BRAIN WAVE SIGNATURES ASSOCIATED WITH VECTION

by

ZHENG, Jiayue

A Thesis Submitted to
The Hong Kong University of Science and Technology
in Partial Fulfillment of the Requirements for
the Degree of Master of Philosophy
in Bioengineering

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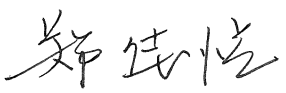

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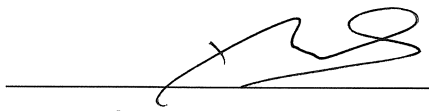

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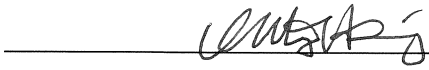

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TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

LIST OF TABLES

Chapter 3

Chapter 4

Chapter 5

Brain Wave Signatures Associated with Vection

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Abstract

Primary visual cortex (V1) in human has been the subject of many studies. However, little is known about its activity associated with visually induced self-motion illusion (vection). Literature suggests a reciprocal inhibition (RI) interaction between visual and vestibular system during vection. However, how activities in V1 will respond during the RI process is unclear. The current thesis tries to answer this question with the noninvasive electroencephalograph (EEG) measurement on human subjects. In particular, high-resolution event related potential (ERP) data were recorded from V1 to determine how V1's activities will change when an optical flow stimulation in the periphery induces different feelings: vection or no vection.

Two experiments were conducted. In Experiment 1, V1 related ERP responses under two circular vection (CV) and one linear vection (LV) conditions (with similar vection intensity) were studied while Experiment 2 studied V1 related ERP responses in two LV conditions (with different vection intensity). Result showed a positive correlation between vection intensity/duration and the ERP component amplitude difference (component in no vection condition minus component in vection condition) for LV induced by stimuli moving from left to right at 45°/s. The stronger the vection, the bigger the amplitude difference between no-vection and vection. The 'feedback regulation' from extrastriate cortex during vection may explain our finding in a linear way while the 'attention control' may also play a part non-linearly. Detailed discussion was reported in the thesis.

CHAPTER 1 INTRODUCTION

1.1 An Overview of Human Senses Contributing to Vection condition

When we move through a given environment, information from visual, vestibular, proprioceptive and acoustic system works together to tell us our position, orientation, displacement as well as our acceleration. By integrating these information from different sensory systems, we can construct a coherent and compelling perception of self-motion (Kovács et al. 2008). This chapter will give a brief introduction on how each system works to generate vection condition.

1.1.1 The Visual System

Vision provides a major source of information for the vection condition.

The visual motion information we experienced – the optic flow – is a result of physical motion like walking, running, or driving. It contains information about all three dimensions (3-D) and the observers' self-motion in addition to the reference (Anon 1995).

The visual sensorial organ is the eye. Light from surrounding goes into the eye and falls on the retina. Then the electrical signal goes from retina photoreceptors to retinal neurons, passes lateral geniculate nucleus and finally ends at the brain cortex.

The primary visual cortex ([V1] Brodmann's area 17) is located on the medial side of the occipital lobe and receives projections from the lateral geniculate nucleus (Different areas in the visual cortex are shown in Figure 1.1.). The secondary visual cortex ([V2] Brodmann's area 18) and tertiary visual cortex ([V3 and V5] Brodmann's area 19) are located adjacent to the primary visual cortex. Visual area V4 is located in the inferior occipito-temporal area. Different brain areas have different role. V3 is associated with form perception, V4 is associated with color perception, and V5 is associated with motion perception.

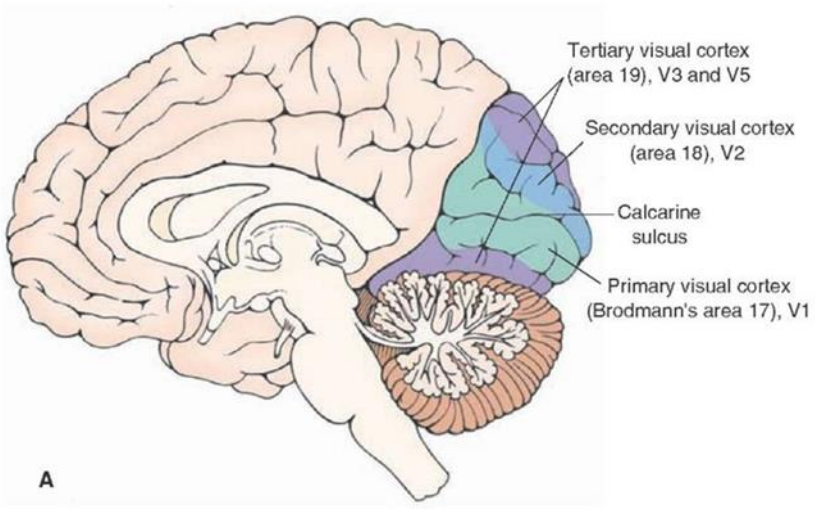


Figure1- 1 The Visual Cortex (adopt from (Anon n.d.))

1.1.2 The Vestibular System

Vestibular system is known as the balance organs of the inner ear. The vestibular system plays an important role in everyday life because it contributes to perception and consciousness at different level.

It contains three roughly orthogonal semicircular canals sensitive to rotational acceleration and two otolith organs (the utricle otolith and the saccule otolith) sensitive to linear accelerations (Warren 1995a; J. Howard & Hudspeth 1988). Vestibular system is continuously active even when we are at rest (the otolith organs sense the pull of gravity) and it is strikingly sensitive to our head's motion. The signals from the semicircular canals and the otolith organs are complementary and their combination is necessary to figure our experienced physical motions in everyday life.

Different from other senses, central vestibular processing is convergent and multimodal. Interactions between vestibular and visual or proprioceptive occur through the central vestibular way and is important for gaze and postural control(Angelaki & Cullen 2008).

1.1.3 The Proprioceptive System

Apart from visual and vestibular system, proprioception can also provide powerful information about self-motion (Harris et al. 2002; Warren 1995b).

As Bastian suggested, proprioceptive system encompasses a complex of sensations including sense of joint movement, joint position, muscle force or tension and effort (Foster 2010).The sense of joint movement (movement sense) is the process by which we perceive movements of parts of the body relative to one another. It includes detection of movements and perception of their direction, velocity, distance, and timing. The sense of joint position (position sense) is the process we perceiving the current positions of parts of our body relative to one another. The sense of force or tension is the process by which we perceive forces generated by the muscles, whereas the sense of effort gives a perception of the strength of muscle contraction relative to the total strength of the muscle. All of these sensations are used separately or together to give the knowledge of body's own actions and its interactions with the environment (Dichgans & Brandt 1978).

1.1.4 The Auditory System

Three main cues for auditory motion discrimination are Doppler Effect, interaural time and level (these are binaural cues). The Doppler Effect results in perceived frequency shifts in the case of motion between a sound source and a listener. Binaural cues provide information about the interaural time and level differences at listener's two ears (Lutfi & Wang 1999).

1.2 Vection

Within those sensory systems (visual, vestibular, proprioceptive and auditory system), visual motion reflects only relative motion information between object and observer, additional cues (vestibular and proprioceptive sensory feedback and input from body, head, and eye movements) are needed to help observer disambiguate object-motion from self-motion (Kleinschmidt et al. 2002; Wertheim 1994; Wexler et al. 2001). When visual motion is the only informative cue for motion perception, a perceptual ambiguity may arise and induce the intermittent illusion of self-motion (vection) (Dichgans & Brandt 1978).

Most people have various real world experience of vection. The most common phenomenon is this one: When one sits in a train waiting to depart from the train station and watches a train on the neighboring track pulling out of the station, one can have the strong impression of self-

moving, even though it was in fact the train on the adjacent track that just started to move (Riecke et al. 2009).

Vection was first referring as the illusion of self-motion elicited by a moving visual stimulus by Fischer and Kornmuller in 1930. Now the most common definition about vection is raised by Dichigans and Brandt, that is, vection is the visual illusions of self-motion in physically stationary observers (Dichgans & Brandt 1978).

Vection are commonly divided into circular vection associated with rotational motion around an axis centered on the viewer, and translational vection involving straight-line movement (Mohler et al. 2005). vection condition

CHAPTER 2 LITERATURE REVIEW

2.1 Visually Induced Vection Perception

Vection has typically been investigated by seating participants in the center of a rotating optokinetic drum that is painted with simple geometrical patterns like black and white vertical stripes. When stationary observers were exposed to such a moving visual stimulus, they will at first correctly perceive motion of the visual stimulus (object motion perception). After a few seconds, however, this perception typically shifts toward the observer is starting to move and the moving visual stimulus slowing down and finally becoming earth-stationary (Riecke et al. 2009).

Like the former scene, by presenting large field of optical stimulus to physically stationary observers, highly compelling illusions of self-motion can be generated in lab (Palmisano et al. 2015). Now there are few stimuli that were often used, including the rotating drum (Post 1988), rotating random dots (Brandt et al. 1998; Deutschländer et al. 2002; Deutschländer et al. 2004), rotating windmill (Kleinschmidt et al. 2002), expanding and contracting dots in depth (Deutschländer et al. 2004; de Jong et al. 1994) and linear moving dots (Tarita-Nistor et al. 2006).

2.2 Brain Activities Relate to Visually Induced Vection

Functional neuroimaging has become increasingly popular in the study of vection in recent years. Most of these studies have investigated the brain activities generated when self-motion-generation stimuli are present to physically stationary observers. They isolated the related brain areas by comparing vection conditions with specific control conditions.

To date, a number of cortical areas have been revealed relate to the processing of visually induced vection information, including the medial temporal area (MT/V5), the medial superior temporal (MST) area and dorsal region of the medial superior temporal area (MSTd), the dorsomedial area (V6), the cingulate sulcus visual (CSv) area, and the ventral intraparietal (VIP) area. Some vestibular/multisensory related areas have also been implicated in this process, including the intra-parietal sulcus motion (IPSmot) area, the parieto-insular vestibular cortex

(PIVC), the putative area 2v (p2v), as well as the precuneus motion area (PcM) (Palmisano et al. 2015).

In a PET study, Brandt et al. used rotating dots to induce vection and they found that visually induced vection in roll activated a medial parieto-occipital brain area (PO) bilaterally while simultaneously deactivating the posterior insula and adjacent retroinsular regions. This led to the concept of an inhibitory reciprocal visual-vestibular interaction as a form of sensory interaction during vection. This model states that during vection stimulated by large-field visual motion stimulation, not only the visual cortex (a medial parieto-occipital visual area separate from motion-sensitive area MT/MST) will be activated, but also simultaneously cause deactivation of the PIVC. And stimulation of the vestibular system by caloric irrigation not only activate the parietoinsular vestibular cortex (PIVC), but also bilaterally deactivate the occipital visual cortex at the same time (Brandt et al. 1998). According to this model, visual and vestibular systems are supposed to be reciprocal inhibited, when one's activity goes up, the other supposes to go down.

2.3 Activity Change in V1 during Vection

Other authors also found the reciprocal inhibitory pattern between the visual and the vestibular pathway (Beer et al. 2002; Della-Justina et al. 2015; Deutschländer et al. 2002; Kleinschmidt et al. 2002; Deutschländer et al. 2004). Although many researches have reached an agreement that there is an inhibitory reciprocal visual-vestibular interaction during vection, the recorded primary visual cortex responses in those papers are not consistent. Some reported V1 activity increase, some reported V1 activity no change while others reported V1 activity decrease.

Study found V1 activity increase:

Deutschländer found that for both visual motion stimulations induced circular vection (about the line of sight) and forward linear vection (along this axis in the same subjects), there were activations in the visual cortex around the calcarine sulcus (Brodmann area 17 and 18) compare to stationary optical flow pattern (Deutschländer et al. 2004).

Studies found V1 activity no change:

For the study done by Brandt, there is no significant activation level difference in the primary visual cortex (Brodmann area 17) under experiment conditions (the visual simulation of 190 dots rotating at the speed of 40°/s clockwise or anti-clockwise) and baseline condtion (190 dots moving randomly) (Brandt et al. 1998). Deutschländer found that unimodal visual motion stimulation led no activation change in primary visual cortex compare to eye closed condition (Deutschländer et al. 2002). And Beer did a positron emission tomography (PET) study using coherent large visual display simulate continuous observer roll, yaw, and linear movement in depth, for all of these conditions, there was no significant activity difference in the primary visual cortex when compare with incoherent stimulation condition (Beer et al. 2002).

Study found V1 activity decrease:

In 2002, Kleinschmidt et al used rotating windmill to induce vection. They found that some visual relate areas (V1, V3/V3a, V4, MT/V5) were deactivated when visual simulation induces vection compare to no vection situation (Kleinschmidt et al. 2002).

There must be some experimental design and operational reason relate to the different response in the primary visual cortex. We know that the activity of V1 is largely affected by motion direction and speed, considering most of former studies used stimuli of different moving speed or direction for experiment and baseline condition, it is reasonable to find the inconsistent result in V1 activity during vection. However, think of the importance of primary visual cortex in visual processing, this problem need to be further studied.

2.4 Role of Early Visual Area in Visual Motion Perception

V1 receives input from Lateral Geniculate Nucleus (LGN) and is the first cortex area to process visual information (Figure 2-1). V1 provides direct input to the V2 and from there information is transferred either to the parietal cortex (the dorsal stream) or to the temporal cortex (the ventral stream) (Lamme et al. 2000).

