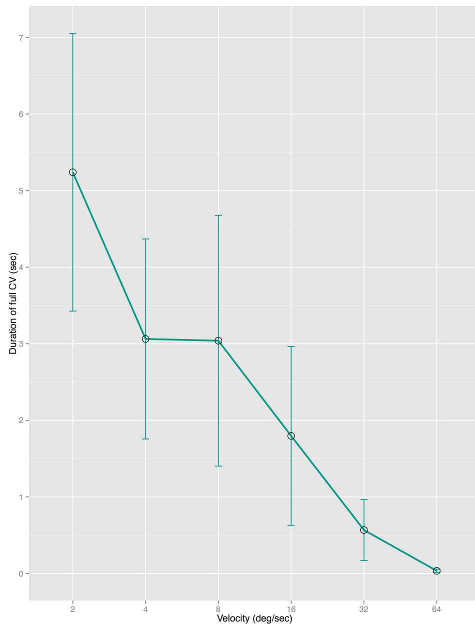


Figure 4.9 Mean with SEM plot of full-CV duration at different velocities. Full-CV duration with supine position.

Table 4.2 P-value of full-CV duration at different velocities with supine position (by Wilcoxon rank test).

deg/sec	2	4	8	16	32
4	0.587	-	-	-	-
8	0.372	0.603	-	-	-
16	0.065	0.114	0.307	-	-
32	0.018	0.029	0.119	0.571	-
64	0.011	0.011	0.063	0.531	0.922

4.7.4 Gender effects

As aforementioned, both female and male subjects participated Experiment 1 and 2 (see Table 4.3). Table 4.3 showed that number of gender participated experiments with supine and upright positions. Gender effect for comparison of upright and supine positions were illustrated in Appendix 4.3-4.10.

Table 4.3 Number of female and male subjects in different experiments

Gender	Exp 1	Exp 2
Female subjects	6	5
Male subjects	14	11
Total subjects	20	16

CHAPTER 5: CONCLUSION AND OUTLOOK

In this dissertation, we investigated the extrinsic factors of the color, angular velocity (2, 4, 8, 16, 32, 64 degree/sec) and body position on visually induced circular vection (CV). Rotating dots were presented to subjects to induce roll vection. Experiment 1 investigated the effects of color and velocity on CV when subjects kept an upright position. Experiment 2 investigated the effect of velocity and body position on CV.

5.1 Major findings and discussions

5.1.1 Major finding 1 and discussion

Major finding 1: Experiment 1 showed that the longest accumulated and average CV duration occurred at 8 deg/sec, 16 deg/sec and 32 deg/sec for upright position. Experiment 2 showed that longest accumulated and average CV duration occurred at 32 deg/sec for supine position. For the CV strength, the larger CV intensity were perceived at 4 deg/sec and 8 deg/sec for upright position and 4 deg/sec, 8 deg/sec and 16 deg/sec for supine position. The shortest onset time occurred at 64 deg/sec for both upright and supine position. Table 5.1 listed the optimal velocities for CV duration and strength.

Ujike et al. (2004) investigated the effects of velocity on CV and VIMS. Different velocities including 2.6, 6.0, 14, 31, 70, 159 and 360 deg/sec were used to induce roll vection. Results showed that the largest subjective score for roll vection occurred at 31 deg/sec. Additionally, Held et al. (1975) also reported that subjects perceived larger magnitude of tilt for roll vection at a velocity between 30 and 40 deg/sec. Both Ujike and Held's conclusions were consistent with our finding.

As demonstrated in section 3.1.1 regarding literature review for velocity, Brandt et al. (1973) used a cylindrical drum to induce roll vection and reported that CV latency was independent of stimulus velocity while our results indicated the shortest CV latency occurred at 64 deg/sec. In Brandt's experiments, CV latency were ranging within 5 seconds. While CV latency in our experiments ranged from 10 seconds for both upright and supine positions. When visual motion stimulation rotated at a constant velocity of 64 deg/sec, subjects perceived CV around 5 seconds for both upright and supine positions.

Table 5.1 The optimal velocities for accumulated CV duration and strength (optimal CV indicates longer duration, larger intensity, shorter onset time, longer average duration and lower frequency of coming in and out of CV sensation).

CV parameters	Upright position (deg/sec)	Supine position (deg/sec)
Duration	8, 16, 32	8, 16, 32, 64
Intensity	4, 8	4, 8, 16
Onset time	64	64
Frequency of coming in and out	8, 16, 32	16, 32, 64
Average duration	8, 16, 32	16, 32, 64

5.1.2 Major finding 2 and discussion

Major finding 2: The stimulus pattern with black and red dots showed no significant results on CV duration.

Seno et al. (2010) examined the color effects of red and green on the strength of linear vection. Different color for background and moving dots were controlled and compared in the experiments. Finally, the conclusion was that stimulus with red components (background or dots) induced weaker vection than green stimulus. Seno interpreted the conclusion as ocular chromatic aberration. It was that red stimuli appeared nearer than green stimuli even though they were presented in the same distance. Under this circumstance, vection was dominated by far or appeared to far stimulus if the stimuli differed in depth (Ito and Shibata, 2005). In contrast, Seya et al. investigated different monocolored stimulus on forward and backward vection and concluded that stimulus with red dots induced stronger vection than the other single colored stimuli (white, red, yellow, green and black). While its conclusion was opposed to ocular chromatic aberration interpreted by Seno. Likewise, Bonato and Bubka (2006) found that chromatic stripes within optokinetic drum (white, red, yellow, black, green and blue) induced stronger vection than black-and-white stripes (Bonato and Bubka, 2006). To investigate the color effect on vection further, Bubka and Bonato (2010) investigated natural visual-filed features on the effect of vection. They employed the stimuli of grayscale and color conditions of first-person perspective video clips presented by a rear projector to induce forward vection. The results suggested that the stimuli of color condition could enhance the vection magnitude and shorten onset time than grey scale condition. As we can see from different studies above that stimulus with red components can facilitate or inhibit vection in different studies with different methodologies. That is, different stimulus luminance, depth cues, field of view or contrast between different colors may have confounding effect on vection strength.

5.1.3 Major finding 3 and discussion

Major finding 3: Longer accumulated and average CV were achieved when subjects kept upright position than supine position, particularly at lower velocity conditions.

When subjects experience CV around earth-horizontal axis, both of visual-otolith conflict and visual-semicircular canal conflict arise. While when subjects experience CV around earth-vertical axis, only visual-semicircular canal conflict occurs. According to the theory that visual-vestibular conflict theory should always impair or reduce vection, then it should be proposed that CV around earth-horizontal axis are weaker than CV around earth-vertical.

Tanahashi et al. (2012) conducted a series of three experiments to examine the correlation for visual-vestibular conflict theory and CV. Three different positions (supine, left lateral recumbent and sitting upright), each position with three stimulus rotating pattern along roll, pitch and yaw axes were used in Experiment 1 and 2 to examine the strength of CV (see Table 5.2), the angle of illusory body tilt and CV convincingness level. Field of view was 93 × 83 degree from a viewing distance of 57cm and visual motion stimuli rotated at constant of 60 deg/sec. The results revealed that strength of roll vection around earth-horizontal axis was greater than around earth-vertical axis. The conclusion was opposed to the visual-vestibular conflict theory but it was consistent with the results from Ujike et al. (2004) and our experiments.

Table 5.2 Representation of different vection types with different body positions in the experiments of Tahanashi et al. (2012)

	Roll vection	Yaw vection	Pitch vection
Supine	earth-vertical	earth-horizontal	earth-horizontal
Left lateral recumbent	earth-horizontal	earth-horizontal	earth-vertical
Sitting upright	earth-horizontal	earth-vertical	earth-horizontal

To explore the causation of conflict between experimental results and theory of visual-vestibular conflicts further, Tanahashi et al. (2012) conducted Experiment 3, three different size of visual stimulus (70, 100 and 180 degree) around three axes were employed to induce CV. The results showed that strength of yaw vection significantly increased to the same level of roll vection strength when increasing the diameter of visual stimulus size. That is, for a smaller visual vestibular conflict, vection strength increased apparently with a larger stimulus size. Ultimately, Tanahashi et al. (2012) concluded that stimulus sizes determined whether the visual-vestibular conflict theory validated or not even though vection strength with different body positions at 180 degrees still did not support the conflict theory. In this dissertation, two body positions for roll vection with sitting upright and supine position were employed to examine CV duration under different velocities. On the contrary to Tanahashi's findings, CV strength between two body positions showed no significant difference at 64 deg/sec. That was possible due to inconsistent luminance of dots and background in two studies. Tahanashi employed the visual motion stimulation consisting of white dots (10.5 cd/m^2) on a black background (0.33 cd/m^2) while we used the stimulation consisting of black dots (0.15 cd/m^2) on a grey background (8.9 cd/m^2). Seno et al. (2010) suggested that luminance of dot played more important role than luminance of background. Specifically, vection induced by stimuli consisting of dots with high-luminance and background with low-luminance were significantly higher than the stimuli consisting of dots with low-luminance and background with high-luminance. Therefore, differential luminance between dots and background were possible causation of inconsistent finding between Tahanashi and our study.

To sum up, the findings of this dissertation were as follows:

- The factor of velocity can significantly affect accumulated and average CV duration when subjects experienced CV with upright position. The longest CV duration occurred at 8 deg/sec, 16 deg/sec and 32 deg/sec for upright position.

- The factor of velocity can significantly affect accumulated and average CV duration when subjects experienced CV with supine position. The longest CV duration occurred at 32 deg/sec for supine position.

- The larger CV intensity were perceived at 4 deg/sec and 8 deg/sec for upright position and 4 deg/sec, 8 deg/sec and 16 deg/sec for supine position.

- The factor of velocity can affect CV onset time. The shortest onset time occurred at 64 deg/sec for both upright and supine position.

- The visual motion stimulation with black and red dots showed no significant results on CV duration and strength comparing the stimuli of black dots.

- Subjects perceived CV with longer duration when they kept upright position than supine position. The lower velocities, the more evident.

5.2 Implication and possible application

In our experiment, the velocity at 64 deg/sec was found to be the optimal velocity to induce CV. While Brandt et al. (1973) used a cylindrical drum to induce yaw vection and reported that CV latency was independent of stimulus velocity. The causation of this inconsistency could be due to different CV types in the experiments. Brandt's experiment investigated yaw vection induced by optokinetic drum while this study examined roll vectionHowever, the lack of repeats in Brandt's experiment might also be the reason. In Brandt's experiment, mean CV onset times collected at 60 deg/sec were shorter than those collected at 10 and 30 deg/sec but the difference was not significantly large enough due to lack of repetitions. In our study, subjects repeated all conditions 6 times to get a better mean estimation and this could be the possible reason why the effects of speeds were significant and more accurate. Furthermore, effects of adaptation were reported in the first 2 to 3 trials in some velocity conditions and this suggests that future functional brain study should not just use one repeat. Using our data as reference, 4 repeats may be the optimal solution as most conditions did not show significant learning effects after 2 repeats.

Additionally, vection duration is a highly critical criterion in addition to CV intensity and magnitude in order to guarantee a strong vection. In recent functional brain studies or behavior studies on CV, only a single velocity (e.g. 30, 40, 45, 60 deg/sec) was selected to induce CV. Since keypress to indicate vection occurrence is forbidden with those functional brain study, the actual duration of CV sensation was not measured and not quantified. Therefore, past studies might have used a stimulus velocity that resulted in sub-optimal CV duration and resulted in lack of significant results. In other words, the choice of stimuli velocity could also be critical. For example, Klosterhalfen et al. (2008) investigated gender effect on circular vection and visually induced motion sickness. CV was induced by the visual stimulus rotating at a constant velocity of 60 deg/sec. As demonstrated in the findings of our experiments, 60 deg/sec is not the optimal velocity to provoke the longest CV duration. Klosterhalfen's experiment failed to demonstrate gender effect on perception of vection, symptom rating and rotation tolerance. One of the reasons why Klosterhalfen failed to reveal significant results could have been due to the use of sub-optimal stimuli velocity. Klosterhalfen's result was consistent with our results that gender at 64 deg/sec did not show any significant difference while gender effect was significant for CV collected with stimuli at other velocities.

Therefore, our findings associated with CV duration and onset time in different velocities and different body positions can provide sufficient information for behavior and functional brain studies. For instance, if researchers would benefit the experimental results from longer CV duration, 32 deg/sec is recommended (while much of previous research employed 60 deg/sec); if researchers would get a trade-off between CV duration and onset time, then 64 deg/sec is recommended. While if researchers aim to investigate brain response under full-vection to avoid object motion as much as possible, 8 deg/sec is recommended. If research would employ a most stable velocity, in that velocity, subjects experienced less intermittent vection, then 32 deg/sec is recommended.

As regarding the finding associated with color in our experiment. Previously, the visual motion stimulus with black and red dots to induce circular vection has been frequently employed in previous functional brain study (Brandt et al., 1998) and behavior studies (Klosterhalfen et al., 2008). However, several psychophysical studies have also revealed that red visual fields may inhibit the magnocellular pathway (motion pathway). Similarly, to cite a few examples, Seno et al. (2010) reported that red stimulus could inhibit linear vection than green dots. For motion perception, Chapman et al. (2004) revealed that adaptation to a visual field results in increased motion coherence thresholds. Accordingly, chromatic stimulus would be preferred to avoid possible effect of color on brain if it would not damage or impair the vection strength. While no such research reported whether the visual stimulus with red and black dots inhibited or facilitated CV comparing with the stimulus with achromatic color. The results from our experiment demonstrated that red, gray and black dots provoked similar level of CV at all velocities. Therefore, the non-significant results in our experiment can provide support that achromatic stimulus should be employed in vection studies, particularly for functional brain studies, since it can avoid the color effect on brain while not impairing or reducing vection strength at the same time.

In our experiments, we also revealed that subjects perceived longer accumulated CV duration, average CV duration and shorter onset time when they kept upright position than supine positions. This may be the reason why conflicting results were reported in the past functional brain experiments. Cardin and Smith (2010) revealed that parietal-occipital visual cortex and posterior insular vestibular cortex (PIVC) were both activated during vection. Antal et al. (2008) reported the activation in the planum temporate/parietal operculum region including PIVC comparing rotation and random moving dots. Findings in both Cardin's and Antal's studies suggested that increased activation of PIVC area was evoked by inducing perceived self-motion, a finding that contradicts with the widely supported visual-vestibular reciprocal inhibition theory. The visual-vestibular reciprocal inhibition theory predicts that visual stimulation with CV not only activates the parieto-occipital visual cortex, but also simultaneously deactivates the PIVC area (Brandt et al., 1998; Dieterich et al., 2003; Kleinschmidt et al., 2002). In both experiments from Cardin and Antal, subjects were in supine position and exposed to the visual motion stimulus rotating with very slow velocity (Cardin: 10 d/s; Antal: 3.5 d/s). As demonstrated in our experiment, when subjects stayed upright position, they reported significantly higher accumulated CV duration and average CV duration than subjects in supine position, particularly at slow velocities (e.g., 2, 4, and 8 deg/sec). Therefore, the contradiction with visual-vestibular reciprocal inhibition theory reported from Cardin and Antal's studies were possibly due to weak CV when subjects kept supine position in fMRI brain studies. As for the other functional brain studies that conformed with the visual-vestibular conflict theory (Brandt et al., 1998; Deutschland et al., 2004), although subjects were also kept in supine position, higher stimulus velocities were used (e.g. 40d/s and 60 d/s). In our study, changing the viewing position from upright to supine did not affect reported CV sensation significantly when higher stimulus velocities were used (e.g., 16, 32, and 64 deg/sec).

5.3 Limitations

Despite the effects of velocity and body position showed significant results on CV duration. Possible limitations were worth to mentioned.

- Stimuli pattern used in our experiments were following the stimulus from Brandt's experiment (Brandt et al., 1998). All dots were randomly distributed in LCD screen and spatial frequency was not controlled. Palmisano and Gillam investigated the most compelling CV was achieved when lower spatial frequency was presented peripherally and higher spatial frequency was presented to the central vision (Palmisano and Gilliam, 1998).

- Field of view used in our experiment was 91 × 60 degree in horizontal and vertical directions. In this condition, significant difference between upright and supine positions on vection duration was achieved. Tanahashi et al. (2012) found that strength of yaw vection was significantly lower than the strength of roll vection with 70 deg of FOV. However, when increasing the FOV to 180 deg, the strength between yaw (rotating along earth-vertical axes) and roll vection (rotating along earth-horizontal axes) were at the same level. However, only roll, yaw, pitch vection with upright position were investigated in Tahanashi's experiments. That gave us a clue visual-vestibular conflict theory may be applicable when increasing FOV for both upright and supine positions.

- Both male and female subjects participated Experiment 1 to 3 and results revealed significant difference between them. To convince the gender effect on CV, we need to recruit more female subjects and counterbalance the experimental design.

5.4 Future research and directions

As stated above, increasing FOV for upright and supine positions to examine visual-vestibular conflict theory can be investigated in the future. Effects of gender were observed in our study and can be explored in future studies.

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APPENDIX 2.1: PRE-EXPOSURE SIMULATOR SICKNESS QUESTIONNAIRE

Pre-exposure Simulator Sickness Questionnaire

SYMPTOM CHECKLIST (Pre-exposure)

Pre-exposure instructions: please fill in this questionnaire. Circle below if any of the symptoms apply to you now. You will be asked to fill this again after the experiment

一般不適	1.	General discomfort	None	Slight		Moderate	Severe
疲 倦	2.	Fatigue	None	Slight		Moderate	Severe
沉 悶	3.	Boredom	None	Slight		Moderate	Severe
想 睡	4.	Drowsiness	None	Slight		Moderate	Severe
頭 痛	5.	Headache	None	Slight		Moderate	Severe
眼 痛	6.	Eyestrain	None	Slight		Moderate	Severe
很難集中視力	7.	Difficulty focusing	None	Slight		Moderate	Severe
口水分秘增加	8.	Salivation increase	None	Slight		Moderate	Severe
口水分秘減少		Salivation decrease	None	Slight		Moderate	Severe
出 汗	9.	Sweating	None	Slight		Moderate	Severe
作 嘔	10.	Nausea	None	Slight		Moderate	Severe
很難集中精神	11.	Difficulty concentrating	None	Slight		Moderate	Severe
精神的壓抑	12.	Mental depression		No	Yes (Slight	Moderate	Severe)
頭 脹	13.	"Fullness of the head"		No	Yes (Slight	Moderate	Severe)
視野模糊	14.	Blurred vision		No	Yes (Slight	Moderate	Severe)
眼 花 (開)	15.	Dizziness eyes open		No	Yes (Slight	Moderate	Severe)
眼 花 (合)		Dizziness eyes close		No	Yes (Slight	Moderate	Severe)
眩 暈	16.	Vertigo		No	Yes (Slight	Moderate	Severe)
幻 覺	17.	Visual flashbacks*		No	Yes (Slight	Moderate	Severe)
昏 厥	18.	Faintness		No	Yes (Slight	Moderate	Severe)
呼 吸 異 樣	19.	Aware of breathing		No	Yes (Slight	Moderate	Severe)
胃感覺異樣	20.	Stomach awareness		No	Yes (Slight	Moderate	Severe)
沒 有 胃 口	21.	Loss of appetite		No	Yes (Slight	Moderate	Severe)
胃 口 增 加	22.	Increased appetite		No	Yes (Slight	Moderate	Severe)
想去洗手間	23.	Desire to move bowels		No	Yes (Slight	Moderate	Severe)
迷 惘	24.	Confusion		No	Yes (Slight	Moderate	Severe)
打 嗝	25.	Burping		No	Yes (Slight	Moderate	Severe)
嘔 吐	26.	Vomiting		No	Yes (Slight	Moderate	Severe)
其 他	27.	Other		No	Yes (Slight	Moderate	Severe)

APPENDIX 2.2: POST-EXPOSURE SIMULATOR SICKNESS QUESTIONNAIRE

Post-exposure Simulator Sickness Questionnaire

SYMPTOM CHECKLIST (Post-exposure)

Post-exposure instruction: please fill in this questionnaire once more. Circle below if any of the symptoms apply to you now.

一般不適	1. General discomfort	None	Slight		Moderate	Severe
疲 倦	2. Fatigue	None	Slight		Moderate	Severe
沉 悶	3. Boredom	None	Slight		Moderate	Severe
想 睡	4. Drowsiness	None	Slight		Moderate	Severe
頭 痛	5. Headache	None	Slight		Moderate	Severe
眼 痛	6. Eyestrain	None	Slight		Moderate	Severe
很難集中視力	7. Difficulty focusing	None	Slight		Moderate	Severe
口水分秘增加	8. Salivation increase	None	Slight		Moderate	Severe
口水分秘減少	Salivation decrease	None	Slight		Moderate	Severe
出 汗	9. Sweating	None	Slight		Moderate	Severe
作 嘔	10. Nausea	None	Slight		Moderate	Severe
很難集中精神	11. Difficulty concentrating	None	Slight		Moderate	Severe
精神的壓抑	12. Mental depression		No	Yes (Slight	Moderate	Severe)
頭 脹	13. "Fullness of the head"		No	Yes (Slight	Moderate	Severe)
視野模糊	14. Blurred vision		No	Yes (Slight	Moderate	Severe)
眼 花 (開)	15. Dizziness eyes open		No	Yes (Slight	Moderate	Severe)
眼 花 (合)	Dizziness eyes close		No	Yes (Slight	Moderate	Severe)
眩 暈	16. Vertigo		No	Yes (Slight	Moderate	Severe)
幻 覺	17. Visual flashbacks*		No	Yes (Slight	Moderate	Severe)
昏 厥	18. Faintness		No	Yes (Slight	Moderate	Severe)
呼 吸 異 樣	19. Aware of breathing		No	Yes (Slight	Moderate	Severe)
胃感覺異樣	20. Stomach awareness		No	Yes (Slight	Moderate	Severe)
沒 有 胃 口	21. Loss of appetite		No	Yes (Slight	Moderate	Severe)
胃 口 增 加	22. Increased appetite		No	Yes (Slight	Moderate	Severe)
想去洗手間	23. Desire to move bowels		No	Yes (Slight	Moderate	Severe)
迷 惘	24. Confusion		No	Yes (Slight	Moderate	Severe)
打 嗝	25. Burping		No	Yes (Slight	Moderate	Severe)
嘔 吐	26. Vomiting		No	Yes (Slight	Moderate	Severe)
其 他	27. Other		No	Yes (Slight	Moderate	Severe)

APPENDIX 2.3: CALCULATIONS OF SSQ SCORES (KENNEDY ET AL., 1993)

None = 0
Slight = 1
Moderate = 2
Severe = 3

Symptoms	Weights for Symptoms Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total*	[1]	[2]	[3]

Score
Nausea = [1] ´ 9.54
Oculomotor = [2] ´ 7.58
Disorientation = [3] ´ 13.92

Total Score = ([1] + [2] + [3]) *3.74

* Total is the sum obtained by adding the symptoms scores. Omitted scores are zero

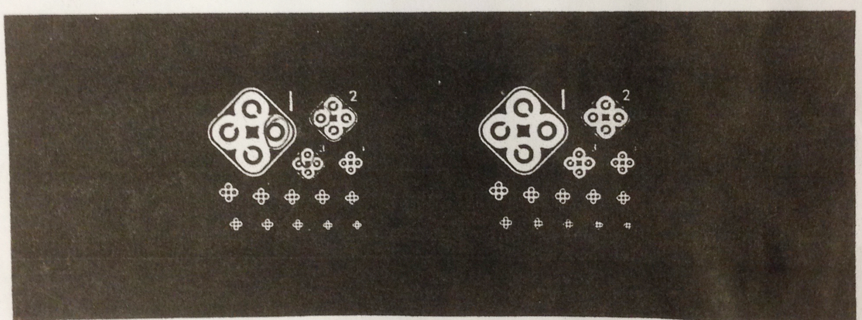
APPENDIX 2.4: INSTRUCTIONS OF MEASURING VISUAL ACUITY AT NEAR POINT

TEST NO. 9 ACUITY BOTH EYES "NEAR"

1. NEAR/FAR Point Switch in the Down position
2. Right and Left eye Switches in the Down position
3. Dial #9 at Blue Indicator (Near)

This test stimulates near vision at a 14 inch distance. Both eyes see the same targets which are fused into a single target when viewed binocularly.

QUESTION: "Look at the #1 target. Is the ring at the RIGHT broken like the other rings or is it unbroken? Where is the unbroken ring in target #4—at the top, bottom, right or left? #5? #6? Score these tests the same as FAR acuity tests. Record last correct answer after two consecutive misses.

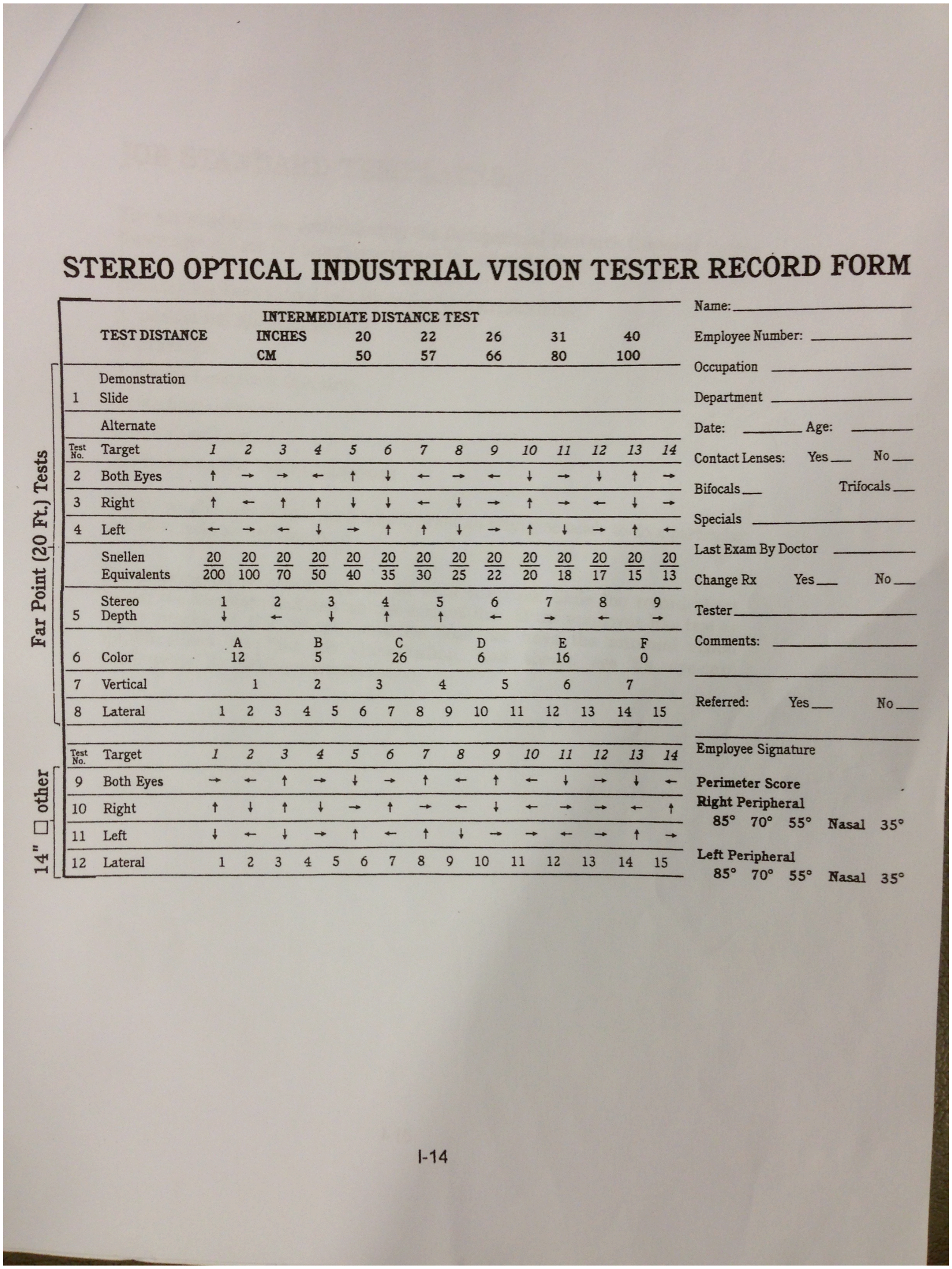


LEFT EYE RIGHT EYE

SCORE	1	2	3	4	5	6	7	8	9	10	11	12	13	14
KEY	R	L	T	R	B	R	T	L	T	L	B	R	B	L
	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	200	100	70	50	40	35	30	25	22	20	18	17	15	13

Left = ←, Right = →, Top = ↑, Bottom = ↓

APPENDIX 2.5: STEREO OPTICAL INDUSTRIAL VISION TESTER RECORD FORM



STEREO OPTICAL INDUSTRIAL VISION TESTER RECORD FORM

TEST DISTANCE	INTERMEDIATE DISTANCE TEST					
	INCHES	20	22	26	31	40
	CM	50	57	66	80	100

Far Point (20 Ft.) Tests

Test No.	Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Demonstration Slide														
	Alternate														
Test No.	Target	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	Both Eyes	↑	→	→	←	↑	↓	←	→	←	↓	→	↓	↑	→
3	Right	↑	←	↑	↑	↓	↓	←	↓	→	↑	→	←	↓	→
4	Left	←	→	←	↓	→	↑	↑	↓	→	↑	↓	→	↑	←
	Snellen Equivalents	20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13

Test No.	Test														
5	Stereo Depth	1 ↓	2 ←	3 ↓	4 ↑	5 ↑	6 ←	7 →	8 ←	9 →					
6	Color	A 12	B 5	C 26	D 6	E 16	F 0								
7	Vertical	1	2	3	4	5	6	7							
8	Lateral	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

14" ☐ other

Test No.	Target	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
9	Both Eyes	→	←	↑	→	↓	→	↑	←	↑	←	↓	→	↓	←	
10	Right	↑	↓	↑	↓	→	↑	→	←	↓	←	→	→	←	↑	
11	Left	↓	←	↓	→	↑	←	↑	↓	→	→	←	→	↑	→	
12	Lateral	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Name: ____________

Employee Number: ____________

Occupation ____________

Department ____________

Date: ______ Age: ______

Contact Lenses: Yes ___ No ___

Bifocals ___ Trifocals ___

Specials ____________

Last Exam By Doctor ____________

Change Rx Yes ___ No ___

Tester ____________

Comments: ____________

Referred: Yes ___ No ___

Employee Signature

Perimeter Score

Right Peripheral

85° 70° 55° **Nasal** 35°

Left Peripheral

85° 70° 55° **Nasal** 35°

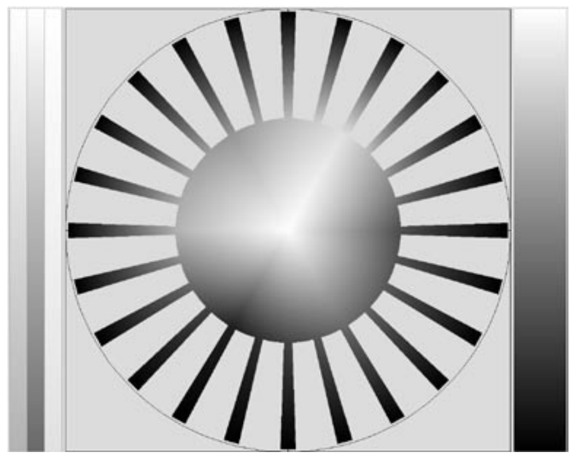
I-14

APPENDIX 3.1: LUMINANCE MODELS FOR GRAYSCALE CONVERSIONS.

According to the luminance model which is used by NTSC and JPEG for nonlinear data in a gamma working space, the conversion formula is as follows (Hoffmann Gernot):

Y=0.299 * Red + 0.587 * Green + 0.114 * Blue

The following figures demonstrates pre and post grayscale conversions.



APPENDIX 3.2: EXPERIMENT 1_P-VALUE FOR CV DURATION, INTENSITY, ONSET TIME, FREQUENCY OF OCCURRENCE AND AVERAGE DURATION UNDER DIFFERENT VELOCITIES WITH UPRIGHT POSITION.

Accumulated CV duration					
	V1	V2	V3	V4	V5
V2	5.9e-13	-	-	-	-
V3	<2e-16	0.9829	-	-	-
V4	<2e-16	0.6033	0.395	-	-
V5	<2e-16	0.0297	0.0091	0.0464	-
V6	<2e-16	0.6642	0.5695	0.101	0.0022

CV intensity					
	V1	V2	V3	V4	V5
V2	5.00E-07	-	-	-	-
V3	8.00E-07	0.5093	-	-	-
V4	1.00E-05	0.0092	0.0086	-	-
V5	0.0049	4.00E-10	1.00E-13	5.00E-09	-
V6	0.8102	< 2e-16	< 2e-16	< 2e-16	< 2e-16

CV onset time					
	V1	V2	V3	V4	V5
V2	6.00E-05	-	-	-	-
V3	8.00E-06	0.5851	-	-	-
V4	6.00E-08	0.1589	0.2826	-	-
V5	1.00E-09	0.0178	0.0549	0.3285	-
V6	3.00E-13	3.00E-05	0.0003	0.0031	0.0388

Frequency of coming in and out of CV sensation					
	V1	V2	V3	V4	V5
V2	0.05424	-	-	-	-
V3	0.00011	0.03699	-	-	-
V4	2.80E-05	0.01499	0.73494	-	-
V5	6.50E-06	0.00602	0.5424	0.7926	-
V6	0.01027	0.51493	0.13109	0.06297	0.03068

Average CV duration					
	V1	V2	V3	V4	V5
V2	<2e-16	-	-	-	-
V3	<2e-16	0.37149	-	-	-
V4	<2e-16	0.18435	0.5324	-	-
V5	<2e-16	0.00179	0.00743	0.02785	-
V6	<2e-16	0.85702	0.1829	0.0329	0.00012

APPENDIX 4.1: EXPERIMENT 2_P-VALUE FOR CV DURATION, INTENSITY, ONSET TIME, FREQUENCY OF OCCURRENCE AND AVERAGE DURATION UNDER DIFFERENT VELOCITIES WITH UPRIGHT POSITION.