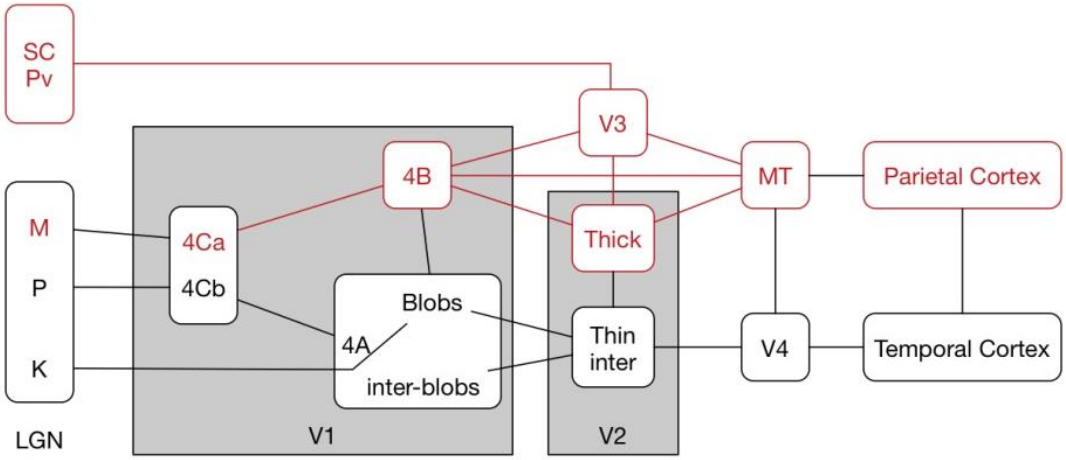


Figure2- 1 Anatomical Connections within the Visual Related Areas (Adapt from Lamme et al., 2000)

The cells in V1 are found to be direction and speed selective. These cells respond best when a stimulus moves in a particular direction at particular speed within the cell's receptive field. The response decreases progressively as the direction or speed of motion deviates more from the preferred ones(Maunsell and Van Essen 1983).

Visual awareness interactive model proposes that V1 participates in visual awareness by forming dynamic recurrent circuits with extrastriate areas (Tong 2003). In such case effective processing of visual information is not purely hierarchically organized but also relies on feedback processing (That is feedback from extrastriate cortex to striate cortex) (Lamme & Roelfsema 2000a)

2.5 Past Study on Feedback Regulation on Early Visual Area

Many studies stated that there is an interactive model of visual processing. Not only a hierarchical processing way exists, but also a reverse way. This model emphasizes the importance of feedback projections from higher to lower order areas (Tong 2003). There are evidences from electrophysiological studies, TMS studies and EEG studies supporting this interactive model listed in following part.

2.5.1 Electrophysiological Evidence

Recordings from macaques V1 during the deactivation of MT/V5 and several psychophysical perceptual studies suggest that feedback projections from extrastriate areas to V1 are necessary for visual awareness (Antal et al. 2003).Hubel et al. found activity increases in MT and concomitant decreases in V1 whenever subjects switching from perceiving incoherent motion to a coherent motion-defined form (Hubel & Wiesel 1962).

Hupe et al. used electrophysiological method to measure brain neurons activity in macaque. They compared the response of V1 cells to moving and flashed visual stimuli when feedback from MT was either present or inactivated by focal cooling. It shows a significant decrease in V1 cell responses with MT/V5 activity (Hupé et al. 2001).

Bullier, Hupe, James and Girard studied the feedback in the macaque brain by moving stimuli in different luminance and found that the inactivation or cooling of a higher order area led to a decreased activity in the lower brain field (Bullier et al. 2001).

2.5.2 TMS Evidence

Silvanto et al. used transcranial magnetic stimulation (TMS) to manipulate human's V1 activity and inferred that back-projections from extrastriate cortex influence activity in V1 and it is V1 that determines whether visual information reaches awareness (Silvanto et al. 2005).

Cowey and Walsha applied TMS to V5 of a much-studied hemianopic subject who lacks of functionally intact V1 in one hemisphere. They found that sensations of moving lights were elicited by stimulation of V5 in his normal hemisphere but not for his damaged side (Cowey & Walsh 2000). In a subsequent study, Pascual-Leone and Walsh (Pascual-Leone & Walsh 2001) used normal subjects to do similar experiment. When they exerted TMS over V5 in normally sighted subjects, it can induce similar experiences of moving lights. But if V1 was inactivated by a second TMS coil, the perception was extinguished. This extinction occurred only at delay selected to block recurrent activation of V1 (Pollen 2003).

More recently, a transcranial magnetic stimulation (TMS) applied to visual cortex demonstrated that vestibular activation could also modulate human visual cortex excitability. They used TMS-

induced phosphenes to probe cortical excitability and found decreased V5/MT excitability versus increased V1 excitability during vestibular activation (Seemungal et al. 2013).

2.5.3 EEG Evidence

Francesco Di Russo et. al (2008) compare visual evoked potential of normal people and right brain damaged people and found that the N1p (140–180 ms) and P2 (180–220) components were delayed and/or reduced in amplitude for stimuli located on the neglected side of the damaged people.

In another ERP study done by Thilo et al., The N70 VEP component showed a significant amplitude reduction when subjects experienced self-motion compared to when the stimulus was perceived as object-motion (Thilo, Kleinschmidt & Gresty 2003b). Therefore, they made the hypothesis that it might be feedback from MT/V5 that influence occipital lobe activity at about 70ms after visual simulation.

2.6 Research Gap and Motivations

Considering the existing studies about vection and early visual area, there are two main gaps to be filled in this study.

1. For former visual induced vection studies, similar or different stimuli were used and inconsistent V1 activity were reported although all of those studies found reciprocal inhibitory visual vestibular interaction. Considering the importance of V1 in visual perception, we thought there is a necessity to focus on V1 and find out how V1 respond during vection.

2. Assuming vection perception will significantly affect V1 activity. There is no study find out how brain will react to vection of different intensity. We will examine how **brainwave data changes** to regulate its activity in response to the **vection of different intensity**.

2.7 Thesis Outline

Two experiments were reported in this thesis. The first experiment was designed to solve the problem of how our brainwave is affected by perception change. The second experiment was designed base on experiment 1. On one hand it aimed at finding whether for individual brain, brainwave data will change as perceived vection intensity change, on the other hand, it also aimed at double-checking the result of experiment 1 because no related result reported before.

The first chapter presented an introduction on human senses and how each sensory system works to detect movement. In addition, a brief introduction about vection was presented.

The second chapter presented existing vection perception theory and gave a review of feedback regulation within the brain not only for the whole brain specifically for V1. Also, V1 activity during vection and motion perception were summarized in this chapter. The reported inconsistency in V1 activity was also summarized in this chapter.

The third chapter presented the details of experiments includes stimuli construction method, electroencephalogram (EEG) apparatus, experimental design and measurement methods.

The forth chapter introduceed the detail of experiment 1, including hypothesis, experimental methods, result and discussion. This experiment mainly studied the inconsistency of V1 activity during vection under different conditions (both circular vection and linear vection condition) and found how our brainwave will be affected by different perceptions.

The fifth chapter introduced the detail of experiment 2, containing experimental design, result and discussion. This experiment followed experiment 1 and mainly aimed at finding how brainwave was affected if we manipulate subjects' perceived vection intensity.

The final chapter, chapter six summarized the thesis and told about the contributions and limitation of the work. Moreover, future works for further study were talked about here.

CHAPTER 3: EXPERIMENT INTRODUCTION

This chapter aims at giving a whole picture of the two experiments included in this thesis. Experimental apparatus, related software and experimental design of the two experiments were elaborated in this chapter.

3.1 Apparatus and stimuli generation

3.1.1 Apparatus

We used DELL OPTIPLEX 9020 desktop with 64-bit windows 7 Enterprise Operating system to generate the visual stimuli and operate experiment relate systems (the NuAmps amplifier system ,Curry 7 acquisition software and Matlab).

The amplifier we used for the two experiments was NuAmp amplifier produced by Compumedical NeuroScan. It is a 40-channel digital EEG amplifier capable of 22 bit sampling at 1000Hz, measuring signals from DC to 260Hz. It interfaces with computer through USB and fully compatible with the SCAN and Curry software and includes a 12-bit trigger input port for synchronizing. Here Figure 3-1 shows the outlook of the amplifier (the left picture is photo of our lab's amplifier, the right picture is the demo picture on Compumedic's website (Compumedics n.d.)).

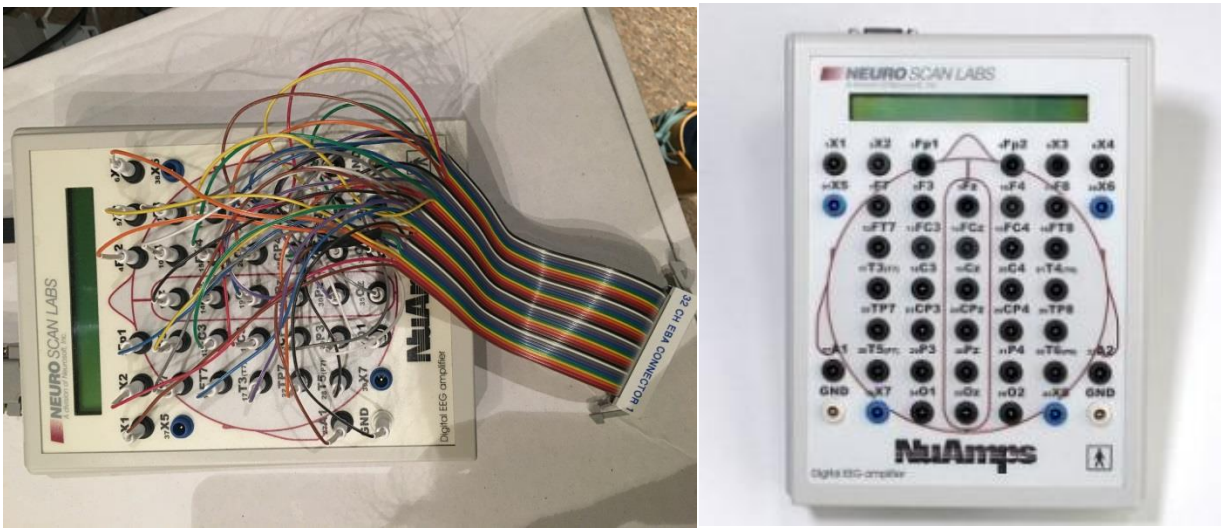


Figure3- 1NuAmp amplifier

The specification of the amplifier shows in Appendix A.

We used standard 32-channel Quik-Cap (Compumedical NeuroScan) with small, medium and large three sizes (For every subjects, choose one according to their head size) measuring the brainwave. Here Figure 3-2 shows the picture of the cap. The conductive gel we used is NeuroMedical Supplied Quik-Gel Conductive Gel.

Figure3- 2 32-channel Quik-Cap (Anon n.d.)

For both of the two experiments, the experiments' stimuli were coded in Matlab using the Psychophysics Toolbox extensions (Brainard 1997; Pelli 1997). The version we used was 3.0.12 for 64-bit windows system.

The visual stimuli were displayed using a 46-inch LCD TV (Sony® Model No. KDL-46EX720). The TV screen resolution is 1920×1080 pixels with refresh rate of 60 frames per second. The TV was placed on a table with the height of 60cm. 48cm in the front of the screen there is a height adjustable chinrest for subjects to lay their chin. The chinrest height adjusted for subjects so that their sitting lines of sight towards the centre of the LCD TV were in line with the earth horizontal axis. Figure 3-3 shows the experimental design.

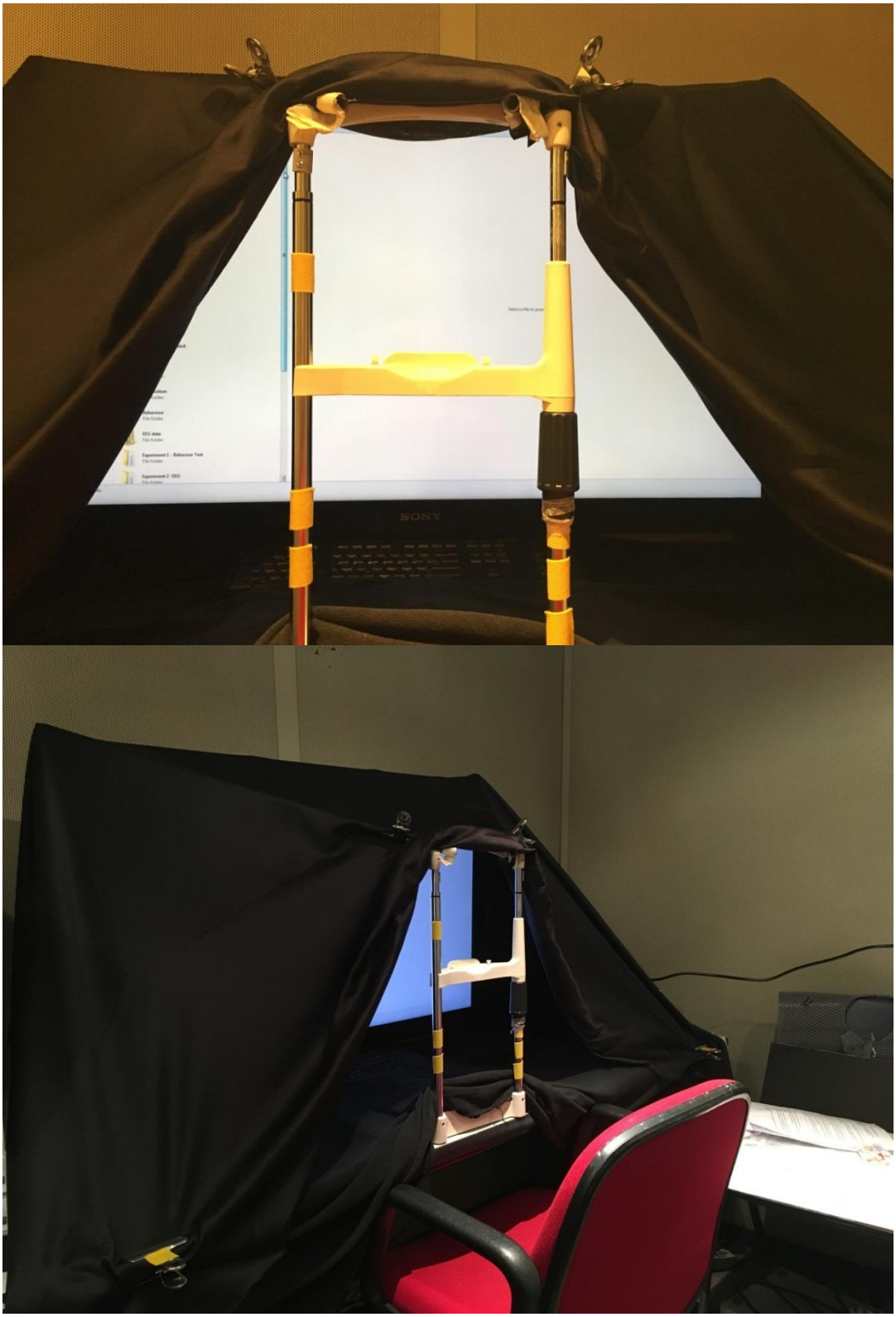


Figure3- 3 Experimental Design (seen from frontal side and left side)