Accumulated CV duration					
	V1	V2	V3	V4	V5
V2	0.0064	-	-	-	-
V3	0.00103	0.42349	-	-	-
V4	0.00064	0.33115	0.79074	-	-
V5	0.00018	0.28938	0.75112	0.9803	-
V6	0.00025	0.39306	0.96993	0.67656	0.77404

CV intensity					
	V1	V2	V3	V4	V5
V2	0.00737	-	-	-	-
V3	0.01245	0.5649	-	-	-
V4	0.02169	0.20338	0.36129	-	-
V5	0.18537	0.00197	0.00094	0.00381	-
V6	0.92945	5.70E-07	1.20E-08	2.60E-09	6.90E-05

CV onset time					
	V1	V2	V3	V4	V5
V2	0.13355	-	-	-	-
V3	0.03460	0.46212	-	-	-
V4	0.01806	0.2138	0.55054	-	-
V5	0.01317	0.15169	0.36228	0.64901	-
V6	0.00037	0.00346	0.01635	0.05006	0.11823

Frequency of coming in and out of CV sensation					
	V1	V2	V3	V4	V5
V2	0.75	-	-	-	-
V3	0.29	0.14	-	-	-
V4	0.54	0.33	0.62	-	-
V5	0.27	0.14	0.96	0.58	-
V6	0.82	0.94	0.17	0.38	0.15

Average CV duration					
	V1	V2	V3	V4	V5
V2	0.00042	-	-	-	-
V3	8.00E-06	0.242	-	-	-
V4	1.20E-05	0.35228	0.84327	-	-
V5	4.60E-07	0.1178	0.66321	0.5091	-
V6	3.70E-06	0.28467	0.80795	0.87812	0.49849

APPENDIX 4.2: EXPERIMENT 2_P-VALUE FOR CV DURATION, INTENSITY, ONSET TIME, FREQUENCY OF OCCURRENCE AND AVERAGE DURATION UNDER DIFFERENT VELOCITIES WITH SUPINE POSITION.

Accumulated CV duration					
	V1	V2	V3	V4	V5
V2	0.00027	-	-	-	-
V3	2.00E-07	0.02055	-	-	-
V4	3.50E-09	0.00103	0.45335	-	-
V5	3.30E-09	0.00061	0.23034	0.75913	-
V6	9.00E-07	0.05874	0.73432	0.22823	0.15578

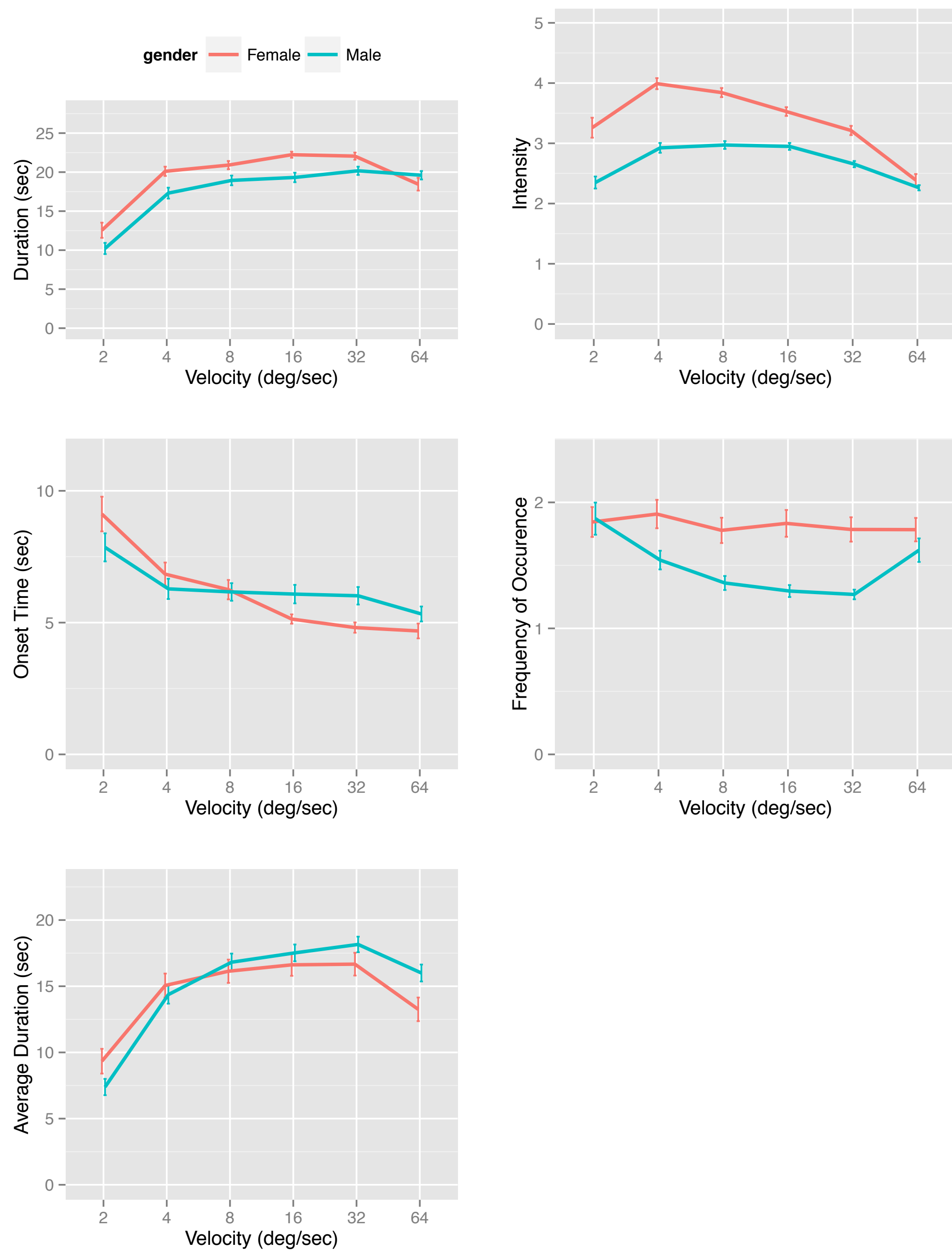
CV intensity					
	V1	V2	V3	V4	V5
V2	0.00463	-	-	-	-
V3	0.0003	0.42593	-	-	-
V4	0.00042	0.9293	0.22128	-	-
V5	0.01442	0.01328	0.000032	0.0002	-
V6	0.40485	2.30E-06	4.20E-11	5.00E-13	2.30E-07

CV onset time					
	V1	V2	V3	V4	V5
V2	0.9959	-	-	-	-
V3	0.1895	0.0889	-	-	-
V4	0.0109	0.0034	0.283	-	-
V5	0.0202	0.0035	0.2318	0.8934	-
V6	0.000042	0.000003	0.0021	0.0388	0.0121

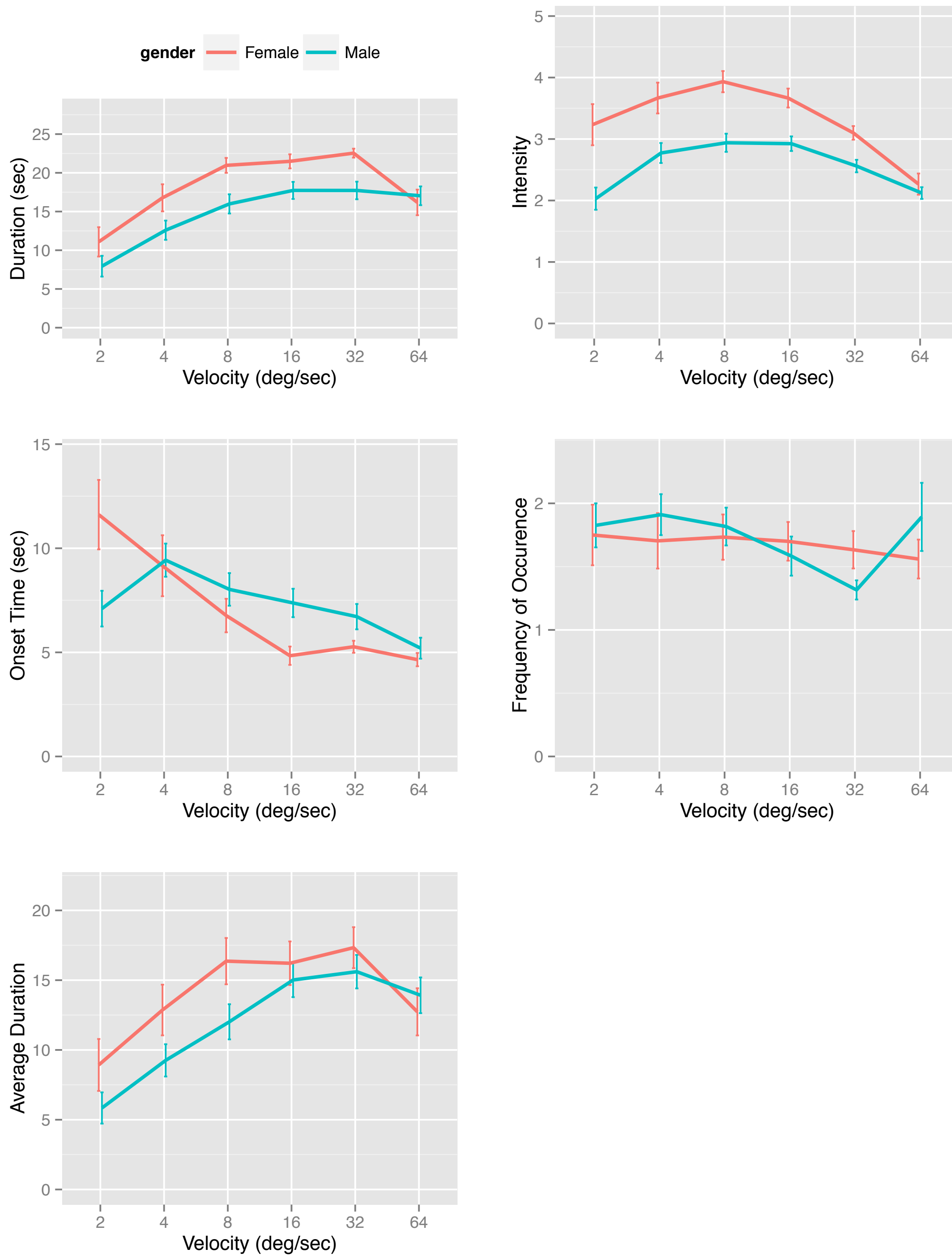
Frequency of coming in and out of CV sensation					
	V1	V2	V3	V4	V5
V2	0.772	-	-	-	-
V3	0.629	0.814	-	-	-
V4	0.148	0.212	0.305	-	-
V5	0.024	0.032	0.052	0.356	-
V6	0.25	0.38	0.517	0.738	0.22

Average CV duration					
	V1	V2	V3	V4	V5
V2	0.00019	-	-	-	-
V3	1.70E-07	0.03295	-	-	-
V4	5.00E-10	0.00037	0.17569	-	-
V5	1.90E-10	0.00011	0.06826	0.72769	-
V6	2.10E-07	0.03587	0.86679	0.21067	0.13294

APPENDIX 4.3: GENDER COMPARISON FOR UPRIGHT POSITION (20 SUBJECTS)



APPENDIX 4.4: GENDER COMPARISON FOR SUPINE POSITION (16 SUBJECTS)



APPENDIX 4.5: RESULTS OF WILCOXON RANK TEST – EFFECTS OF GENDER ON CV DURATION, STRENGTH AND SUSCEPTIBILITY

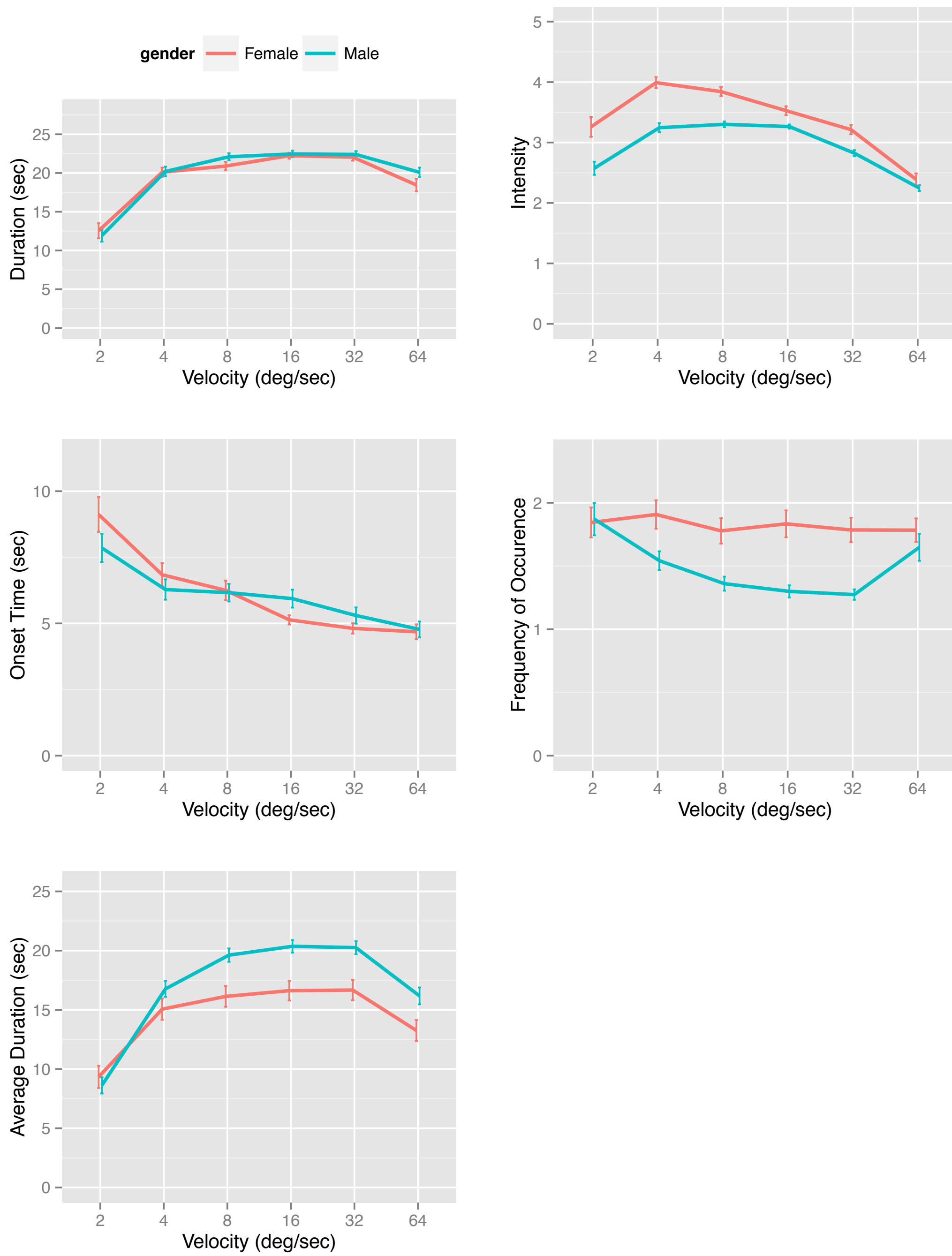
P-value for gender comparison of CV duration, intensity, onset time, frequency of occurrence and average duration at different velocities subjects with upright position (20 subjects).

CV parameters	V1	V2	V3	V4	V5	V6
Duration	0.049	0.66	0.86	0.96	0.91	0.079
Intensity	3E-06	8.00E-	2.20E-	2.50E-	9.50E-	1
Onset time	0.017	0.0081	0.044	0.24	0.63	0.55
Frequency of occurrence	0.56	0.0027	1.6E-05	2.40E-	1.80E-	0.00068
Average duration	0.0069	0.4	0.52	0.21	0.084	0.013

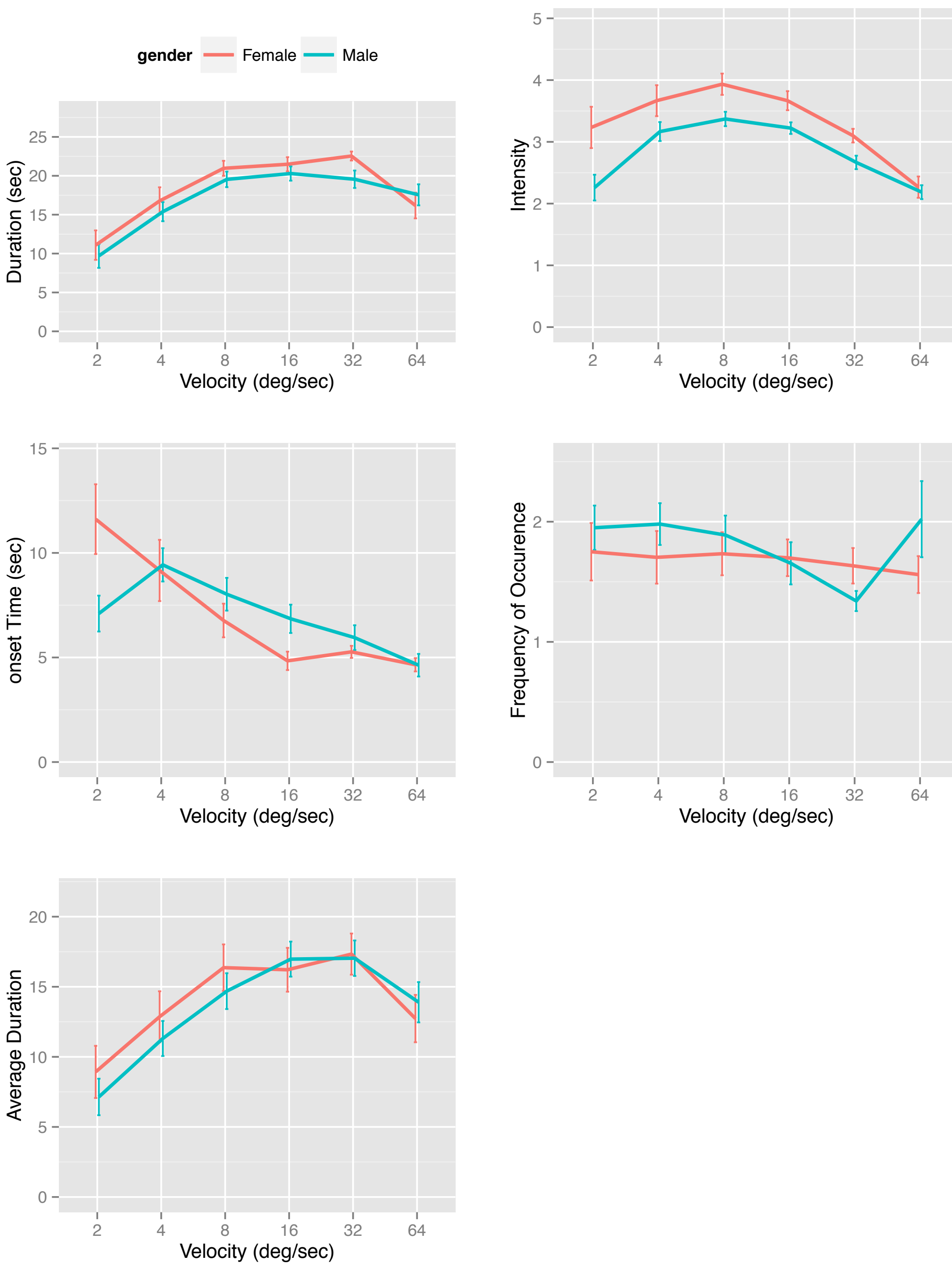
P-value for gender comparison of CV duration, intensity, onset time, frequency of occurrence and average duration at different velocities subjects with supine position (16 subjects).