During the experiment, all the lights inside the experiment room were turned off. The subjects were asked to wear a pair of ear plug-in to avoid noise effect. Both the LCD TV and the subject were covered by a black curtain to get rid of surrounding influence and construct a scene of sitting alone inside a small room to watch out of the window. Within the covered space, there was a keyboard on the table in the front of the chinrest. The indication light on the keyboard was covered with black tape to avoid light distraction.

3.1.2 Stimuli

Checkerboard is a well-studied stimulus with particular defined parameters and relative deep studied ERP components. Another advantage of this stimulus is its high stability because pattern-reversal visual evoked potentials are less variable in waveform and timing than the ERP elicited by other stimuli (Odom et al. 2010).

All of three stimuli in experiment 1 composed of central visual field stimuli and peripheral visual field stimuli. The visual fields for the two experiments are same, that is, the whole visual filed is 94°× 62° and the central visual field is 24° × 18°.

The central visual filed stimuli is a 24 × 18 checkerboard subtending 24° × 18° of visual field with the check size of 1° × 1°. White and black checks of the checkerboard have luminance of 31.4 cd/m^2 and 0.68 cd/m^2. Contrast of the checkerboard is 95.8%. There is a red dot with the diameter of 1° at the centre of the checkerboard as fixation point. The peripheral visual stimuli are 94°× 62° of visual field with different pattern for different conditions. The three types of peripheral stimuli were grey background, dot pattern and windmill pattern.

For the grey background pattern, the peripheral visual field is totally grey with luminance same as the average luminance of central checkerboard (16.04 cd/m^2).

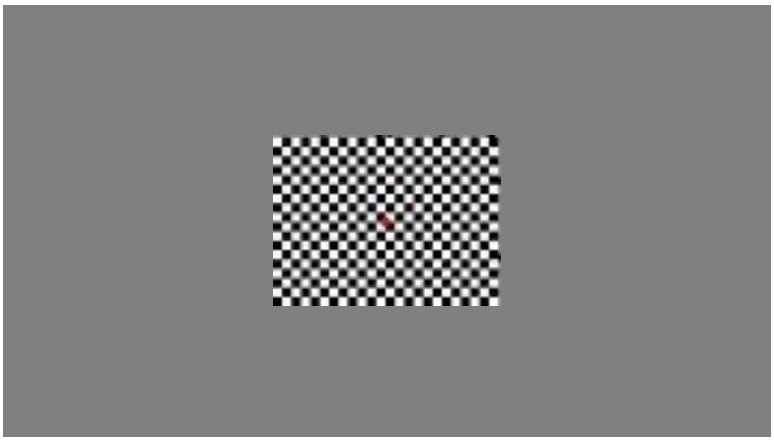


Figure3- 4 Grey Background Stimulus

For the dot pattern, there are 700 black dots with random size in the range of 0.4°- 1° visual field randomly distributed on the screen (some of those located within central visual field were covered by the checkerboard). The average luminance of the peripheral stimuli is same as the average luminance of central checkerboard. For translation condition, the dots in the rightest side will disappear once they reach the right side of the screen and then appear on the leftist side. For the rotation condition, dots with same density covers a round space with diameter same as the diagonal of screen and centre at the red dot.

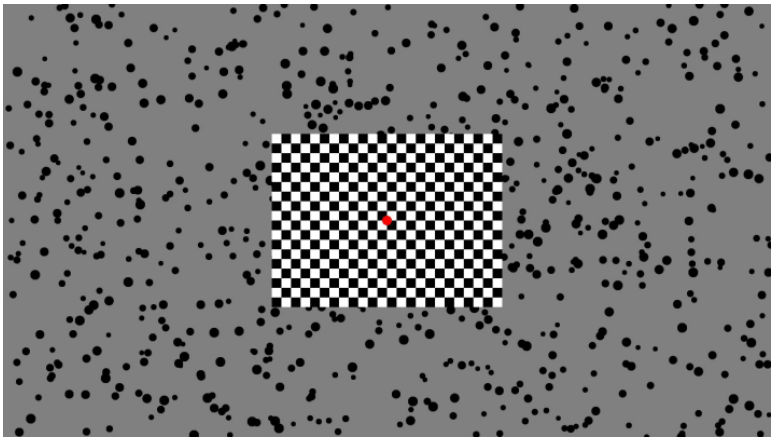


Figure3- 5 Dots Background Stimulus

For the windmill pattern, there are 36 fluorescent radial stripes alternating with black and white of equivalent angle. This control condition is adapted from the former ERP study (Thilo, Kleinschmidt & Gresty 2003b). In this study, we modified the stripe number from 12 to 36

because we want to keep the vection intensity between experiment condition and control condition in similar level.

(Before we have done a behaviour test measuring vection intensity under different stripe number and finally we found that when the stripe number was 36, there was no significant difference in intensity with the dots condition).

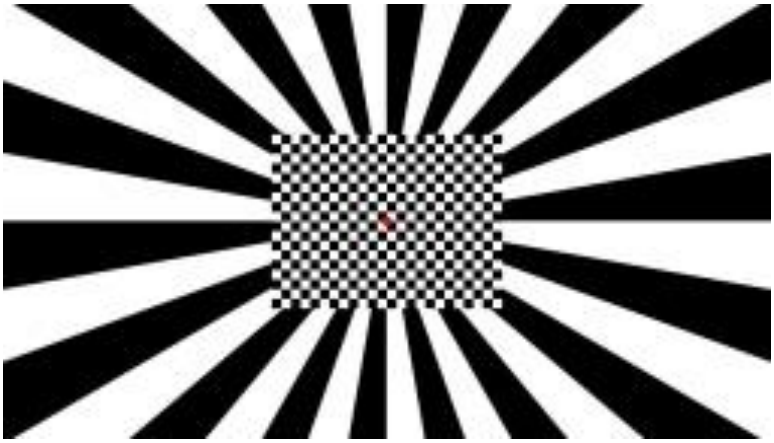


Figure3- 6 Windmill Background Stimulus

3.1.3 Synchronization of visual stimuli, brain wave data and behavior response

Synchronization achieved by a stim-to-scan cable insert in the Digital (TTL) inputs/outputs port of the amplifier (shown in figure 3-7, the left picture shows the port on the amplifier, the right picture shows the ports of stim-to-scan cable, the cable with 8 pins is for amplifier and the cable with 25 pins is for computer parallel port). A Matlab program (Mex-File Plug-in for Fast MATLAB Port I/O, http://apps.usd.edu/coglab/psyc770/IO64.html) generated the TTL input from the stimuli-generating computer to the amplifier and the event marker was saved as the 41th channel in the data.

Figure3- 7 Trigger Port on Amplifier and Ports of Stim-to-Scan Cable

At the start of the stimuli program and every reversal action of checkerboard, there was a TTL trigger sends to amplifier to mark the exact time of the event. At the same time, once stimuli start, two Matlab arrays were generate to record the time of self-motion and no-vection condition separately (this perception is made by subjects through keyboard pressing). Every time the subject pressed the keyboard for perception indication, relate Matlab arrays extended and added a new element contain time of that press behaviour.

Finally all data were aligned according to the start time of the stimuli. And the checkerboard reversal action in different perception statuses were marked according to the following criteria: for those reversal events fall in no-vection condition stage, the reversal action marker will be marked as 2 while for those fall in vection condition stage, the reversal action marker will be 1.

3.2 Experimental paradigm

3.2.1 Data acquisition

The brain wave data in this thesis were recorded using Curry 7 acquisition module with the sampling rate of 1000Hz and 22-bit A/D resolution. The electrodes used here were defined by a standard 32-channel Quik-Cap (Compumedical NeuroScan). 30 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) were arranged according to a modified international 10–20 system, and 2 reference electrodes (A1 and A2) were placed on left and right mastoid bones. 4 channels were

used for measuring horizontal (for both eyes) and vertical (for the left eye) Electro-Oculogram. Inter-electrode impedance was always controlled under 10 kΩ before the start of experiment.

3.2.2 Experiment Process

A training session was delivered for each of the two experiments to get subjects familiar with the task and experimental settings. For experiment 2, this training session also acted as a screening session for us to filter the subjects. After the training session, subjects were asked to wash their head and dry it. This process took more than half an hour, so the after effect of training would fade and not affect further main experiment. The experiment process shows in Figure 3-8.

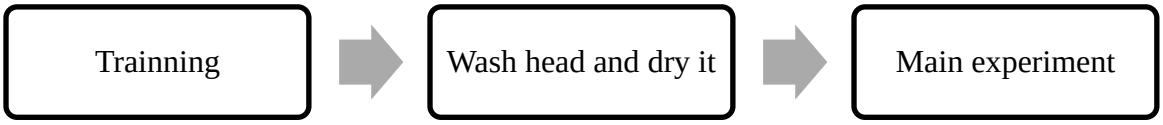


Figure3- 8 Complete Experiment Process (for experiment 2, if subject doesn't pass training, the experiment will stop)

3.2.3 Data Process and Analysis

The raw data recorded by amplifier is .dat format. This data can be read by LoadCurryDataFile.mat file accompany with Curry 7 acquisition.

Because we care about the primary visual cortex and the data is very big to be processed, not all the channels we used for the data processing. We only chose data from Fz, FCz, Cz, CPz, A1, Pz, O1, Oz, O2, VEOU, VEOL, HEOR, HEOL and event trigger for processing. Then after event data synchronization, the data was import into EEGLAB (v13.4.4b) and ERPLAB for the following processing:

- Import event information from the event channel
- Re-reference all the data to Fz channel (this channel is far away from primary visual cortex so it’s often chose to be reference for visual field analysis)
- Filter the data with band filter from 0.1Hz to 30Hz
- Create event list with 1 means object-motion status and 2 means self-motion status
- Extract bin based event epochs with length of 450ms and 50ms before the reversal action treated as baseline

- Remove baseline
- Artifact detect using moving window (length of 200ms and threshold of 100uV) in the epoched data
- Compute averaged ERPs without those rejected data

3.3 Subjects

The subjects were randomly recruited Chinese university students through email or forum, having normal or correct to normal vision (They were tested to attain at least 20/20 visual acuity). They all have no history of visual perception related neurological or sensory disease. Consent form for participation were obtained from all subjects before they take the experiment. All experiments had been approved by the Human Subject Committee of the Hong Kong University of Science and Technology.

3.4 Measurement Methods

3.4.1 Scale of Visually Induced Vection Intensity

Participants were asked to verbally report the intensity of their illusive sensation of self-motion (vection) according to the vection ratings scale at the end of each trial. The vection ratings scale is an 11-point scale from 0 – 10 modified from Griffin (Webb & Griffin 2003) shows in Table3-1.

Table3- 1 Vection Intensity Scale

Perception of self-motion (vection)	Your report
You feel like you are stationary and it is the dots which appear to be moving only.	0
You feel like you are moving a bit in the opposite direction of the dots, but the dots are moving more.	1-4
You feel like you are moving at the same speed as the dots but in the opposite direction of the dots.	5
You feel like you are moving a lot in the opposite direction of the dots and the dots are moving a bit.	6-9
You feel like you are moving in the opposite direction of the dots and the dots appear stationary.	10

The vection ratings scale ranges from 0 (means "I perceive that the only thing moving is the visual stimulus and I remain stationary") to 10 (means "I perceive that the visual stimulus is stationary, and a strongly feeling that I am moving"), reflecting the relative intensity of perceived motion between the participants themselves and the visual stimuli. This scale cares more about the relative speed between subjects' self-moving and the moving of the stimuli. When subjects report 5, it means that their self-moving speed is same as the perceived speed of the visual stimuli but in the opposite direction.

All participants were educated about the meaning of vection before the experiment to make sure that they understood the difference between self-motion illusion and object-motion. The typical train moving illusion scenario was used, we reminded them of their experience that is when they were in a stationary train: there is a train just next to them. They were looking at the train. When that nearby train pulled out the station, they may have the illusion that their train was moving in the opposite direction.

The following indication was provided to them for familiarizing with vection feeling:

In the experiment, after you staring at moving patterns for a while, you may feel the moving of the pattern gradually slow down and this is a sign that you are starting to generate the illusion of self-motion. Then, you may gradually start to feel the TV frame and yourself is tilting or even slowly moving toward the opposite direction in which the pattern is moving.

3.4.2 Motion sickness susceptibility questionnaires Short-form (MSSQ-short)

In order to classify subjects and see whether the result we found in the experiments correlated with subjects' susceptibility of motion sickness, we collected MSSQ data for further analysis.

Before the start of the main experiment, subjects were asked to complete a short form of the motion sickness susceptibility questionnaires (Golding 1998). The MSSQ is a survey to quantify people's susceptibility to nauseogenic conditions by setting a series of questions of each individual's past history of motion sickness. The layout and the scoring method of the MSSQ were attached in Appendix D. It has two sections. Section A concerns with one's experiences of traveling and motion sickness as a child before the age of 12. Section B concerns with one's

experiences of traveling and motion sickness in the past 10 years. The raw score of the MSSQ is a simple summation of the scores from both sections (MSSQ = MSA + MSB). The MSSQ raw score is then converted to the percentile score of MSSQ, with the 50%-tile representing the susceptibility of a normal population.

3.4.3 Transition between Different Perception Statuses

Behavior data was needed in the experiments to classify the EEG data into different bins. We used keyboard for subjects to report their perception statuses. Exclusive report method was used here that is subjects can only report self-motion or object-motion at one time. If both of the two perceptions exist, they need to define which the dominant one is and report that one.

In detail, when the subjects felt self-motion they need to press left arrow once and then release. While they felt object-motion, they need to press right arrow once and release. At the very beginning of each trial, they didn't need to report object-motion for the program would generate a marker for object-motion automatically.

To be noted, during the whole process, they only need to indicate the transition between different perception statuses; intensity change is not need to report. So we could expect the report result is alternating between self-motion and object-motion.

CHAPTER 4 EXPERIMENT ONE: PRIMARY VISUAL CORTEX BRAINWAVE SIGNATURE UNDER DIFFERENT VECTION CONDITION

4.1 Introduction

When we walk through the environment, our visual system will sense the optical flow of the surrounding, our vestibular system will sense the acceleration change, our auditory system will sense the surrounding sound change and our proprioceptive system will sense the pressure change. All these sensory systems will work together and information from these systems will combined to inform us our movement condition. But sometimes when we only get information from visual system we will generate the illusion of self-motion, that is, vection.

Vection is commonly experienced in our daily life. When we sit in a stationary train looking at the adjacent train pull out of the station, we may have the feeling that our train is moving in the opposite direction. Virtual reality visual stimuli will also induce similar sensation and it was also proved that experimental visual optical stimuli can induce vection on physically stationary subjects.

In a PET study, Brandt et al. used rotating dots to induce vection and they found that visually induced vection in roll activated a medial parieto-occipital brain area (PO) bilaterally while simultaneously deactivated the posterior insula and adjacent retroinsular regions. This led to the concept of an inhibitory reciprocal visual-vestibular interaction as a form of sensory interaction during perception of vection. The following table 4-1 shows the brain activation detail of in Brandt's work for both visual and vestibular stimuli.

Table4- 1 Brain Areas Activation and Deactivation When Visual or Vestibular Stimuli Applied

	Stimulus	Activate	Deactivate
Vestibular	Caloric irrigation	Parieto-insular vestibular cortex(PIVC)	(Bilaterally) occipital visual cortex (covers BA 17,18, 19)
Visual	Large-field visual motion simulation	Medial parieto-occipital visual area	PIVC

This model, however, does not clearly declare the activity of primary visual cortex in both conditions. V1 plays an important role in visual perception. Other studies proved this model but when put them together; we found that they reported inconsistent responses in V1.

Primary visual cortex plays an important role in visual information intake and works as a gate for information goes into higher order visual field. Beside this bottom-up information process way, people now believe there is feedback regulation from top brain areas toward the bottom brain areas like the primary visual cortex because people found that visual cortical neurons remain active after their participation in the feedforward sweep. And in a review Lamme and Roelfsema summarized the evidences (Lamme & Roelfsema 2000b).

1. The first one is the change in the tuning of a neuron over the course of its response. Silvanto et al. reported time window for MT/V5–V1 feedback is 10–50ms after V5 manipulation (Silvanto et al. 2005).

2. The second indication is contextual information's modulation on a cell's response occurs outside its central receptive field (cRF). The cRF was defined as the region of visual space from which a cell receives information by way of feedforward connections, influences from outside the cRF depend, by definition, on recurrent connections.

3. The third evidence is the visual information processing time. The fast feedforward sweep of activity is completed within approximately 100 ms. Longer delays are obtained when recurrent connections have to be involved in those visual tasks (Lamme & Roelfsema, 2000).

In one ERP study, Thilo et al found that the electrical cortical responses to an independent central visual stimulus change as optical flow stimulation in the periphery induces different feelings (object-move or self-move). The N70 VEP (visual evoked potential) component showed a significant amplitude reduction when the peripheral visual stimulus induced vection (Kai V. Thilo, Andreas Kleinschmidt et al.2003). Feedback regulation was thought to play role in this change considering the experimental design and peak time.

As a functional consequence, the decreased cortex activity protects the subject from conflicting inputs, that is, the reduced activation level in visual cortex during vestibular stimulation suppress visual motion input, and the reduced signal in vestibular cortex during visual stimulation reduce the vestibular system's sensitivity (Della-Justina et al. 2015). Primary entry route counts 90% for visual signals to the cerebral cortex, thus V1 inhibition could compromise visual discrimination during self-motion (Seemungal et al. 2012).

4.2 Hypothesis

The objective of this study is to find the effect of vection on the electrical activity of V1. To extend the universality, we use both the translation stimuli and rotation stimuli. Base on the former study done by Thilo et al (Thilo, Kleinschmidt & Gresty 2003a), we made the following hypothesis of the brainwave recorded by O1, Oz and O2 electrodes.

- During vection condition, the amplitude of negative component at about 100ms will decrease comparing to no vection condition.

4.3 Method

4.3.1 Experiment Design

In order to permit the general applicability and control the experiment time, we used three stimuli here to induce circular vection and linear vection. Then the main focus was to compare the following three pairs to see how vection induced by different visual stimuli affect brainwavedata obtained from O1, Oz and O2.

- Rotating dots induced circular vection vs. no vection
- Translating dots induced linear vection vs. no vection
- Rotating windmill induced circular vection vs. no vection

We set windmill here as a control, on one hand we want to see whether we can replicate the former study result done got by Thilo et al, on the other hand because it is a very common visual stimulus used in a lot of vection studies.

Dots stimulus was proved a very strong stimulus to induce circular vection and our research group had some behavior and NIRS experiment experience on it. We could well control the property of these stimuli to generate vection of different intensity. Another advantage of dots stimulus is its direction un-limitation. We could move the same stimulus linearly or circularly which is impossible for windmill. This property will help us better compare the linear vection and circular vection induced by dots.

4.3.2 Subjects

Fifteen university students (11 males and 4 females) with average age of 23.57 years old and standard deviation of 1.28 years joined the experiment and signed the consent form in compliance with the declaration of Helsinki. They all had normal or corrected to normal vision and no known visual related illness history and not receiving any medical treatment during the experiment period. They were naive to the aim of this experiment and didn't attend to similar experiment before.

They were paid 50 HKD/hour for the training and formal experiment. The experiment was approved by the Human Subject and Research Ethics Committee at the Hong Kong University of Science and Technology (HKUST).

All of the subjects have taken part in a training session before the formal experiment. This training session took about half an hour. It contained all the stimuli displayed in the formal EEG experiment. The length of each trial was 30 seconds. Before start, experimenter explained vection to the subject by showing them the stimuli and let subjects to explain their feeling about their self-motion status and the movement condition of the stimuli. After they understood what vection is (that is they can feel the movement of stimuli slow down, themselves tilt in the rotating condition and linear moving in the translating condition), training session would start. The procedure of each trial is:

- Shows introduction interface, three points were highlighted here: 1. avoid eye movement and keep staring at the central red dots; 2. press left arrow once and release when perceive self-motion. Press right arrow once and release when perceive object-motion. 3. Press any key to start when understands the introduction.

- Shows stimuli animation (30s). During this time, subjects need to be relaxed and staring at the central red dot. Then they need indicate their perception status by press keyboard.
- After the stimuli, there is an interface remind subjects to report their perceived veciton intensity verbally towards experimenter.

There were five trials for each stimulus, so in total there were fifteen trials. Between each trial, subjects were asked to close their eye and rest for 1 minute.

Because the stimuli used in the first experiment are strong, all the subjects have vection, all the subjects went forward to the main EEG experiment.

4.3.3 Visual Motion Stimuli

A general conclusion from previous research on visually induced self-motion is that peripheral visual field is specialized for vection condition while the central visual field is responsible for the perception of object motion (Dichgans & Brandt 1978).

In this study, we used both the central and peripheral visual stimuli. We intended to study the effect of vection on visual perception. Whether the perception induced by peripheral visual field will influence subjects' visual perception towards the central visual stimulus which was treated as standard.

The experiment setup and stimuli were introduced in detail in chapter 3. Table 4-2 summarizes the stimuli and their movement condition used in the first experiment.

Table4- 2 Stimuli and Movement Conditions in Experiment 1

<table>
<tr><th></th><th>Central Visual Field</th><th>Peripheral Visual Field</th><th>Status</th></tr>
<tr><td rowspan="3">Control Condition</td><td rowspan="6">Flashing Checkerboard</td><td>Grey background</td><td>Stationary</td></tr>
<tr><td rowspan="2">Windmill with 36 alternating black and white stripes</td><td>Stationary</td></tr>
<tr><td>Rotating</td></tr>
<tr><td rowspan="3">Experiment Condition</td><td rowspan="3">700 dots with random size randomly occupy the screen</td><td>Stationary</td></tr>
<tr><td>Rotating</td></tr>
<tr><td>Linear Moving</td></tr>
</table>

All six conditions in this study are summarized below.

Baseline Condition 1 The peripheral grey background is stationary while the central checkerboard reverses at the rate of 1Hz.

Baseline Condition 2 The peripheral random dots stimulus is stationary while the central checkerboard reverses at the rate of 1Hz.

Baseline Condition 3 The peripheral windmill stimulus is stationary while the central checkerboard reverses at the rate of 1Hz.

Control Condition The peripheral windmill stimulus rotates counter- clockwise from the subject's viewpoint at an angular velocity of 45°/sec while the central checkerboard reverses at the rate of 1Hz.

Experiment Condition 1 The peripheral random dots stimulus rotates counter- clockwise from the subject's viewpoint at an angular velocity of 45°/s while the central checkerboard reverses at the rate of 1Hz.

Experiment Condition 2 The peripheral random dots stimulus translates from left to right at velocity of 45°/sec while the central checkerboard reverses at the rate of 1Hz.

4.3.4 Procedure

The whole experiment consisted of six conditions. Trial length of all the baseline condition was 3 mins, while for experiment conditions, it was 9 mins divided into three 3 mins trials. All the experiment trials conducted in random order.

Similar to the former study, the perception of vection was not continuous. During sustained optokinetic visual stimulation, the perception of vection does not typically continue uninterruptedly but is alternating between self-motion and no-vection condition (Thilo et al. 1999). In each perception status, bistable perceptions of ambiguous visual stimuli were not always mutually exclusive. Sometimes both perceptual interpretations can coexist simultaneously, especially during transition periods (Thilo, Kleinschmidt & Gresty 2003b). In this study, subjects were asked to make decision on the following criterion 1. Report object-

motion when they only perceive the object movement; 2. Report self-motion when all other conditions were met.

During each experiment trial, subjects were instructed to report their perception status using the keyboard. When they had self-motion feeling, they should press left arrow key once and release, while they had object-motion feeling, they should press right arrow key once and release.

After each trial, there was a screen indication remind them to report vection intensity according to vection scale verbally towards the experimenter.

Then they were asked to close their eye and rest for three to five minutes before the start of next trial.

4.3.5 Electrophysiology

Electrophysiological data acquisition was carried out on a NuAmps 40 channel system (Neuroscan Inc.). There were 32 Ag/AgCl electrodes attaching to a 32-channel Quik-Cap (Compumedical NeuroScan). 30 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) were arranged according to a modified international 10–20 system, and 2 reference electrodes (A1 and A2) were placed on left and right mastoid bones. 4 channels were used for measuring horizontal and vertical Electro-Oculogram. The sampling rate was 1 kHz with 22-bit A/D resolution. Inter-electrode impedance was always kept below 10 kΩ.

4.4 Data Analysis

11 male subjects and 4 female subjects participated in the first experiment. 1 male subject was eliminated from data analysis because of missing behavior data.

The continuous EEG record was windowed with a pre-stimulus baseline of 50ms before pattern onset, and a 400ms post-stimulus epoch. Then epoch within each perception status was grouped to calculate averaged ERP. The five epochs proceeding as well as following each transition between perceptual states was excluded to avoid contamination of the signal by components related to transitional states and their reporting action.

All the channels were re-referenced to Fz and signal with frequency larger than 30Hz and smaller than 0.1Hz is filtered offline.

The average amplitude and latency of the ERP waveforms were measured at primary visual cortex (average among O1, Oz, and O2) for four different components: P2, N1 (posterior), N2 and P3. These components were measured for each individual (the following are in millisecond, N1: 100-200; P2: 150-200; N2: 200-300; P3: 250-350) using ERPLAB. Then we ran between subjects paired t-test to see the change of component amplitude and latency change.