CV parameters	V1	V2	V3	V4	V5	V6
Duration	0.08	0.056	0.088	0.12	0.11	0.39
Intensity	0.0011	0.0021	0.00011	0.00098	0.0033	0.66
Onset time	0.016	0.59	0.62	0.035	0.65	0.58
Frequency of occurrence	0.52	0.37	0.95	0.14	0.064	0.94
Average duration	0.045	0.073	0.038	0.41	0.53	0.56

APPENDIX 4.6: GENDER COMPARISON FOR UPRIGHT POSITION (18 SUBJECTS)



APPENDIX 4.7: GENDER COMPARISON FOR SUPINE POSITION (14 SUBJECTS)



APPENDIX 4.8: RESULTS OF WILCOXON RANK TEST – EFFECTS OF GENDER ON CV DURATION, STRENGTH AND SUSCEPTIBILITY

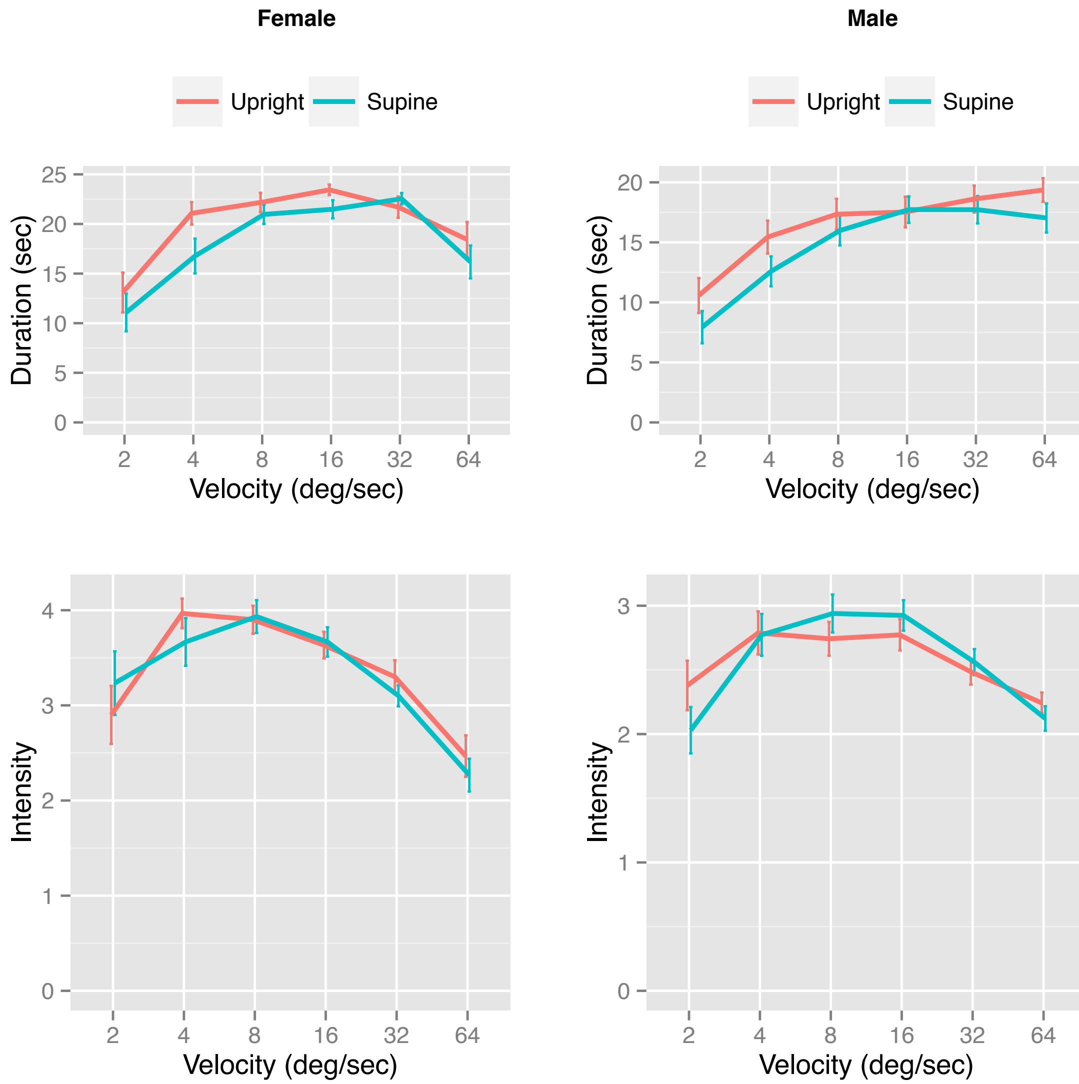
P-value for gender comparison of CV duration, intensity, onset time, frequency of occurrence and average duration at different velocities subjects with upright position (18 subjects).

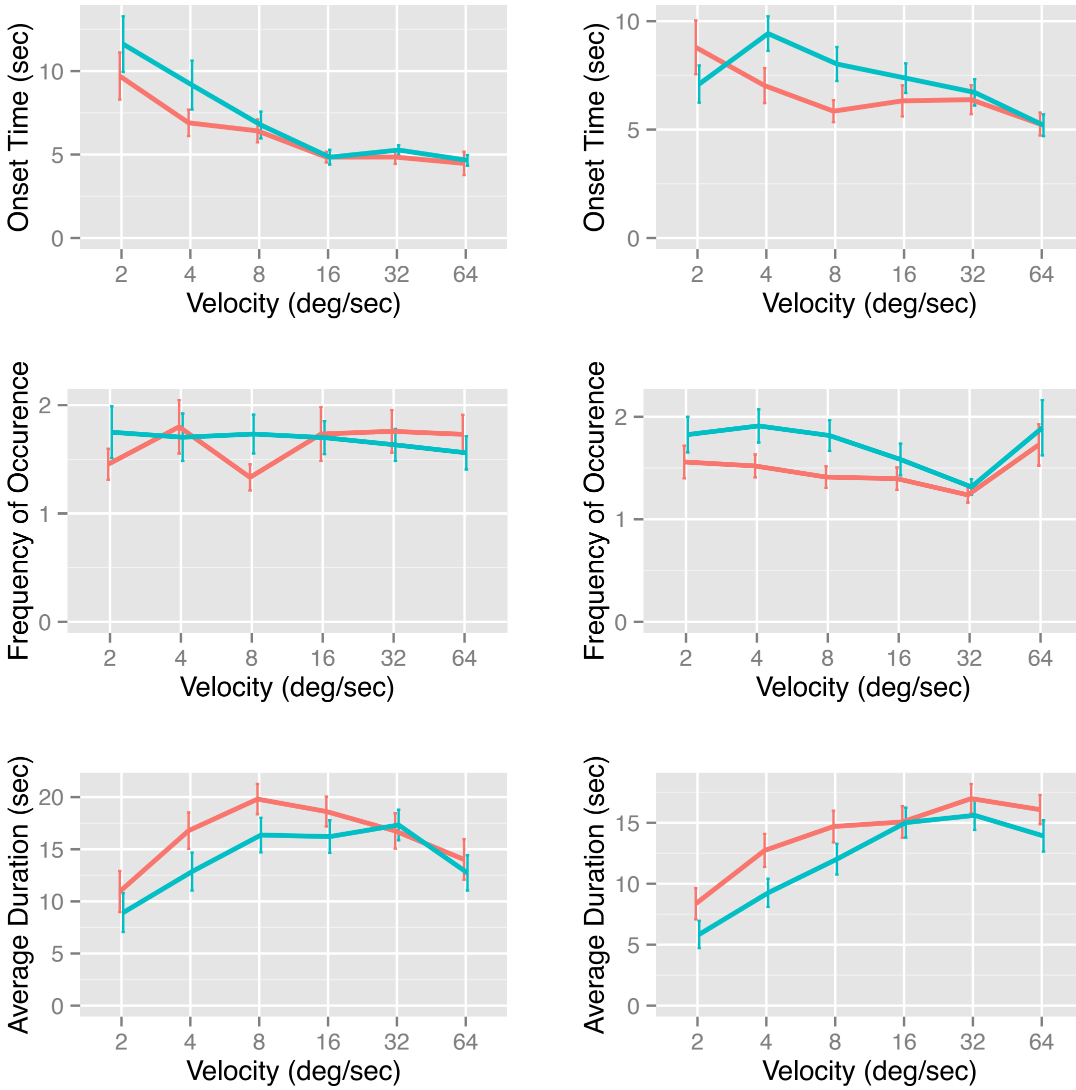
CV parameters	V1	V2	V3	V4	V5	V6
Duration	0.68	0.052	0.0082	0.017	0.031	0.0095
Intensity	0.0005	1.40E-	3.40E-	0.0061	0.00014	0.87
Onset time	0.017	0.0081	0.044	0.19	0.057	0.017
Frequency of occurrence	0.56	0.0027	1.6E-05	3.10E-07	3.60E-07	0.0012
Average duration	0.22	0.14	0.0015	0.00014	0.00035	0.0086

P-value for gender comparison of CV duration, intensity, onset time, frequency of occurrence and average duration at different velocities subjects with supine position (14 subjects).

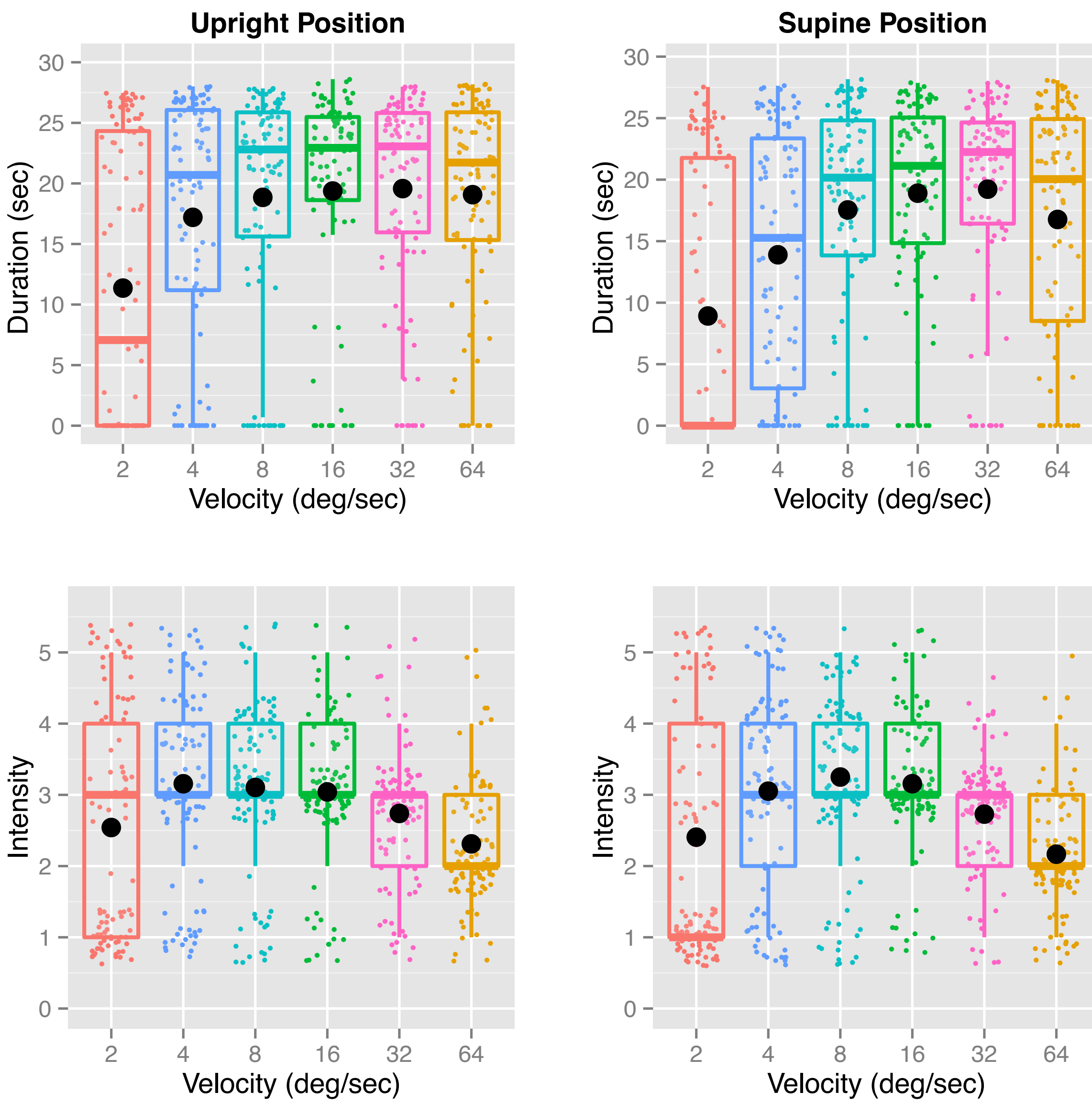
CV parameters	V1	V2	V3	V4	V5	V6
Duration	0.4	0.46	0.74	0.65	0.61	0.22
Intensity	0.01	0.037	0.0043	0.019	0.022	0.92
Onset time	0.016	0.59	0.62	0.11	0.61	0.089
Frequency of occurrence	0.27	0.26	0.73	0.27	0.1	0.69
Average duration	0.26	0.55	0.44	0.91	0.86	0.5

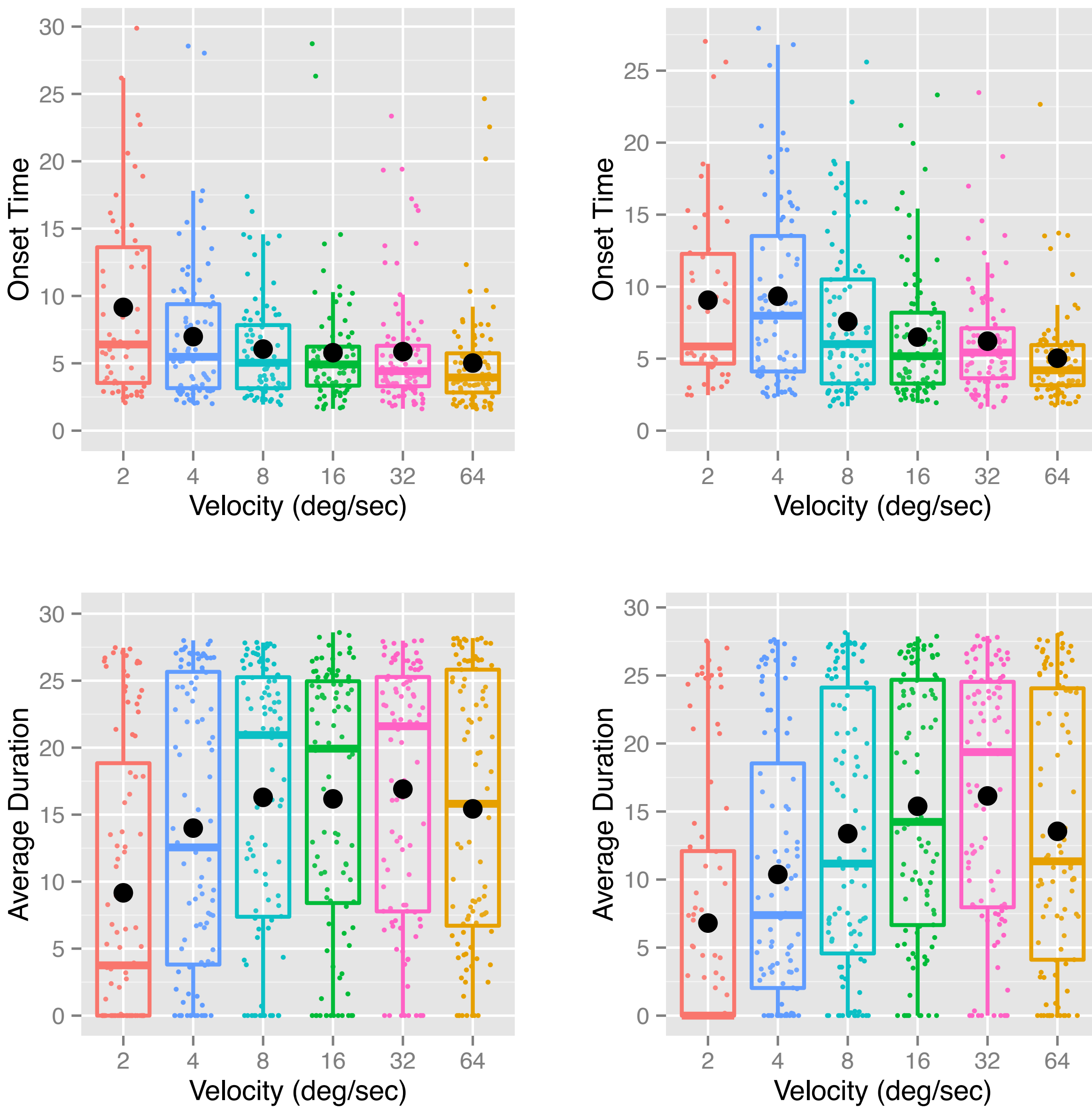
APPENDIX 4.9 COMPARISON OF BODY POSITION FOR CV DURATION, STRENGTH AND SUSCEPTIBILITY WITHIN FEMALE AND MALE GROUPS