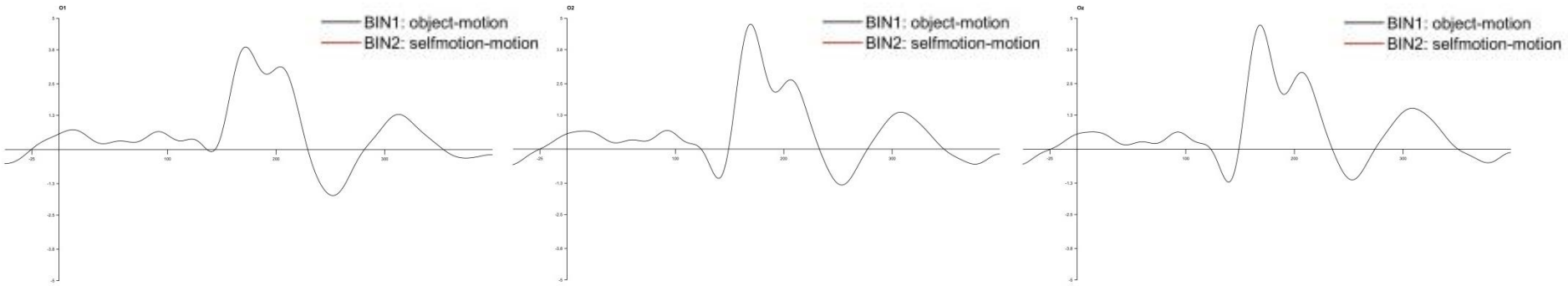
4.5 Result

All following data analyses were performed using statistical tools in IBM SPSS Statistics version 22 (MAC version) and in Matlab R2014b. Before doing t-test, we have used Q-Q plot to test and found all the data follow normal distribution.

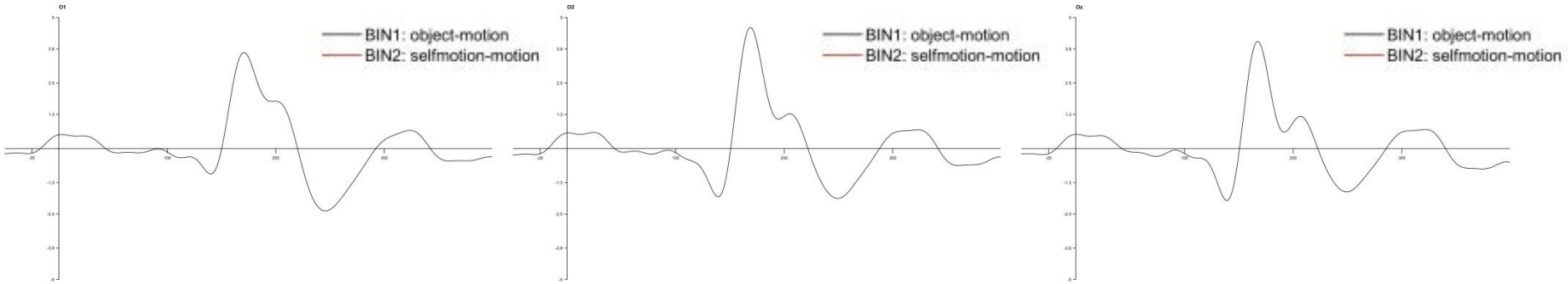
4.5.1Background Effect

Figure 4-1 shows the averaged ERP plots among all the 14 subjects of electrodes O1, Oz and O2 under different background conditions (the sequence of electrodes in each condition is O1, O2 and Oz. The black line means no-vection condition condition while the red line means vection condition condition).

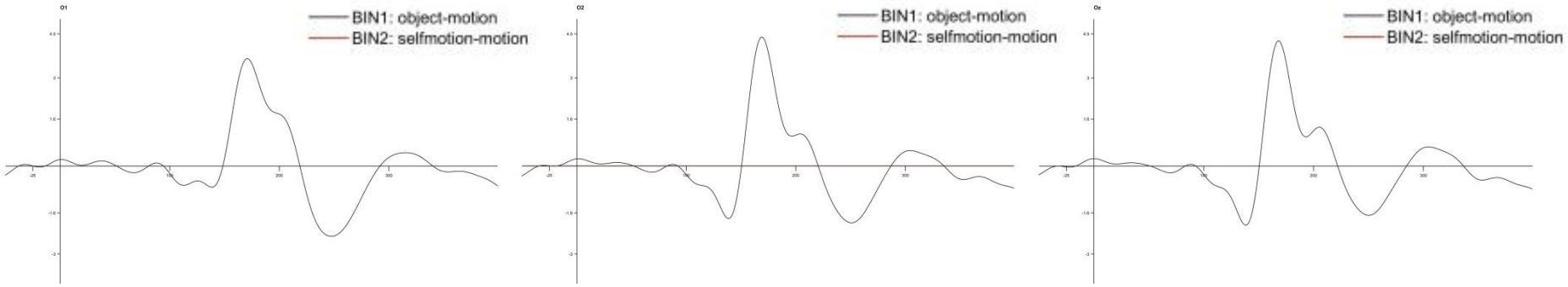
Stimulus 1: Grey Background and Reversal Checkerboard



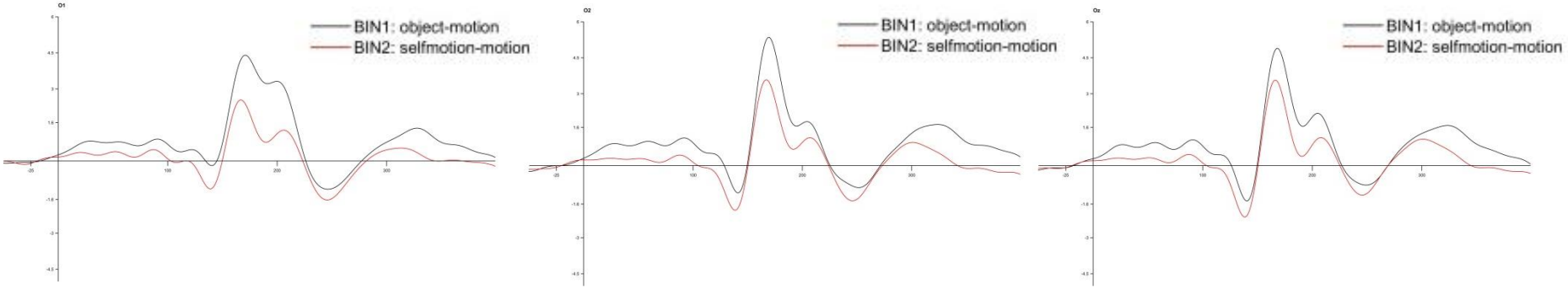
Stimulus 2: Stationary Dots and Reversal Checkerboard



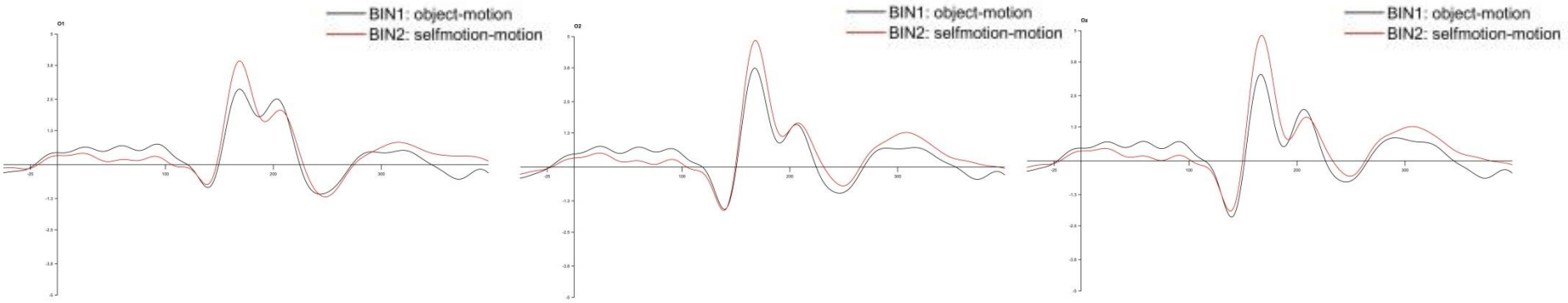
Stimulus 3: Stationary Windmill and Reversal Checkerboard



Stimulus 4: Rotating Dots and Reversal Checkerboard



Stimulus 5: Translating Dots and Reversal Checkerboard



Stimulus 6: Rotating Windmill and Reversal Checkerboard

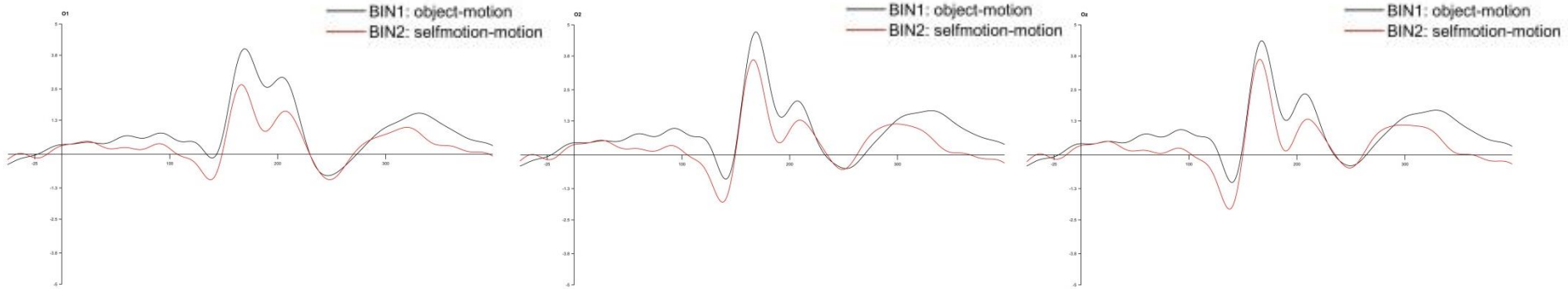


Figure4- 1 ERP Plots of All 6 Stimuli (Averaged among 14 subjects)

Paired t-test was applied to test whether the background has effect on component latency and amplitude. Here the Table 4-3 summarizes all the effect of background. The increase or decrease inside the block means the trend when compare the latter condition with the former condition.

Table4- 3 The Background Effect in Experiment 1

Component	Property	Stationary Dots vs. Grey Background	Stationary Windmill vs. Grey Background
N1	Latency	-	-
	Amplitude	-	Increase (p = 0.003)
P2	Latency	-	-
	Amplitude	-	-
N2	Latency	-	-
	Amplitude	-	Increase (p = 0.021)
P3	Latency	Increase (p = 0.004)	Increase (p = 0.036)
	Amplitude	-	-

When compare Stationary Dots condition with Grey Background condition, P3 latency shows a significant increase (p = 0.004).

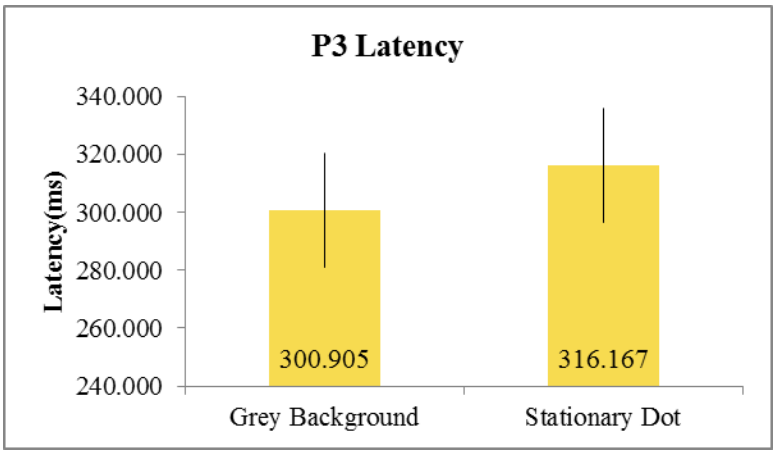


Figure4- 2 P3 Latency Change (Grey Background vs. Stationary Dots)

When compare Stationary Windmill condition with Grey Background condition, N1 amplitude shows a significant increase (p = 0.003), N2 amplitude shows a significant increase (p = 0.021), P3 latency shows a significant increase (p = 0.036).The consistent in P3 latency change indicate that the processing of different background pattern may start from about 300ms after the spot.