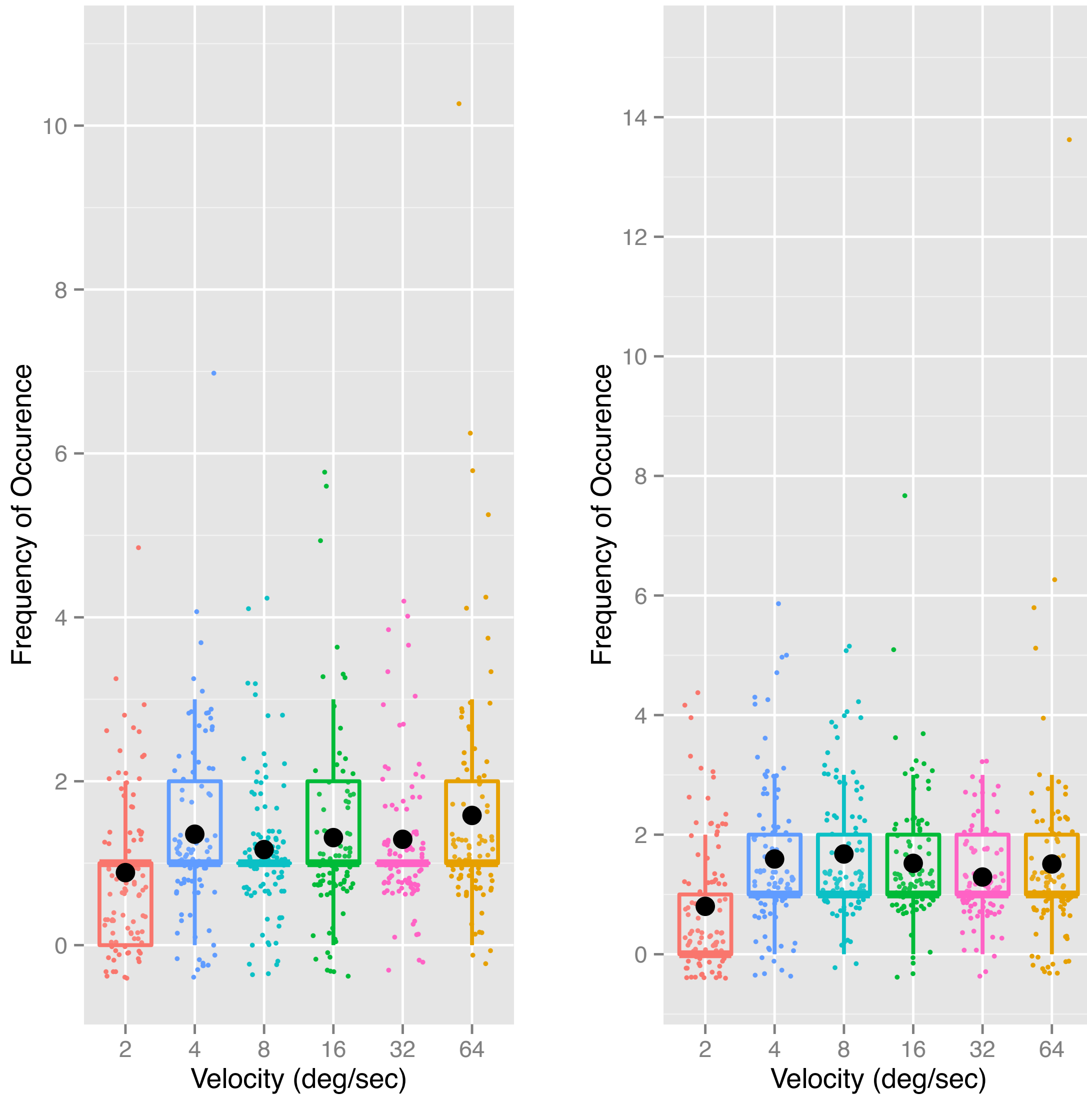



Onset Time (sec)
0
5
10
2
4
8
16
32
64
Velocity (deg/sec)
Onset Time (sec)
0
5
10
2
4
8
16
32
64
Velocity (deg/sec)
Frequency of Occurence
0
1
2
2
4
8
16
32
64
Velocity (deg/sec)
Frequency of Occurence
0
1
2
2
4
8
16
32
64
Velocity (deg/sec)
Average Duration (sec)
0
5
10
15
20
2
4
8
16
32
64
Velocity (deg/sec)
Average Duration (sec)
0
5
10
15
2
4
8
16
32
64
Velocity (deg/sec)

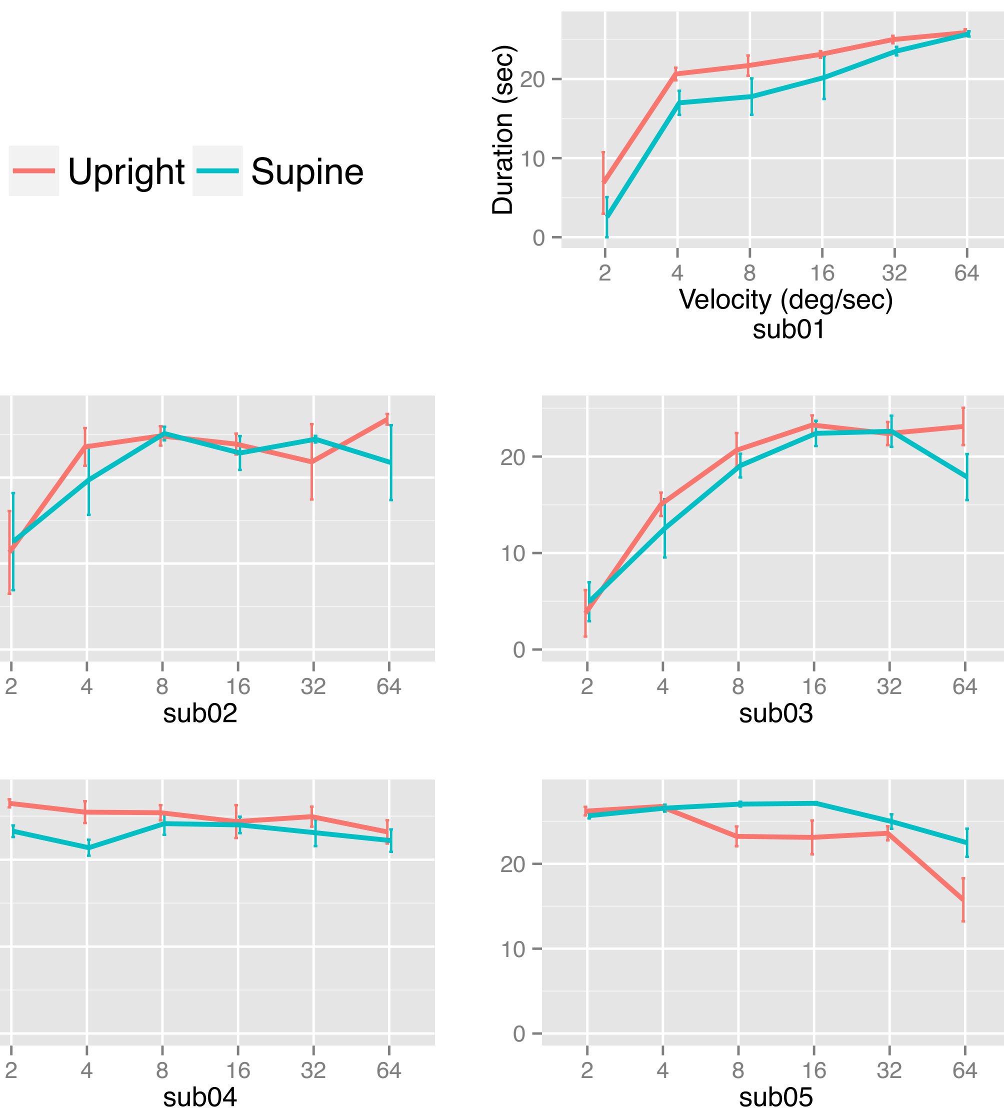
APPENDIX 4.10 BOXPLOT OF GENDER COMPARISON FOR CV DURATION, STRENGTH AND SUSCEPTIBILITY WITH UPRIGHT POSITION

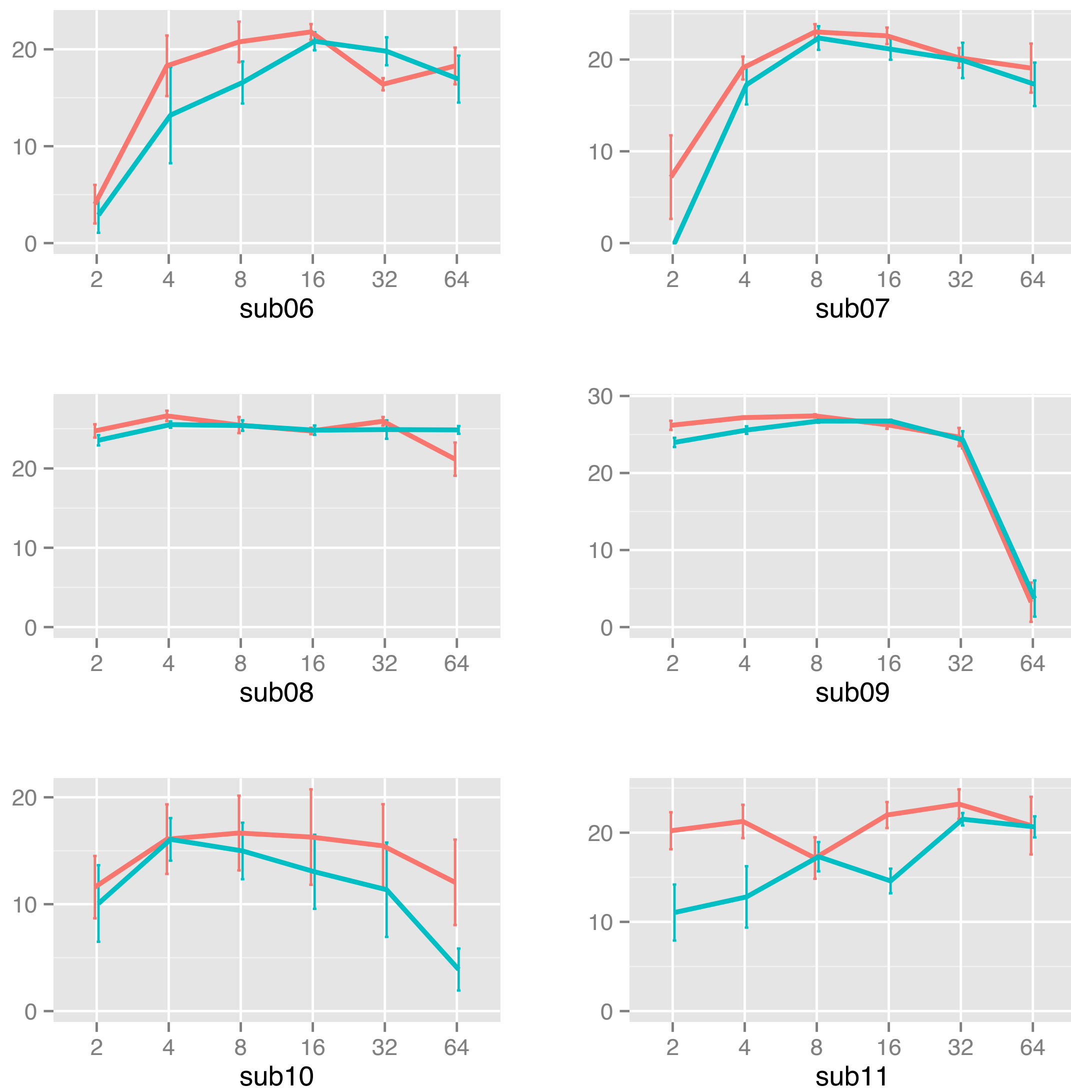


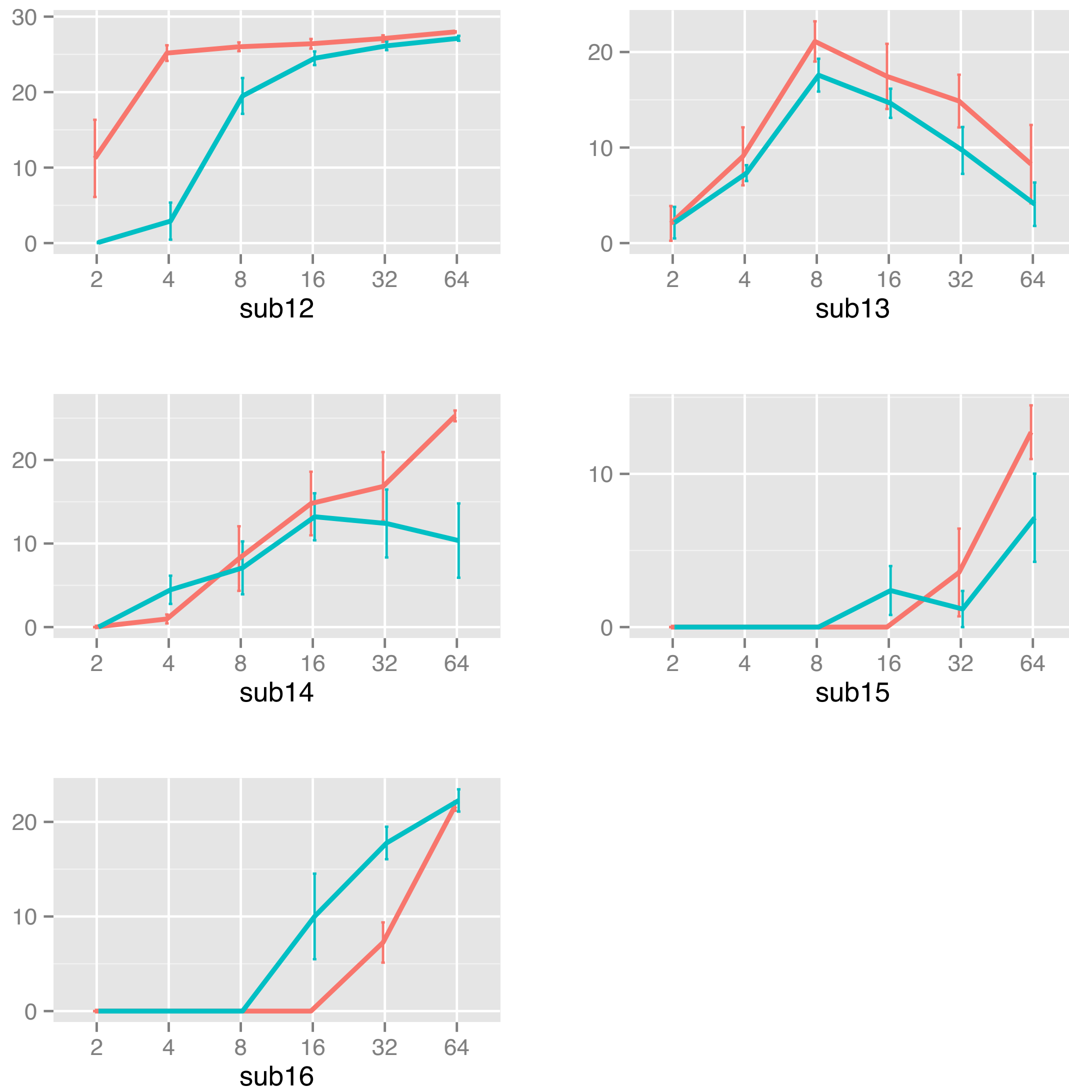

Onset Time
30
25
20
15
10
5
0
2
4
8
16
32
64
Velocity (deg/sec)
Onset Time
25
20
15
10
5
0
2
4
8
16
32
64
Velocity (deg/sec)
Average Duration
30
25
20
15
10
5
0
2
4
8
16
32
64
Velocity (deg/sec)
Average Duration
30
25
20
15
10
5
0
2
4
8
16
32
64
Velocity (deg/sec)


Frequency of Occurence
Velocity (deg/sec)
0
2
4
6
8
10
2
4
8
16
32
64
Frequency of Occurence
Velocity (deg/sec)
0
2
4
6
8
10
12
14
2
4
8
16
32
64