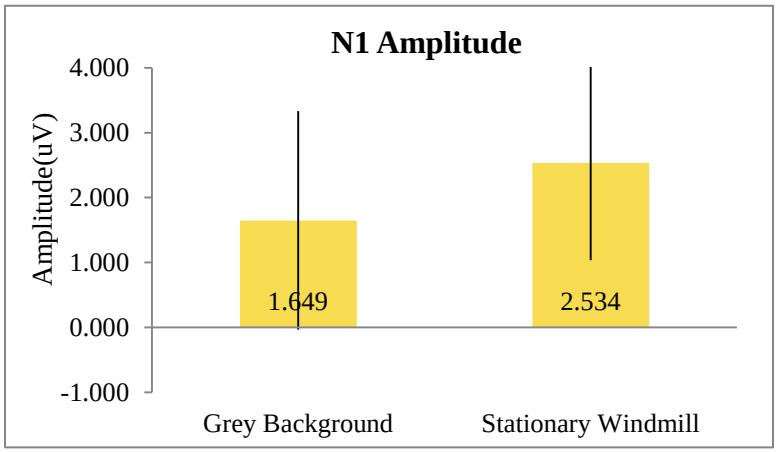


Figure4- 3 N1 Amplitude Change (Grey Background vs. Stationary Windmill)

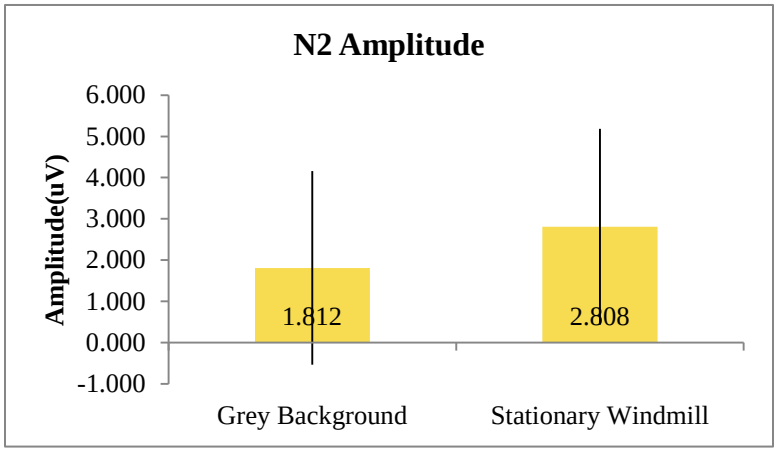


Figure4- 4 N2 Amplitude Change (Grey Background vs. Stationary Windmill)

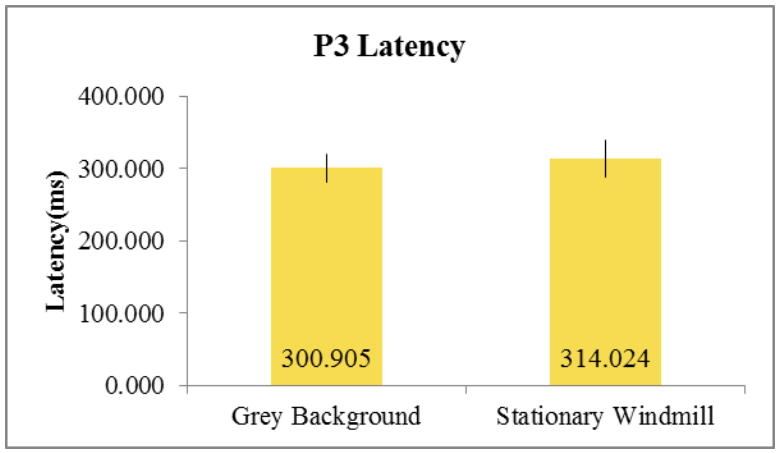


Figure4- 5 P3 Latency Change (Grey Background vs. Stationary Windmill)

4.5.2 Movement Effect

In this section, we analyzed the effect of movement of the peripheral stimuli. Here we did the paired t-test for each moving stimuli with their relative stationary stimuli. The following Table 4.4 summarizes the result. The increase or decrease inside the block means trend when compare the moving condition with the stationary condition.

Table4- 4 the Effect of Movement for Different Visual Stimuli

	Moving Stimulus – Stationary Stimulus		
	Component	Amplitude	Latency
Rotating Dots	N1	-	-
	P2	-	-
	N2	Decrease (p = 0.024)	-
	P3	-	-
Translating Dots	N1	-	Decrease (p = 0.04)
	P2	-	-
	N2	Decrease (p = 0.003)	-
	P3	-	-
Rotating Windmill	N1	-	-
	P2	-	-
	N2	Decrease (p = 0.002)	-
	P3	-	-

When compare Rotating Dots condition with Stationary Dots condition, N2 amplitude shows a significant decrease (p = 0.024).

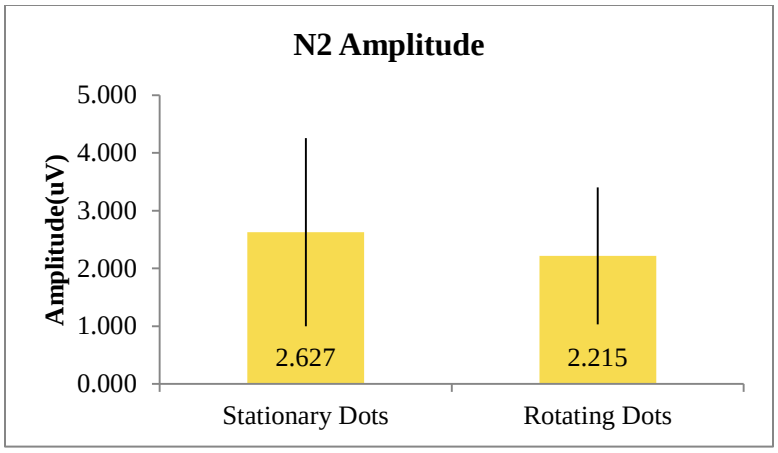


Figure4- 6 N2 Amplitude Change (Rotating Dots vs. Stationary Dots)

When compare Translating Dots condition with Stationary Dots condition, N1 latency shows a significantly decrease ($p = 0.04$), N2 amplitude shows a significant decrease ($p = 0.003$).

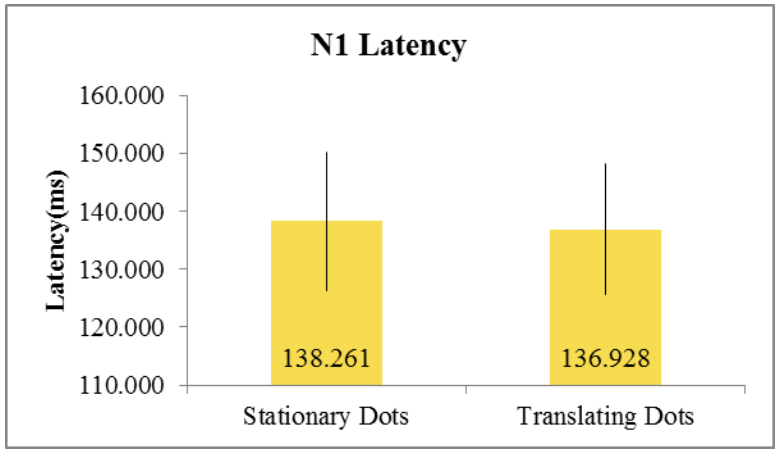


Figure4- 7 N1 Latency Change (Translating Dots vs. Stationary Dots)

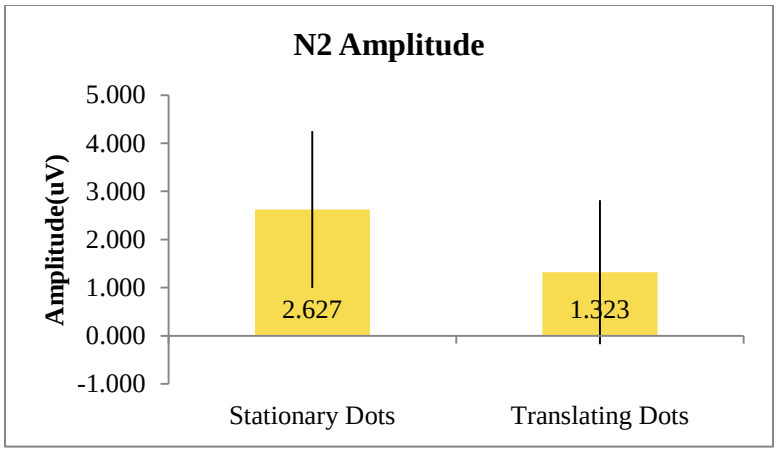


Figure4- 8 N2 Amplitude Change (Translating Dots vs. Stationary Dots)

When compare Rotating Windmill condition with Stationary Windmill condition, N2 amplitude shows a significant decrease ($p = 0.002$).

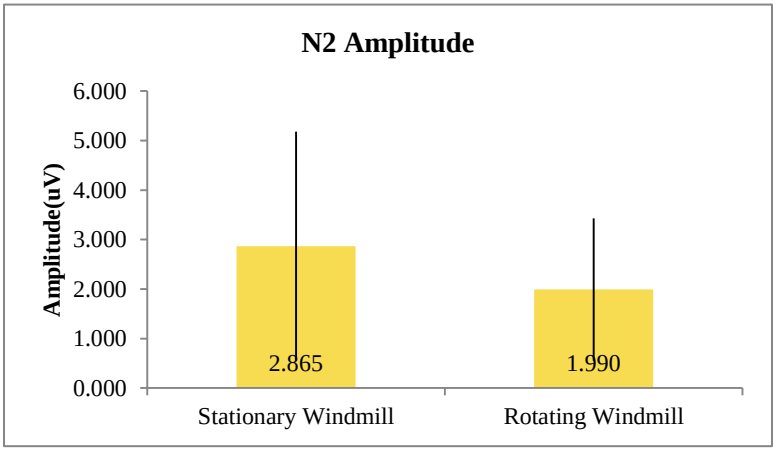


Figure4- 9 N2 Amplitude Change (Rotating Windmill vs. Stationary Windmill)

All three moving conditions show N2 amplitude decrease when compare to relate stationary condition, this indicate that the movement perception effect starts at nearly 200ms after stimulus start.

4.5.3 Perception Effect

4.5.3.1 Rotating Dots Induced Circular Vection

For circular vection condition, there is no significant change for components amplitude and latency when compare vection condition with no vection condition.

But when compare moving stimulus condition (the summation of vection and no vection) with no vection condition, N1 latency show a significant increase in no vection condition. Table 4.5 summarizes the vection effect for rotating dots induced circular vection (the result in the block is the result when compare row condition with column condition).

Table4- 5 the Effect of Vection on Rotating Dots Condition

Condition	Moving Stimulus	Moving Stimulus with Vection condition	Moving Stimulus with Object-motion Perception
Moving Stimulus	-	None	N1 Latency increase
Moving Stimulus with Vection condition	-	-	None
Moving Stimulus with Object-motion Perception	-	-	-

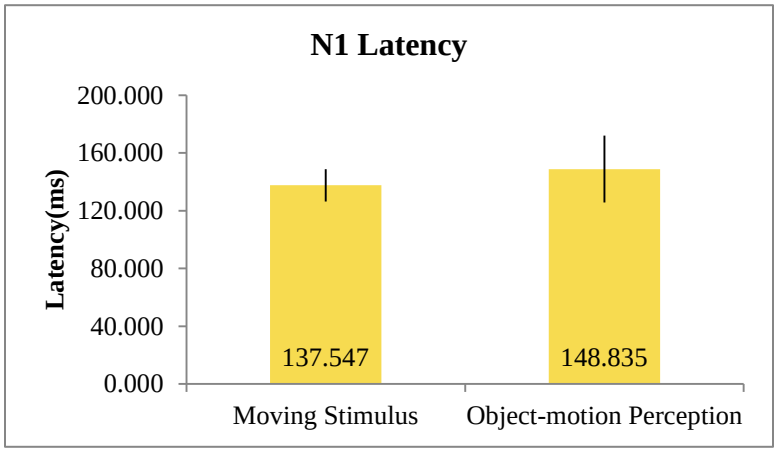


Figure4- 10 N1 Latency Change (moving stimulus condition vs. no-vection condition condition)

4.5.3.2 Translating Dots Induced Linear Vection

For linear vection condition, P2 latency in vection condition is significantly lareger than P2 latency in no vection condition. And when compare moving stimulus condition with both vection and no vection condition, we find N1 amplitude and P2 latency shows a significant decrease in no vection condition compare to moving stimulus condition.

Table4- 6 the Effect of Vection on Translating Dots Condition

Condition	Moving Stimulus	Moving Stimulus with Vection condition	Moving Stimulus with Object-motion Perception
Moving Stimulus	-	-	N1 Amplitude increase, P2 Latency increase
Moving Stimulus with Vection condition	-	-	P2 Latency increase
Moving Stimulus with Object-motion Perception	-	-	-

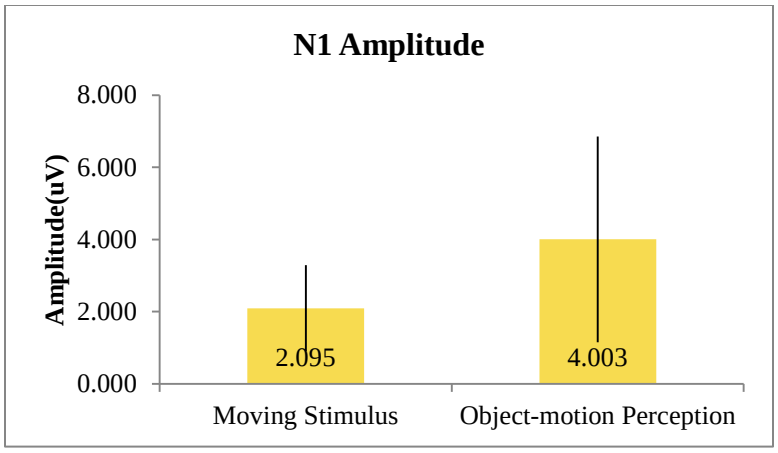


Figure4- 11 N1 Amplitude Change (Moving Stimulus Condition vs. No-vection condition Condition)

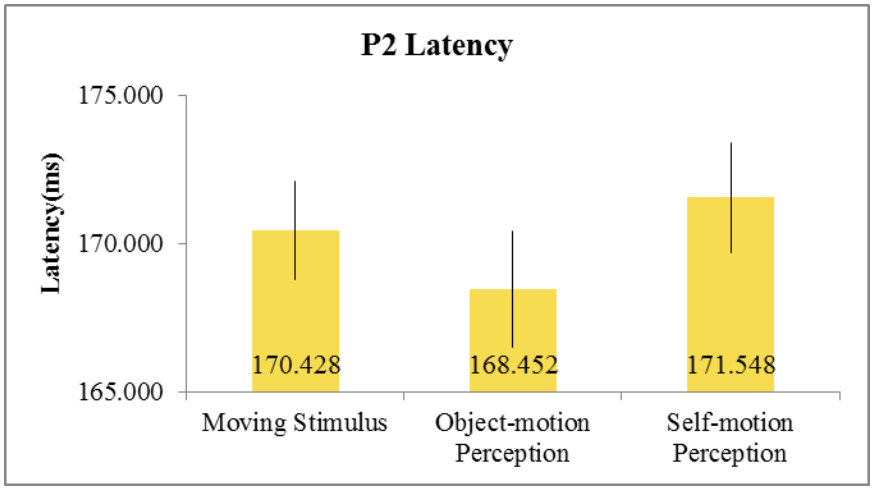


Figure4- 12 P2 Latency Change (Moving Stimulus Condition vs. No-vection condition Condition vs. Vection condition Condition)

4.5.3.3 Rotating Windmill Induced Circular Vection

There is no significant difference for components amplitude and latency when compare vection condition with no vection condition.