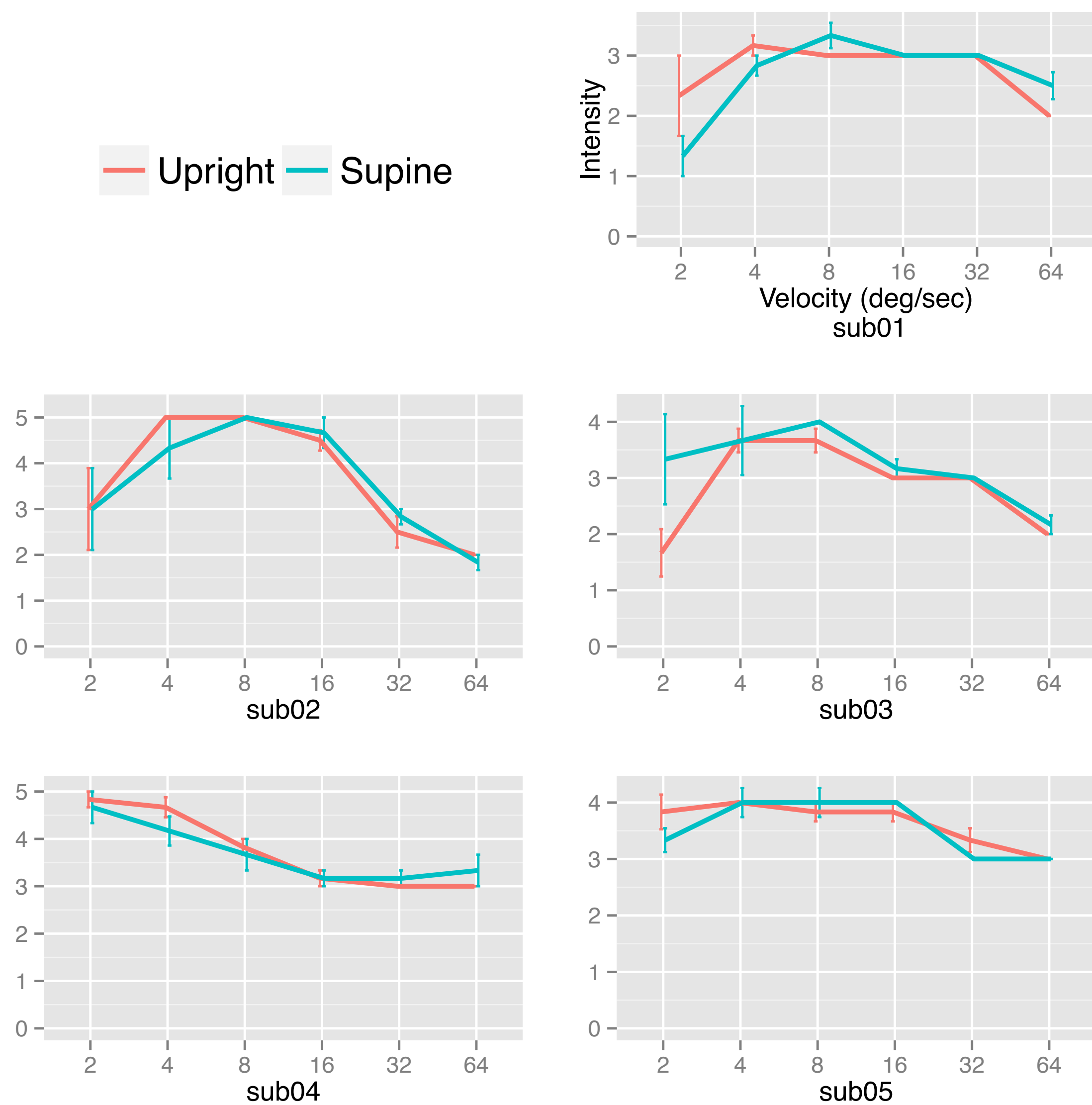
APPENDIX 4.11 CV DURATION COMPARISON BETWEEN TWO BODY POSITIONS FOR ALL 16 SUBJECTS

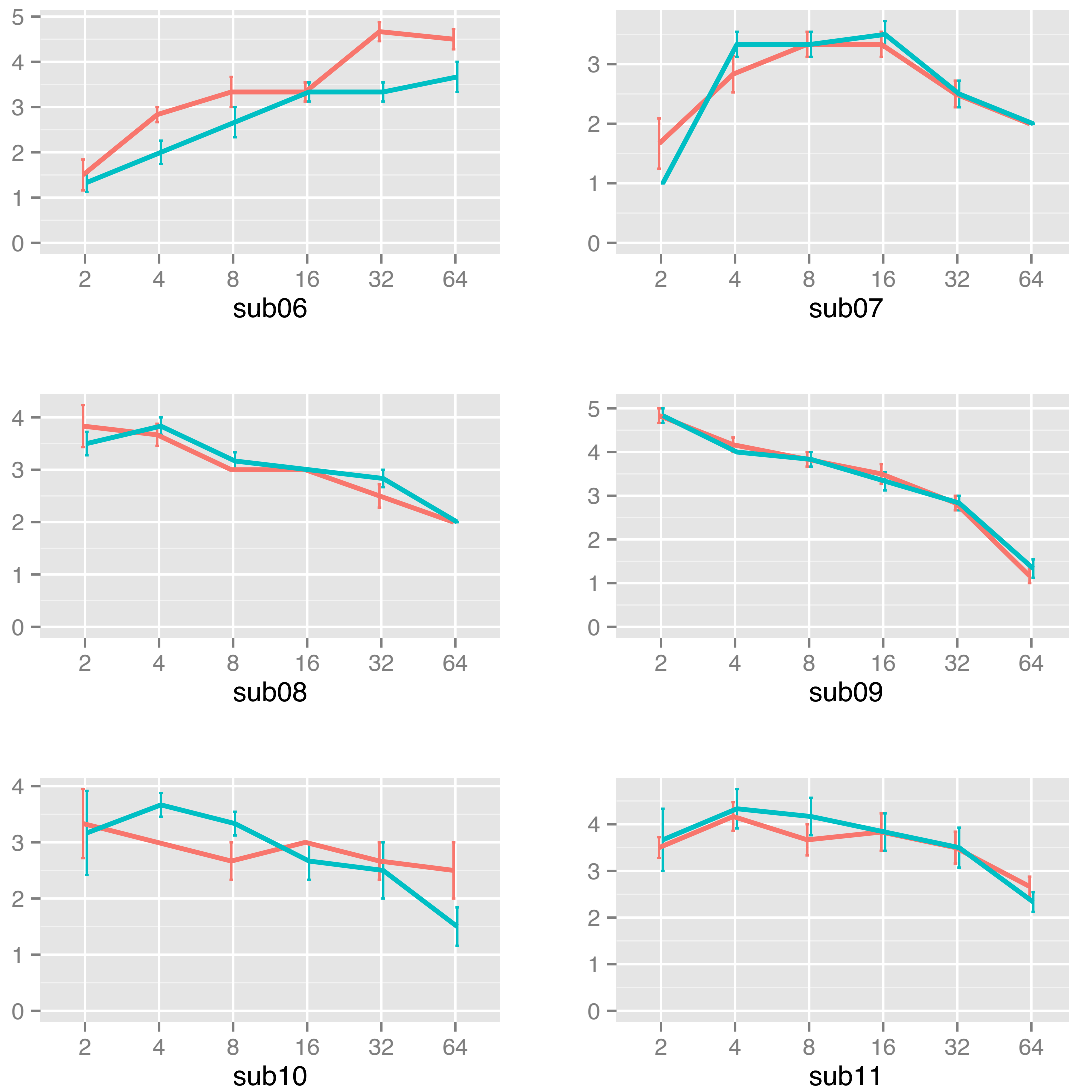


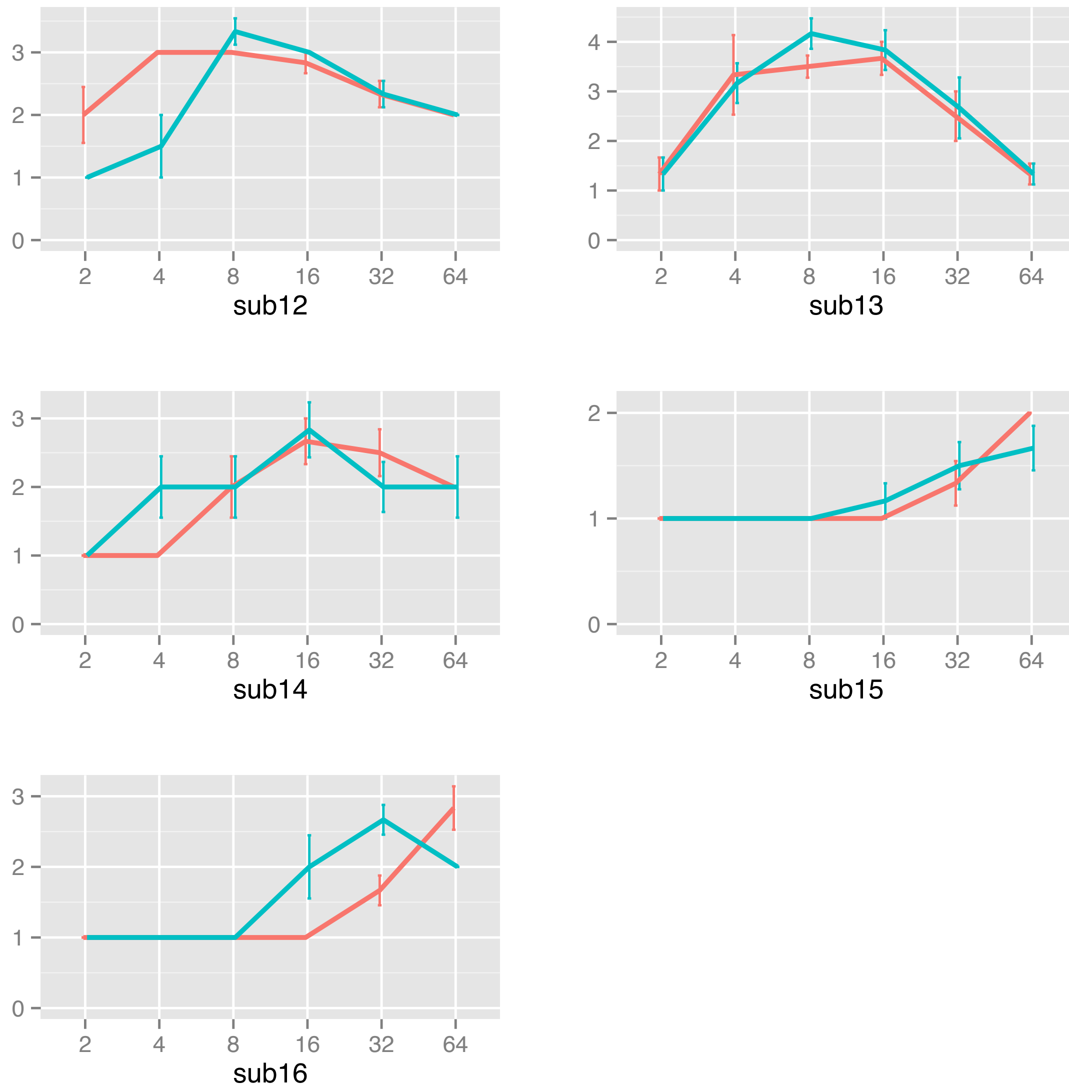

0
10
20
2
4
8
16
32
64
sub06
0
10
20
2
4
8
16
32
64
sub07
0
10
20
2
4
8
16
32
64
sub08
0
10
20
30
2
4
8
16
32
64
sub09
0
10
20
2
4
8
16
32
64
sub10
0
10
20
2
4
8
16
32
64
sub11


30
20
10
0
2
4
8
16
32
64
sub12
sub13
sub14
sub15
sub16

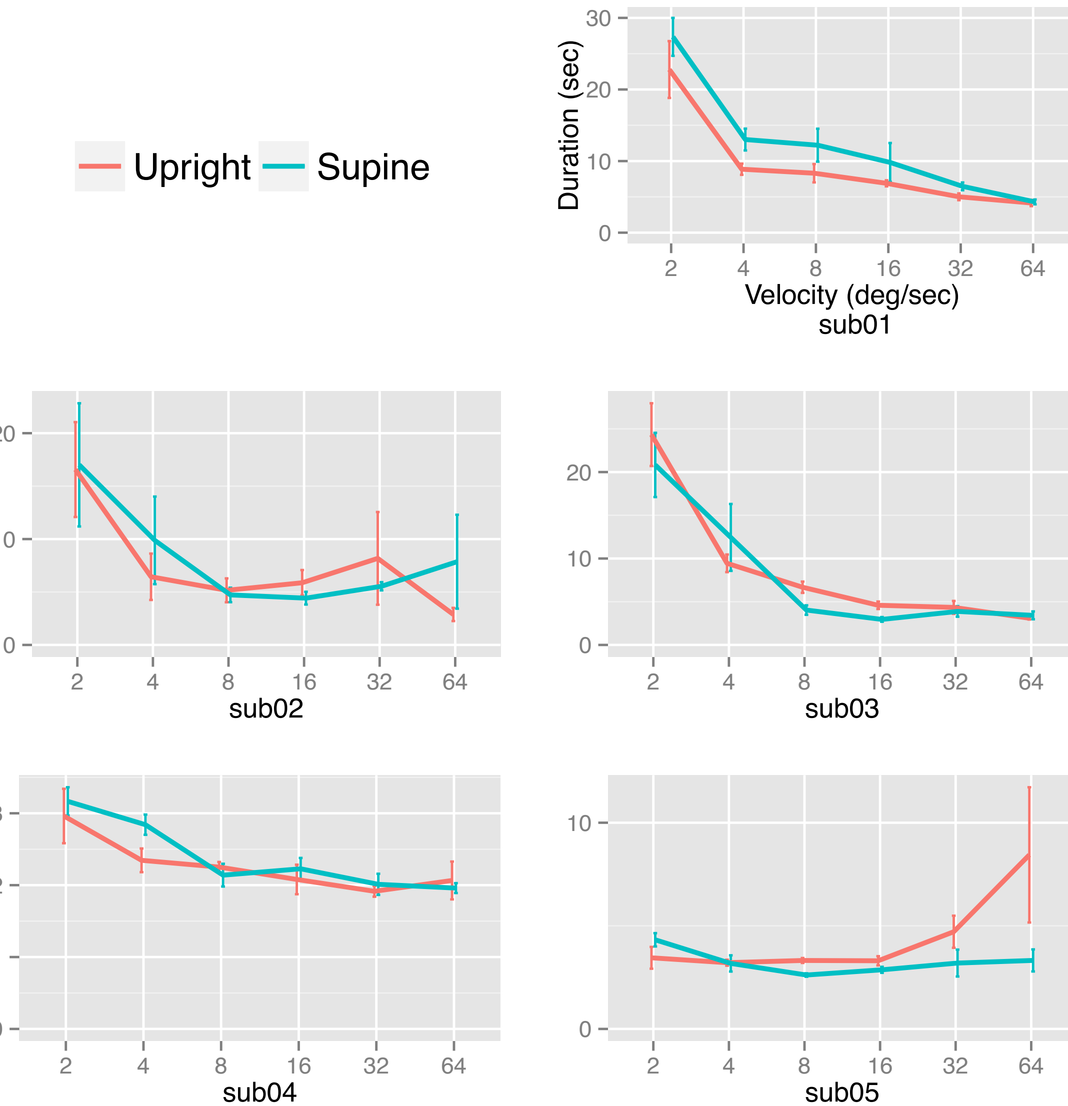
APPENDIX 4.12 CV INTENSITY COMPARISON BETWEEN TWO BODY POSITIONS FOR ALL 16 SUBJECTS