But N1 and N2 latencies show significant difference when compare vection condition with moving stimulus condition. But their change directions are different. Table 4-7 summarizes the effect of vection on windmill stimulus.

Table4- 7 the Effect of Vection on Windmill Dots Condition

Condition	Moving Stimulus	Moving Stimulus with Vection condition	Moving Stimulus with Object-motion Perception
Moving Stimulus	-	N1 Latency increase, N2 Latency decrease	-
Moving Stimulus with Vection condition	-	-	-
Moving Stimulus with Object-motion Perception	-	-	-

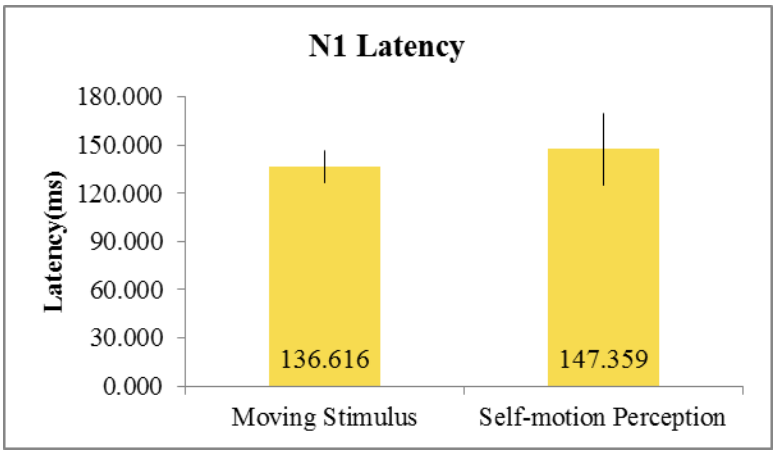


Figure4- 13 N1 Latency Change (Moving Stimulus Condition vs. Vection condition Condition)

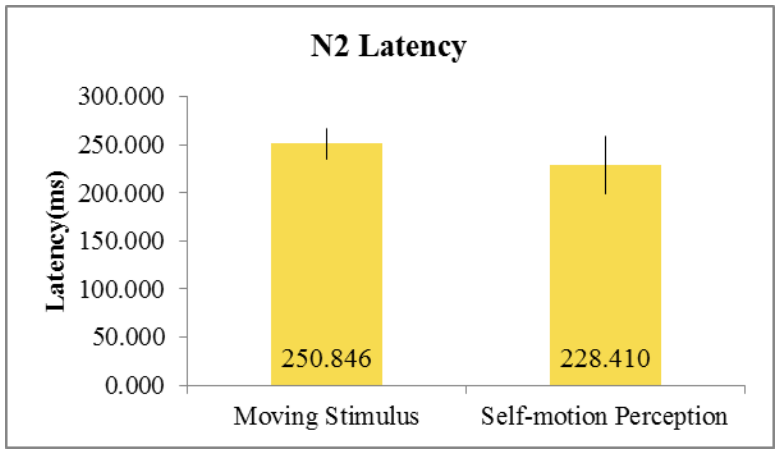


Figure4- 14 N2 Latency Change (Moving Stimulus Condition vs. Vection condition Condition)

4.5.4 Correlation between Vection Intensity/Duration and Component Properties

We also performed two-tailed Pearson correlation analyses in order to assess the relationship between ERP components properties and actual behavior.

For both the circular vection condition, there is no significant correlation between vection intensity/duration and amplitude or latency change.

But for the linear vection condition, there are significant correlations shown as below.

The vection duration and intensity were linearly correlated with component amplitude change (no-vection - vecion).

Table4- 8 Relationship between Vection Duration/Intensity and Component Amplitude Change in Linear Vection Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude Change	N1	r = 0.5442	0.04
Vection Intensity		N1	r = 0.6519	0.01
		N2	r = 0.5145	0.06

Relationship between vection duration/intensity and component amplitude change in LV condition (no-vection – vection) shows better in the following plots. The numbers beside each

dot indicate the number of subject. Here for the relationship between vection duration and N1 amplitude change, because the experimental design, vection duration should be no greater than 540s and no smaller than 0s, and it is understandable that we could clearly see two asymptotic limits near each side.

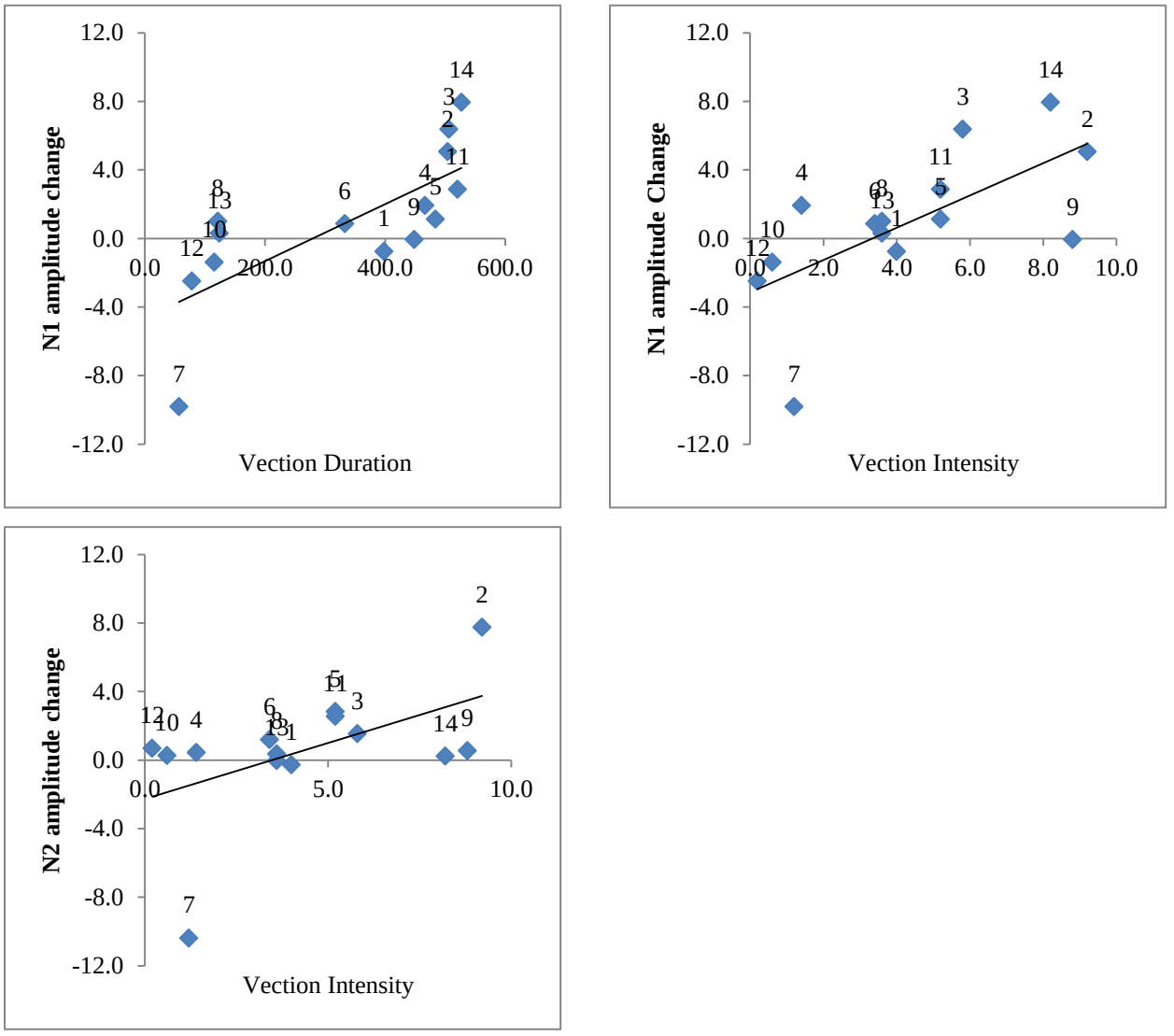


Figure4- 15 Relationship between Vection Duration/Intensity and Component Amplitude Change in LV Condition (no vection - vection)

Also, vection duration also correlate with the amplitude difference among left and right brain lobe (left – right).

Table4- 9 Relationship between Vection Duration/Intensity and Amplitude Difference (O1-O2) in Linear Vection Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Left-Right Amplitude Difference	N1	r = - 0.6789	0.007
Vection Intensity		N1	r=- 0.5103	0.06

Here shows the scatter plots for this relationship.

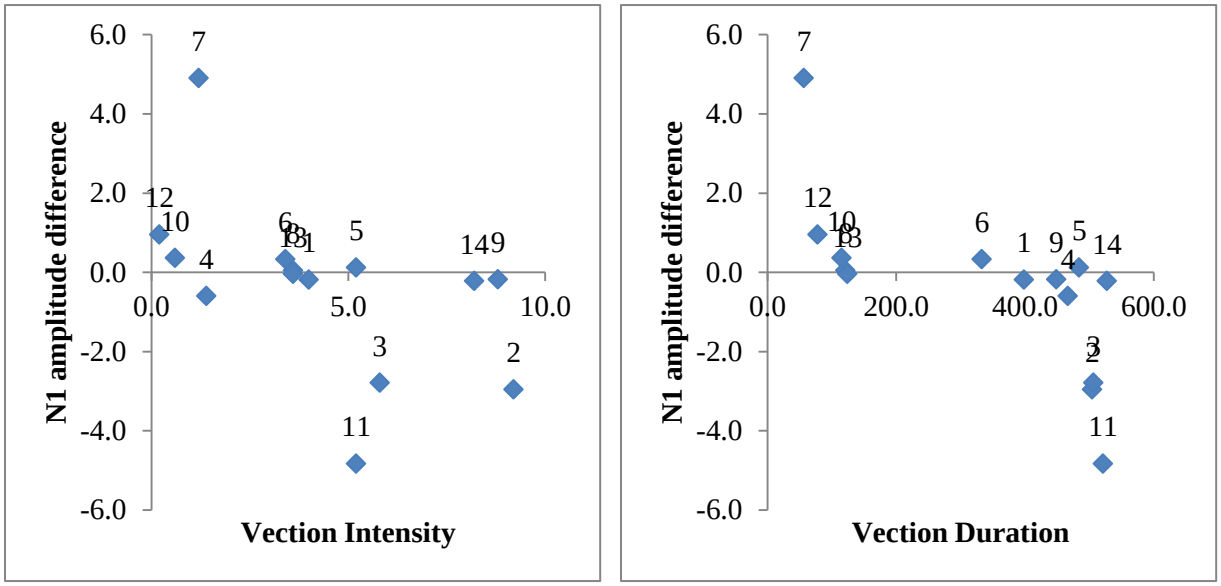


Figure4- 16 Relationship between Vection Duration/Intensity and Component Amplitude Change in LV Condition (no vection - vection)

4.6 Discussion

There are two findings of this experiment:

- Peripheral visual stimuli will affect the amplitude of N2 (200ms – 300ms) component. When the background moves, the N2 component amplitude will significantly decrease.

- Vection intensity/duration positively correlates with N1, N2 components amplitude (average among O1, Oz and O2 electrodes) change between different perception status in linear vection condition (averaged amplitude in no-vection condition minus averaged

amplitude in vection conditionvection condition). But this correlation doesn't exist for circular vection condition.

The time range of feedforward and feedback activities in the visual system was well studied. Visual input reaches the early visual areas (V1) at 40 ms after stimulus onset. Visual information then rapidly fed forward to the extrastriate areas and parietal and temporal cortex (60 ms). This feedforward sweep of information processing is unconscious. At around 100 ms, early visual areas and higher areas engage in recurrent interactions, which are necessary for visual awareness. Specifically, extrastriate activation is fed back to V1 in order for that activation to be consciously perceived (Lamme 2001).