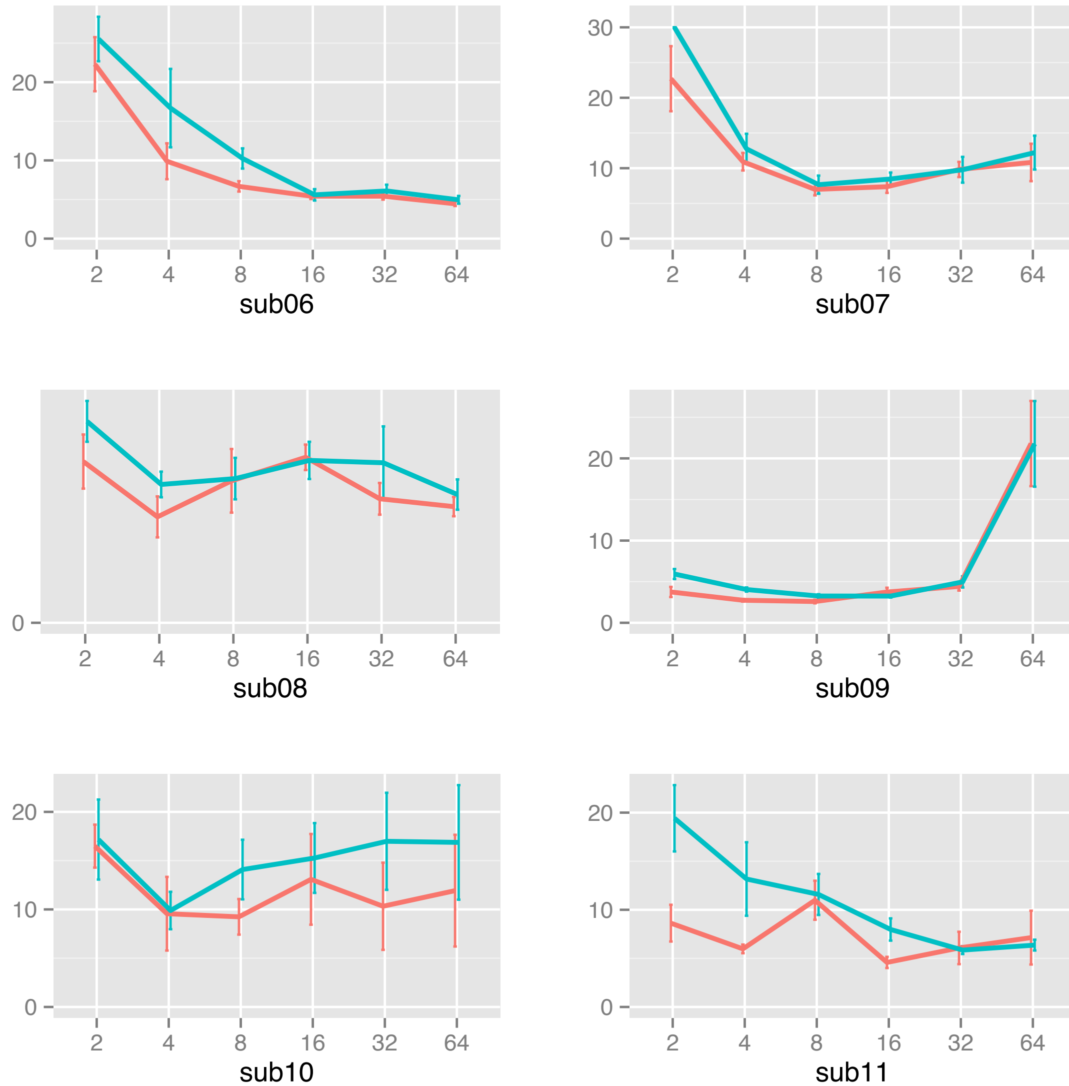



0
1
2
3
4
5
2
4
8
16
32
64
sub06
sub07
sub08
sub09
sub10
sub11


sub12
sub13
sub14
sub15
sub16

APPENDIX 4.13 CV ONSET TIME COMPARISON BETWEEN TWO BODY POSITIONS FOR ALL 16 SUBJECTS




20
10
0
2 4 8 16 32 64
sub06
30
20
10
0
2 4 8 16 32 64
sub07
0
2 4 8 16 32 64
sub08
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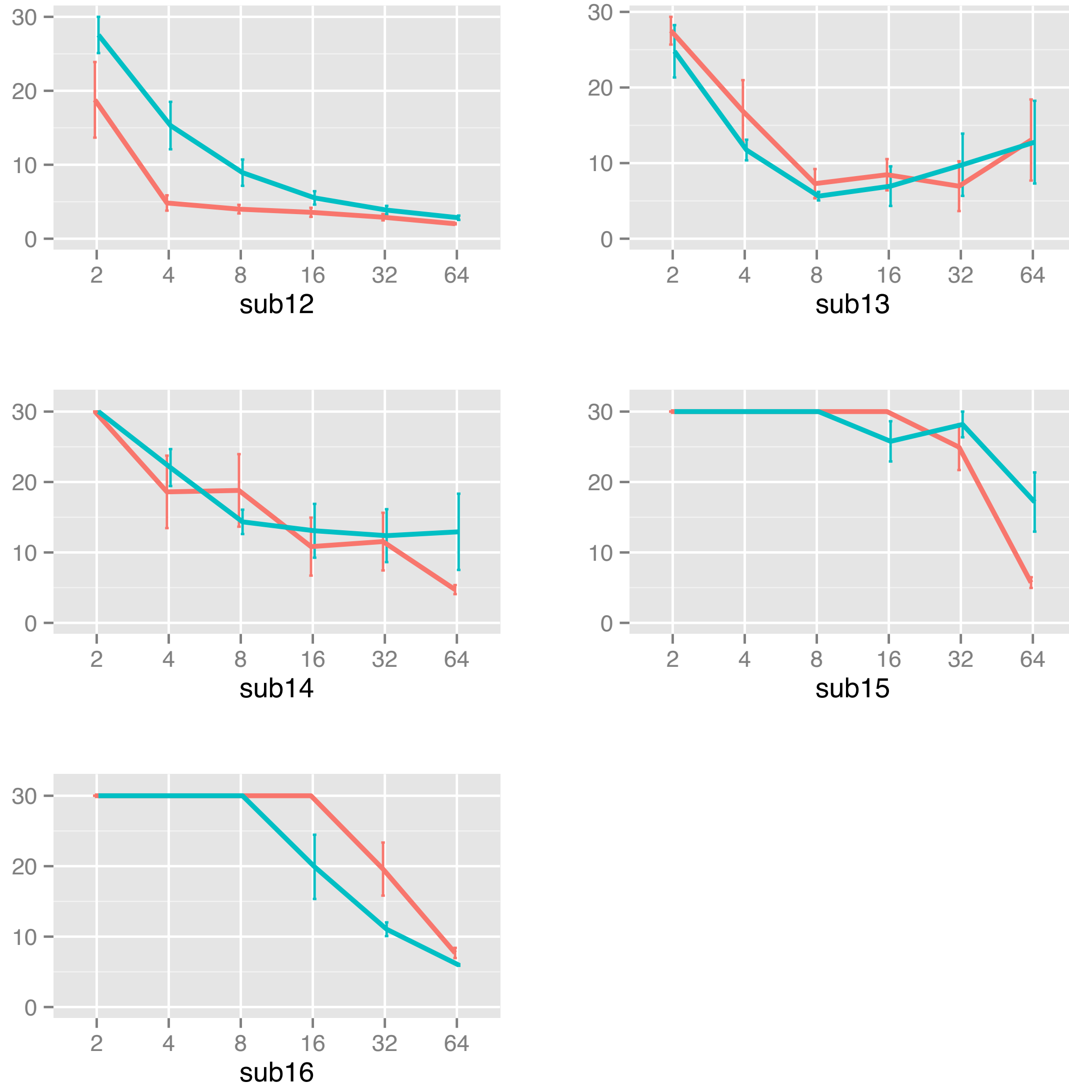
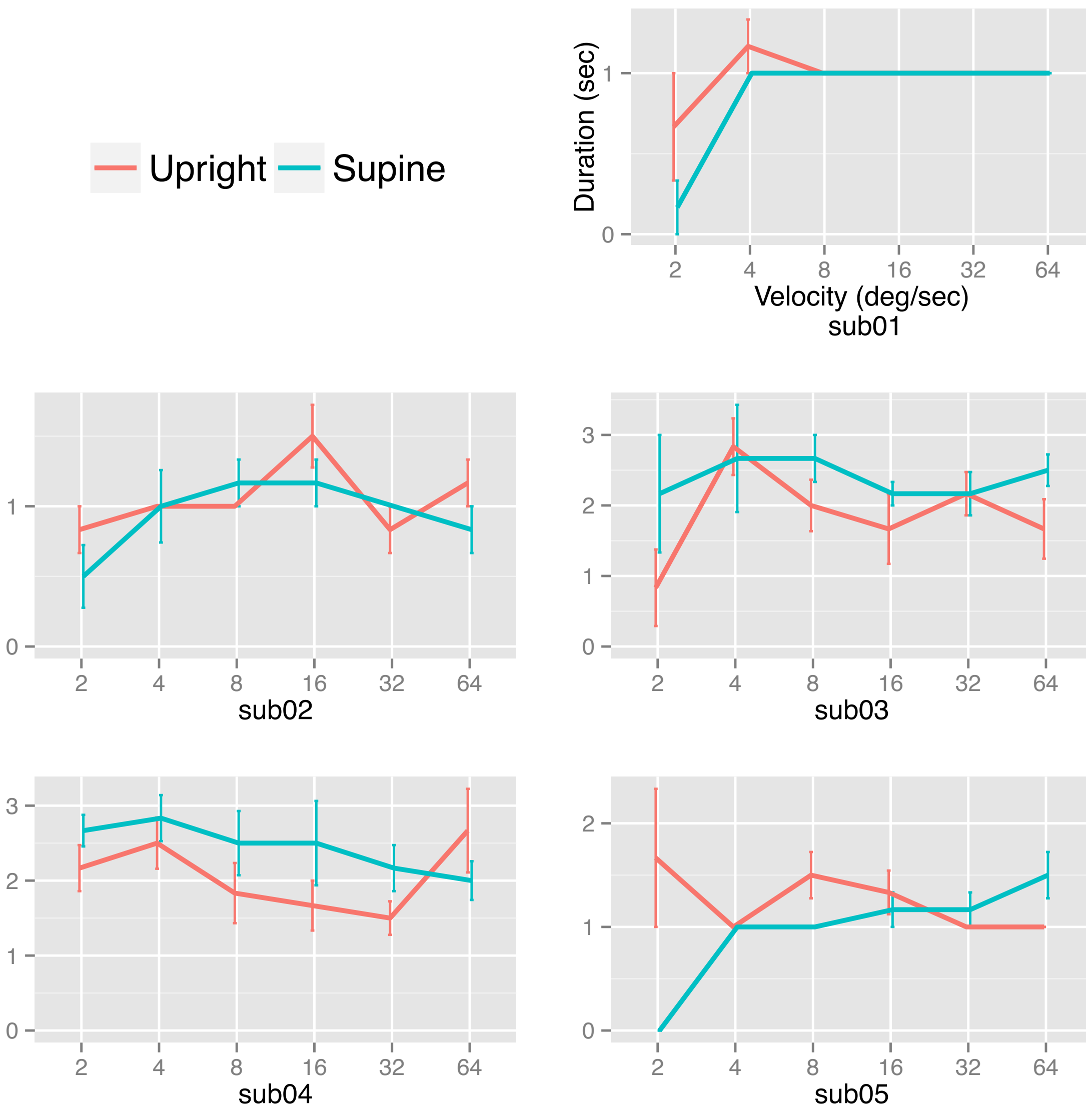
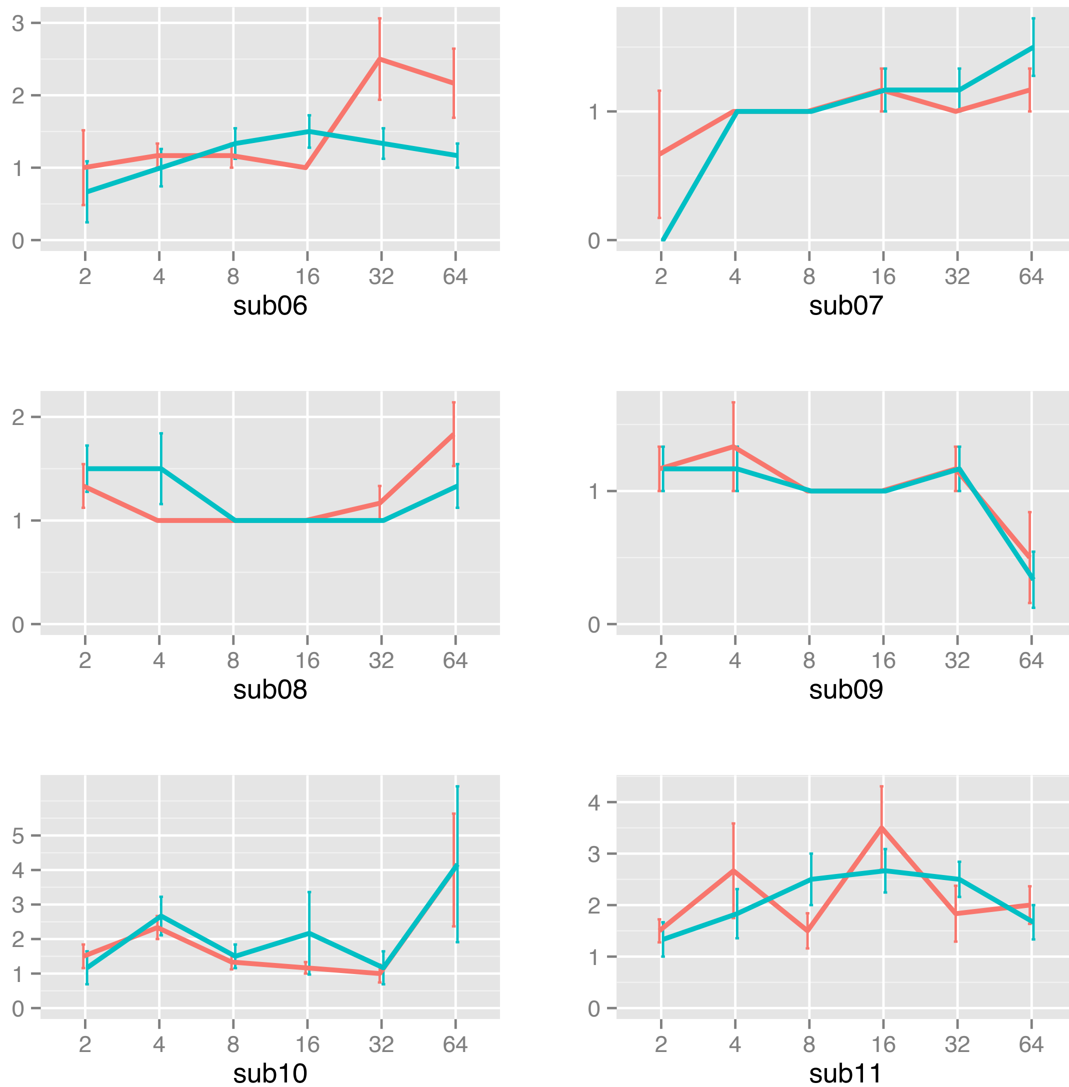
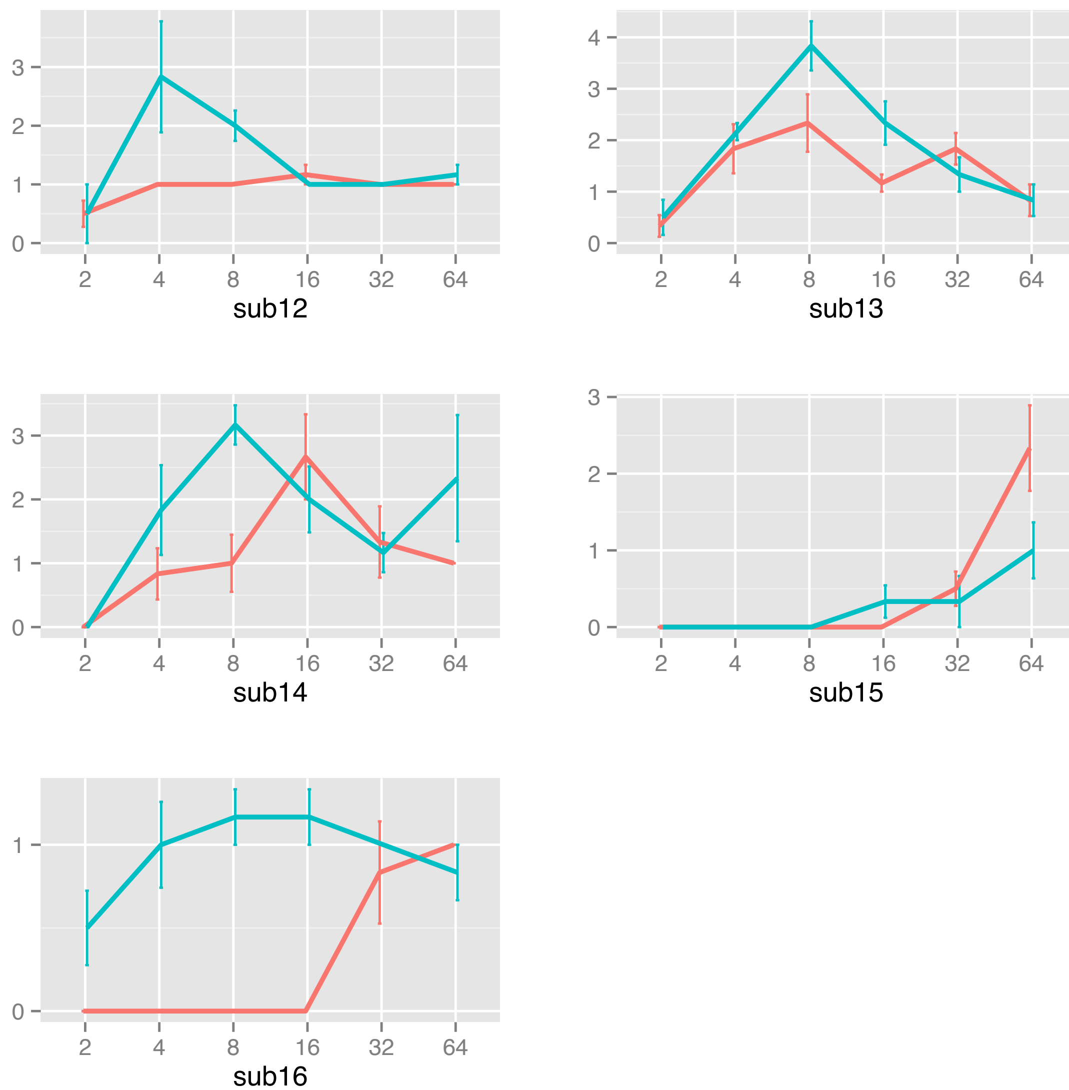
0
2 4 8 16 32 64
sub11


30
20
10
0
2 4 8 16 32 64
sub12
sub13
sub14
sub15
sub16

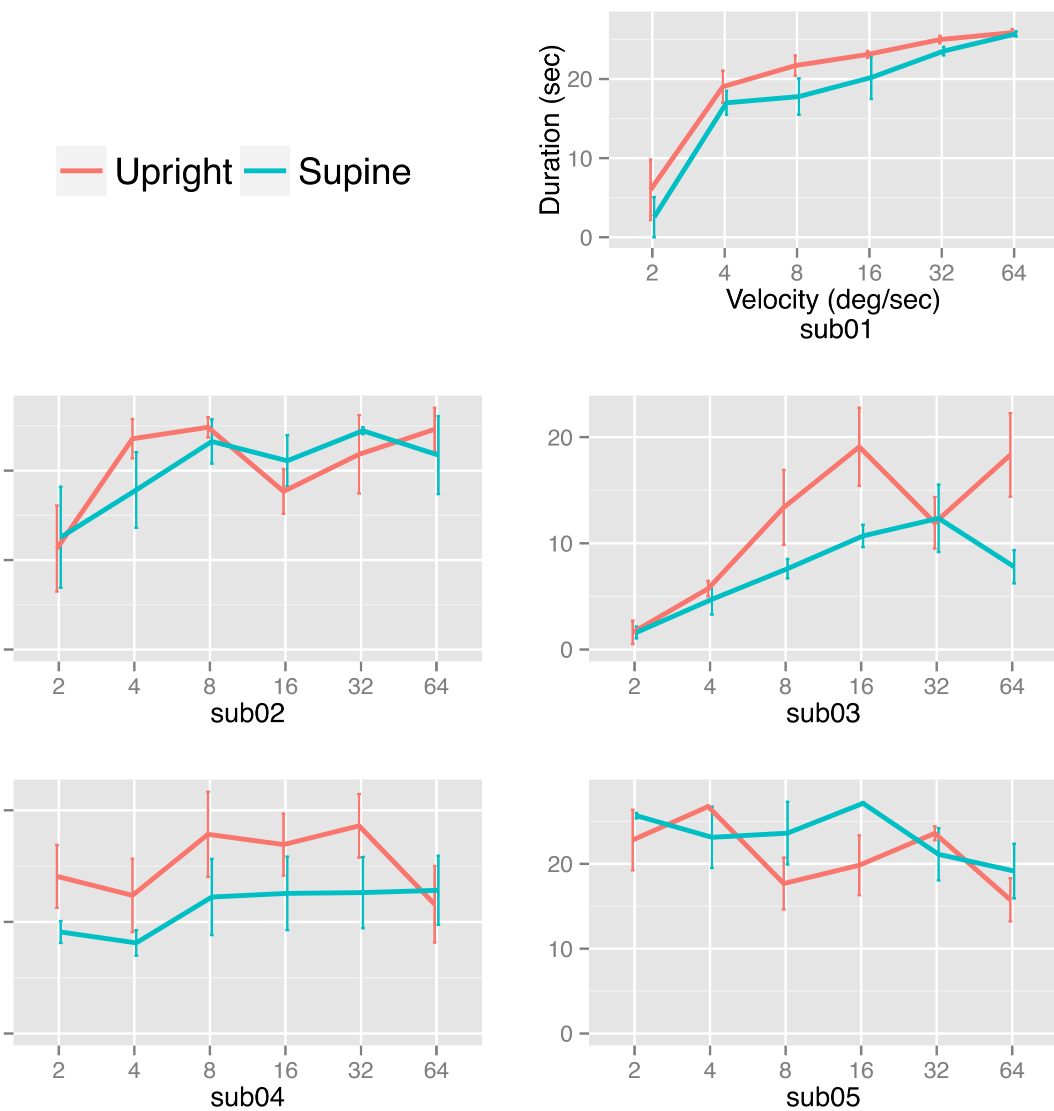
APPENDIX 4.14 FREQUENCY OF CV OCCURRENCE COMPARISON BETWEEN TWO BODY POSITIONS FOR ALL 16 SUBJECTS

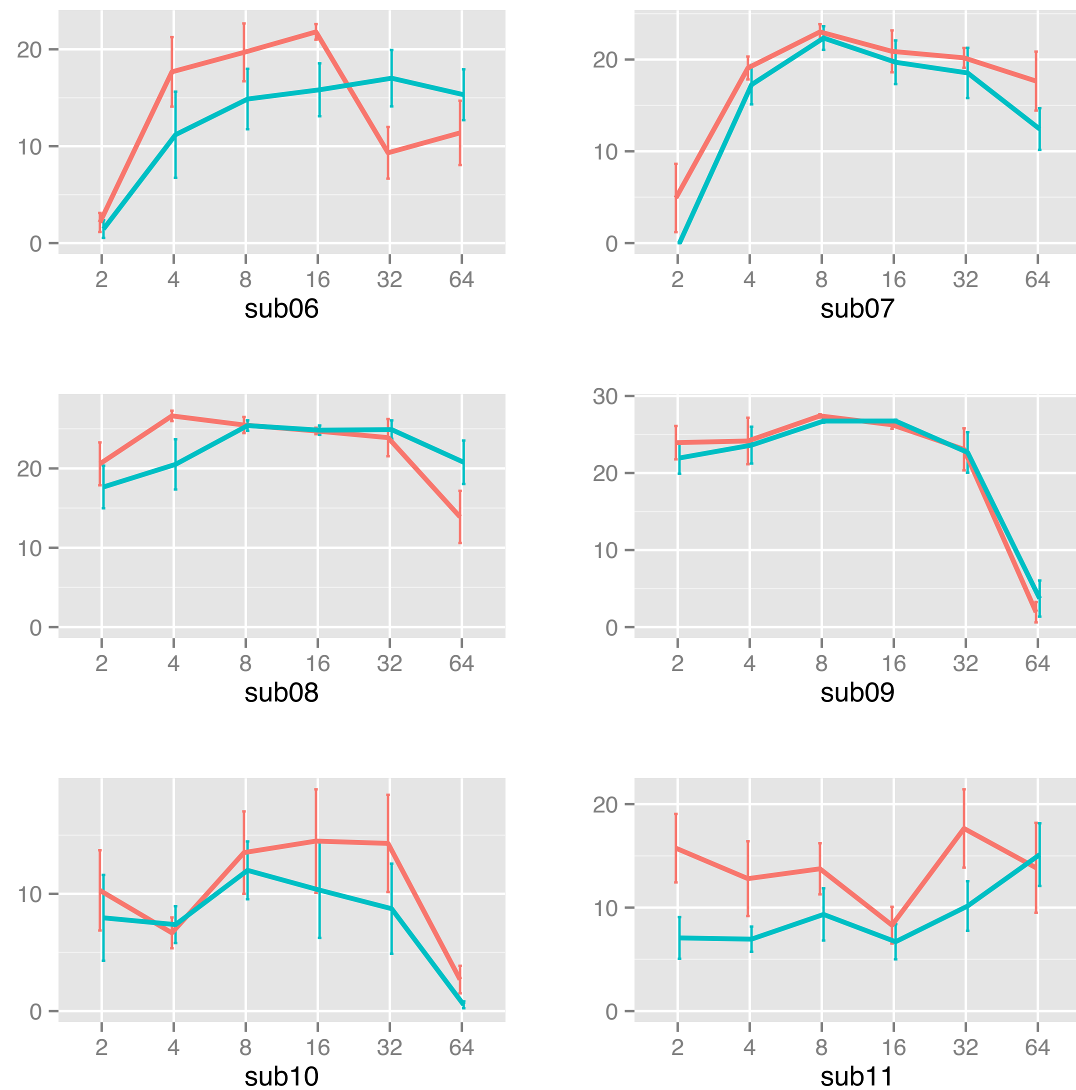


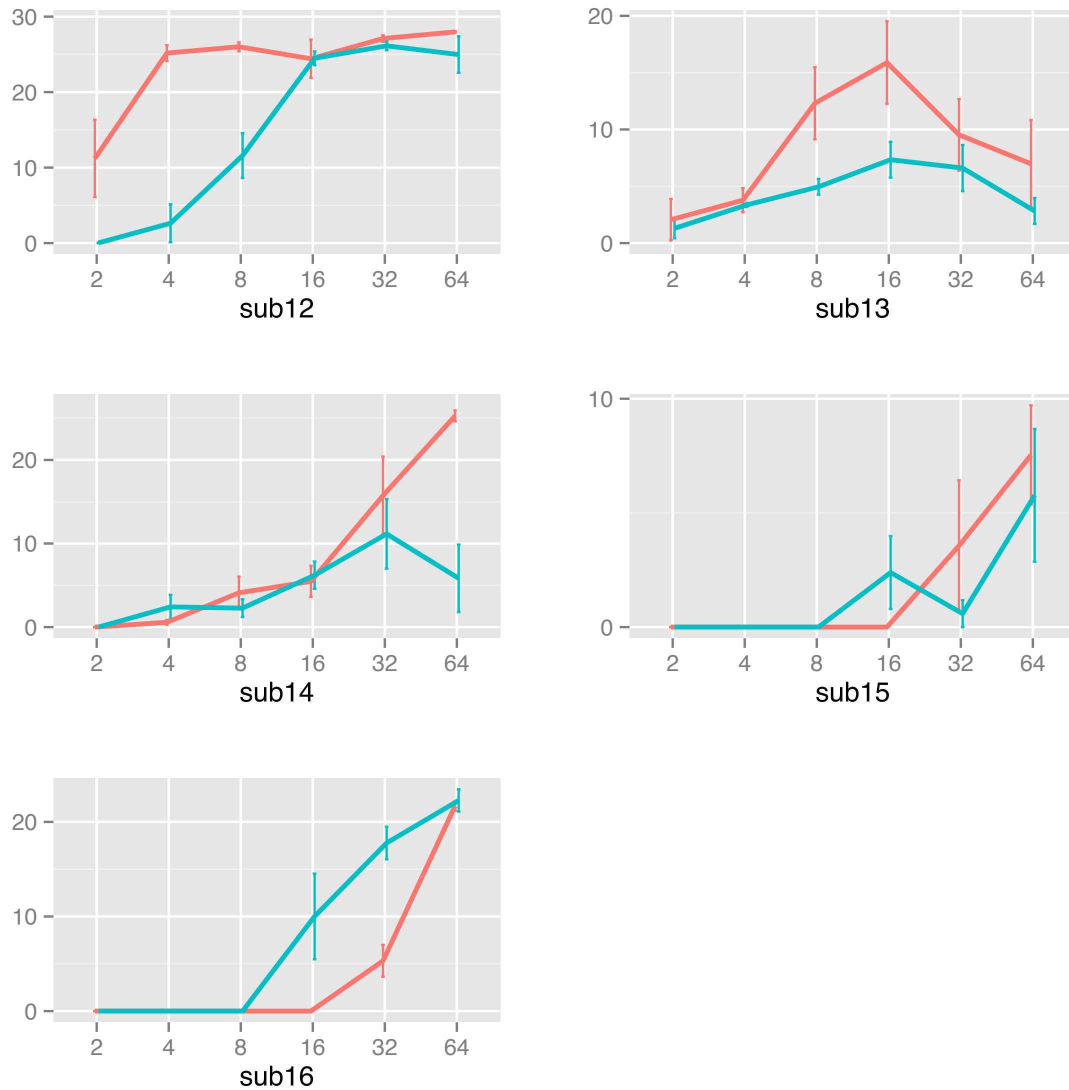

sub06
sub07
sub08
sub09
sub10
sub11
2
4
8
16
32
64


0
1
2
3
2 4 8 16 32 64
sub12
0
1
2
3
4
2 4 8 16 32 64
sub13
0
1
2
3
2 4 8 16 32 64
sub14
0
1
2
3
2 4 8 16 32 64
sub15
0
1
2 4 8 16 32 64
sub16

APPENDIX 4.15 CV AVERAGE DURATION COMPARISON BETWEEN TWO BODY POSITIONS FOR ALL 16 SUBJECTS




20
10
0
2
4
8
16
32
64
sub06
20
10
0
2
4
8
16
32
64
sub07
20
10
0
2
4
8
16
32
64
sub08
30
20
10
0
2
4
8
16
32
64
sub09
10
0
2
4
8
16
32
64
sub10
20
10
0
2
4
8
16
32
64
sub11


30
20
10
0
2 4 8 16 32 64
sub12
20
10
0
2 4 8 16 32 64
sub13
20
10
0
2 4 8 16 32 64
sub14
10
0
2 4 8 16 32 64
sub15
20
10
0
2 4 8 16 32 64
sub16

APPENDIX I: INSTRUCTIONS FOR EXPERIMENT 1

Topic: Effects of angular velocity and color on circular vection under viewing different conditions in virtual reality.

Experimenter: DU Bo, HKUST; email: bdu@ust.hk

Supervisor: Dr. Richard So, HKUST

Dear subjects, welcome to the Acoustic Lab and thank you for your participation in this vection study! Please turn off your mobile phones during the experiments.

Introductions for the experiment

This experiment will take about 15 minutes for one trial (we will conduct the experiment one trial per day at most) and there are 6 trials in total. Each experiment consists of a training session and main experiment. You will be rewarded $50 HKD per hour after the experiments.

Experimental procedures and tasks

A) You need to look at the LCD screen when sitting on the chair and putting your head on the medical chin-rest. The stimuli consist of dots with a grey darker dot in the center. Dots are circulating around the grey dark center. During the experiment, make sure you stare at the grey dot in the center through the entire experiment and do not follow the moving dots.

B) During the period of rotating dots, as soon as you experience any sensation of self-motion, press the button 1 or 2 to give an assessment of vection intensity.

Perception of self-motion (vection)	Subjects Press:
You feel that you are stationary and only the dots are moving	Nothing
You feel that you are moving at the same time the dots are moving	a
You feel that you are moving and the dots stay stationary	b

If you experience the continuous vection, keep pressing the button. If you do not experience the self-motion, release the button. Please make sure that you do this reliably during the whole experiment.

C) After each rotation you will see the screen that only a darker gray dot in the center, then you need to verbally report the intensity of perceived self-motion to the experimenter using a, b, c, d, e,

Perception of self-motion (vection)	Subjects report:
You feel like you are stationary and it is the dots which appear to be	1
You feel like you are moving a bit, but the dots are moving more.	2
You feel like you are moving at the same speed as the dots.	3
You feel like you are moving a lot and the dots are moving a bit.	4
You feel like you are moving and the dots appear stationary.	5

Notice

1). Please make sure that you have a consistent judgement when you give the subjective rating of vection during the whole experiments.

2). If you realize that you forget to press the keyboard to indicate the vection or report incorrect vection intensity, please tell the experimenter.

APPENDIX II : INSTRUCTIONS FOR EXPERIMENT 2

Topic: Effects of angular velocity and body position on circular vection under viewing different conditions in virtual reality.

Experimenter: DU Bo, HKUST; email: bdu@ust.hk

Supervisor: Dr. Richard So, HKUST

Dear subjects, welcome to the Acoustic Lab and thank you for your participation in this vection study! Please turn off your mobile phones during the experiments.

Introductions for the experiment

This experiment will take about 5 minutes for one trial and there are 6 trials in total. And it will be conducted in one day. There will be a training session before the formal experiment. You will be rewarded $50 per hour after finishing the experiment.

Experimental procedures and tasks

A) You need to lie down on the sports mat under the instruction of experimenter and look at the center of screen. The stimuli consist of dots with a grey darker dot in the center. Dots are circulating around the grey dark center. During the experiment, make sure you stare at the grey dot in the center through the whole experiment and do not follow the moving dots.

B) During the period of rotating dots, as soon as you experience any sensation of self-motion, press the button 1 or 2 to give an assessment of vection intensity.

Perception of self-motion (vection)	Subjects Press:
You feel that you are stationary and only the dots are moving	Nothing
You feel that you are moving at the same time the dots are moving	a
You feel that you are moving and the dots stay stationary	b

If you experience the continuous vection, keep pressing the button. If you do not experience the self-motion, release the button. Please make sure that you do this reliably during the whole experiment.

C) After each rotation you will see the screen that only a darker gray dot in the center, then you need to verbally report the intensity of perceived self-motion to the experimenter using a, b, c, d, e,

Perception of self-motion (vection)	Subjects report:
You feel like you are stationary and it is the dots which appear to be moving only.	1
You feel like you are moving a bit, but the dots are moving more.	2
You feel like you are moving at the same speed as the dots.	3
You feel like you are moving a lot and the dots are moving a bit.	4
You feel like you are moving and the dots appear stationary.	5

Notice

1). Please make sure that you have a consistent judgement when you give the subjective rating of vection during the whole experiments.

2). If you realize that you forget to press the keyboard to indicate the vection or report incorrect vection intensity, please tell the experimenter.

APPENDIX III: CONSENT FORM FOR HUMAN FACTORS EXPERIMENT PARTICIPATION

Name ______________________________ Age __________________________

Are you feeling ill in any way? Yes/No

Do you suffer from diabetics (糖尿病) or epilepsy (癲癇症)? Yes/No

Are you under medical treatment or suffering disability which affects your daily life? Yes/No

Have you had any intake of alcohol (飲酒) during past 24 hours? Yes / No

Have you had injuries or over-exercises during the past 24 hours that will affect your postural stability? Yes / No

If your answer is "Yes" to question (2) to (6), please give details to the Experimenter.

DECLARATION

I consent to take part in the experiment. My replies to the above questions are correct to the best of my belief, and I understand that they will be treated as confidential by the experimenter.

I understand that I may at any time withdraw from the experiment and that I am under no obligation to give reasons for withdraw declared above.

I undertake to obey the regulations of the laboratory and instructions of the experimenter regarding safety only to my right to withdraw declared above.

The purpose and methods of the experiment have been explained to me and I have had the opportunity to ask questions.

Signature of Subject ___________________ Date _________________________

This experiment conforms to the requirement of the University Research Ethic Committee.

Signature of Experimenter _________________ Date ________________________

Starting time __________________________ Finish time ____________________