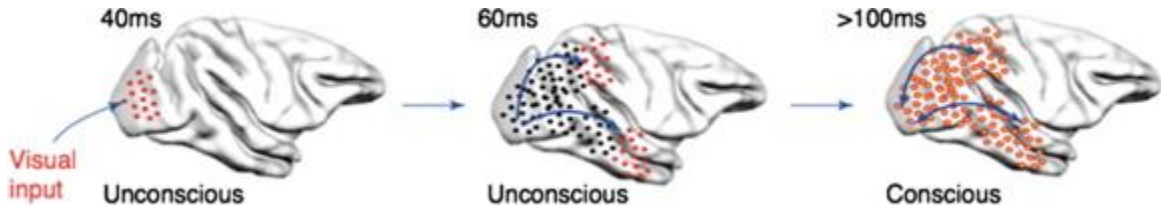


Figure4- 17 Time Range of Visual Information Processing (Adopted from Lamme 2001)

In our first experiment, when analyze the movement effect, it was found that all three moving conditions show a N2 amplitude decrease when compare with relate stationary condition, this indicates that the movement perception effect shows at nearly 200ms after stimulus start. But consider this latency is too late for feedforward visual information process. This effect may attribute to feedback process. For the correlation we found, feedback from higher brain areas on V1 and subjective attention control may play a role to regulate the primary visual cortex activities and responsible for the component amplitude change.

For the typical checkerboard relate component N75 and N145, the N75 component has been associated with generators in V1 in the calcarine fissure, the inferior surface of the occipital lobe. The generators of the N145 have also been localized in V1.Here table 4-10 lists all the studies used ERP only or combined with MEG or neuroimaging methods to locate the generation area of ERP components induced by checkerboard.

Table4- 10 Conclusions of previous studies regarding the visual–cortical areas that generate the first (N75), second (P100), and third (N145) major components of the pattern-reversal ERP(Di Russo et al. 2005).

Study	Technique	N75 (N1 in our study)*	P100	N145 (N2 in our study)*
Michael and Halliday, 1971 (Michael & Halliday 1971)	VEP	V1		
Barrett et al., 1976 (BARRETT et al. 1976)	VEP		V1	
Lehmann et al., 1981 (Lehmann et al. 1981)	VEP		V2–V3	
Haimovic and Pedley, 1982 (Haimovic & Pedley 1982)	VEP		V1	
Hoeppner et al., 1984 (Hoeppner et al. 1984)	VEP		V1	
Maier et al., 1987 (Maier et al. 1987)	VEP	V1		
Biersdorf, 1987 (Biersdorf 1987)	VEP	V1	V1	
Ducati et al., 1988 (Ducati et al. 1988)	VEP	V1	V1	
Onofrj et al., 1993	VEP	V1	V2/V3	
Noachtar et al., 1993 (Noachtar et al. 1993)	VEP	V1	V1–V2	V2–V3
Schroeder et al., 1995 (Schroeder et al. 1995)	VEP	V1–V2	V3–V4	V2–V3
Onofrj et al., 1995a (Onofrj, Fulgente, Thomas, Malatesta, et al. 1995)	VEP	V1	V2/V3	
Onofrj et al., 1995b (Onofrj, Fulgente, Thomas, Curatola, et al. 1995)	VEP	V2	V2/V3	V2/V3
Nakamura et al., 1997 (A. Nakamura et al. 1997)	VEP/MEG		VI	
Seki et al., 1996 (Seki et al. 1996)	MEG		V1	
Hatanaka et al., 1997 (Hatanaka et al. 1997)	MEG	V1	V1	V1
Brecelj et al., 1997 (Brecelj et al. 1997)	VEP/MEG		V1	
Shigeto et al., 1998(Shigeto et al. 1998)	VEP/MEG	V1	V1	V1
Slotnick et al., 1999 (Slotnick et	VEP		V1	

al. 1999)				
Hashimoto et al., 1999 (Hashimoto et al. 1999)	VEP/MEG	V1	V1	V1
Nakamura et al., 2000 (M. Nakamura et al. 2000)	VEP/MEG		VI	
Vanni et al., 2001 (Vanni et al. 2001)	MEG	V1	Extrastriate	
Bonmassar et al., 2001(Bonmassar et al. 2001)	VEP/fMRI	V1	V1	
Tobimatsu, 2002 (Tobimatsu 2002)	VEP/MEG	V1	V1	V1
Tabuchi et al., 2002 (Tabuchi et al. 2002)	MEG	V1	V1	

* Because of difference in stimuli, N1 in our study closely corresponding to N75 and N2 in our study corresponding to N145.

But it's notable that there is a latency delay in our experiment this may because we add peripheral stimuli and it contains more information to be processed, which from former studies will lead an increase in latency. In addition, V1 couldn't be the only source of signal in our experiment because electrodes receive brainwave data from the whole brain although V1 is the major source.

When analyze the component N1, N2 amplitude change, we found that the N1, N2 amplitude change positively correlate with vection behavior data. We thought feedback regulation might play a role here cause the positive correlation, because we've already control input in the experiment, and considering the time range of components, the effect is of large possibility coming from feedback regulation in the brain. When subjects have vection, higher brain area will exert control over primary visual cortex to regulate activity there. Referring to former studies, we would expect the amplitude of those two components N1 and N2 is reduced compare to no-vection condition. And the stronger the vection is, the greater the inhibition effect is. This would finally result in an increase in ERP amplitude difference between no vection and vection. And the expected result of this regulation is a linear function start from zero.

But when compare with our data, we found there is an obvious shift in baseline. This could be explained by subjective attention control. Attention was thought to play prominent role in V1 activity changes. Stimuli presented to attended locations elicits larger N1 (150–200 ms) components of the visual ERP over the posterior scalp than do stimuli presented outside the spotlight of spatial attention (Anllo-Vento et al. 1998). It was found that this amplitude enhancement occurred with little component latencies or scalp distributions change, suggesting that spatial attention exerts a gain control or selective amplification of attended inputs within the visual-cortical pathways in the interval between 80–200 ms after stimulus onset (Hillyard et al. 1998). During the experiment, subjects were asked to keep focus on the central dot, they would put more attention when they feel their illusion perception affect their focus. In such condition, the brainwave amplitude for checkerboard perception would increase in vection condition and result in a decrease in ERP amplitude difference.

The correlation found in our study could provide a possible way to explain why former studies have found difference in V1 activity when compare vection condition with no vection baseline. Because we found that V1 activity would change as the vection intensity/duration, we could infer the difference in V1 activity was caused by different vection intensity induced by stimulation. As we know, visual field, stimuli type and speed will all affect vection intensity(I. P. Howard & Heckmann 1989). Sometimes for the limitation of neuroimaging machine, former study could only use stimuli with small visual field, which would have lower vection compare to larger visual field. Like Deutschlander (Deutschländer et al. 2002), the visual field they used was only ±22°, which is a relative weak stimulation. And consistent to our correaltion, they observed V1 activity increase compare to no-vection condition . But visual field is not the only factor affect the result, the combination of stimuli type, speed and subject group chosen will all influence the intensity they perceived, the best way is to measure subjects' vection intensity according to existing scale. And our result could provide a way to explain the activity change measured in V1. But because the limitation of resource, we could not design experiment replicate all former studies, the result here could only provide an speculation.

When analyze the correlation in different stimuli condition, we found that the correlation only exists for linear vection condition, not for the two circular vection conditions. We may refer this problem to the duration of vection for all the three conditions and the perception status reverse. In linear vection condition, the vection perception was more stable so the status change frequency was less, and during each vection session, there was enough time for attention attenuation and gain back, so we could see significant regulation result. And when refer to study done by (Deutschländer et al. 2004), who also found significant brain activity increase in early visual area when compare LV condition with CV condition. They thought depth perception may play a role here When extend to our study, other factor like vection compatibility may also work for that because linear vection is more common in our daily experience.

In the former study, Thilo et al. found that N70 amplitude significantly decrease in vection condition compare to no vection condition (Thilo, Kleinschmidt & Gresty 2003b). The time range of this N70 is close to the N1 component in this study, for which the time range is 100ms – 200ms, the latency difference may cause by dots stimulation we used, which contain more information than windmill for visual perception, so a latency increase caused by basic information processing is expected for our result. We didn't find the significant decrease in our rotating windmill study, one major reason is the stimuli difference, we changed the visual field of the stimulus. And in order to get similar vection intensity compare to the other two stimuli, we also modified the stripe number in the windmill stimuli. These changes may both affect the visual perception process and generate different ERP component.

4.7 Summary

In this study, we studied the effect of vection (both linear vection and circular vection) on the visual perception process. We wanted to use a non-intrusive way to study the influence of vection on visual processing, so we chose EEG as a method and studied the effect of vection on the perception of central checkerboard. We made the hypothesis that brainwave measured at the early visual area would be affected by perception status change, and this effect would express through the change of ERP component properties.

We found that there is a correlation between vection intensity/duration and N1, N2 components amplitude (average among O1, Oz and O2 electrodes) change between different perception statuses in linear vection condition (averaged amplitude in no-vection condition condition minus averaged amplitude in vection condition condition). According to former studies, we infer this phenomenon may cause by combined effect of feedback regulation and subjective attention control.

In the next stage, we want to study the effect of different vection intensity within subject to see whether brainwave will be affected by perceived vection intensity.

CHAPTER 5 EXPERIMENT TWO: PRIMARY VISUAL CORTEX BRAINWAVE SIGNATURE UNDER DIFFERENT VECTION INTENSITY CONDITION (WITHIN SUBJECT COMPARISON)

5.1 Motivation

In experiment 1, we studied the effect of both linear vection and circular vection on the perception of checkerboard. Finally, we had two main findings:

- N2 amplitude (average among O1, Oz and O2 electrodes) shows a significantly decrease when compare peripheral movement condition with stationary condition. This means that N2 component reflect some underlying activities that related to background movement perception.

- There is a correlation between vection intensity/duration and N1, N2 components amplitude (average among O1, Oz and O2 electrodes) change between different perception status in linear vection condition (averaged amplitude in no-vection condition no-vection condition minus averaged amplitude in vection conditionvection condition). This could be explained by the co-effect of feedback regulation from top brain area and subjective attention control.

In experiment 1, however, we used between-subject analysis, so this is only the tendency shows in a group of people with different perceived vection intensity towards linear moving dots. We then were curious about what will happen for the individual brain. How will brainwave be affected by perceived vection intensity if we could manipulate vection intensity for the same brain?

In this experiment 2, we tended to extend the experiment 1 but only focus on linear vection. We wanted to see how individual brainwave changes in response to the vection of different intensity.

5.2 Introduction

It was proved that spatial-selective attention could operate as early as about 100ms after stimulus presentation. Luck et al. argued that N1 might reflect the orienting of attention towards task-relevant stimuli. It was found that N1 amplitude progressively increased with greater attentional allocation to the eliciting stimuli (Herrmann & Knight 2001).

Kenneth Vilhelmsen et al. used EEG to study forward-backward linear vection. Low, medium and high speeds were used to find the effect of speed. Significant differences in N2 latencies and peak amplitudes were found between the three speeds of visual motion in parietal P3 and P4 electrodes. As motion speed increased, peak latency increased while peak amplitude decreased (Vilhelmsen et al. 2015). They said this might cause by neuron synchronization towards their sensitive speed. Considering they didn't measure vection intensity, we could not generate conclusion how brainwave activity is affected by vection intensity.

Keshavarz and Berti used black and white vertical stripes in the central and peripheral visual field to induce vection, and it appeared to provide evidence that the N230 at O1 and O2 were more pronounced for stronger linear vection (LV). But the trial duration they used was too short to permit vection generation. Further study still need to prove this point of view (Keshavarz & Berti 2014).

5.3 Hypothesis

Base on the first experiment, we made the following hypothesis that there is a correlation between vection intensity/duration and component amplitude change (averaged amplitude in no-vection condition minus averaged amplitude in vection conditionvection condition) within subject. That is for individual, their brainwave will change as their perceived vection intensity differs.

5.4 Method

5.4.1 Experiment Design

For simplicity and concentration, control conditions were removed. We used two stimuli of different speeds and displayed the randomized 100-second trial for sixteen times each stimulus to get enough data point for further analysis.

In the later processing stage, we grouped every two or four trials together to generate one data point. Choosing of the group methods depended on the valid event epoch number of each perception condition in each trial. We grouped them and made sure that for each event, there were more than one hundred valid epochs.

5.4.2 Subjects

According to the requirement of the experimental design, we filtered the subjects using a test study before the formal EEG experiment. Subjects were recruited through email or campus forum. Totally, twenty-eight subjects (twelve females and sixteen males) participated in the test. They all had normal or corrected to normal vision, no known visual related illness history and not receiving any medical treatment during the experiment period. They were naive to the aim of this experiment and large part of them didn't attend to similar experiment before.

In the test study, we select subject base on the following criteria. Because we want to make sure they have vection for both the two stimuli and their number of ERP events in each perception condition is suitable for further study (At least 100 events in each condition to do average). At the same time, we need to make sure that they can distinguish those two stimuli so that we can study the effect of vection intensity on brain wave (it doesn’t matter which stmilus they thought is stronger).

1. Don’t have too weak vection for the weaker stimulus, that is, their reported vection intensity should be larger than 0 and their vection duration during that 30 second should be at least 20% of the time;

2. Don’t have too strong vection for the stronger stimulus, that is, their reported vection intensity should be less than 10 and their vection duration during that 30 second should be at most 20% of the time;

3. Difference between intensity of those two stimuli should be as least 1.

Finally, fourteen of them (Average age 23.43 years old with standard deviation of 2.59. Eight males and six females) passed the test and proceeded toward the EEG experiment.

The reasons for those who were excluded for further experiment are listed below:

1. Too weak vection for the weaker stimuli (Subject 8, Subject 10, Subject 13, , Subject 26)

2. Too strong vection for the stronger stimuli (Subject 5, Subject 23)

3. No perceived intensity difference for the two stimuli (Subject 6, Subject 11, Subject 12, Subject 15, Subject 21, Subject 22, Subject 25)

4. Subject 20 is eliminated because her hair is too long and thick

Before the start of EEG experiment, the fourteen subjects were asked to sign the consent form in compliance with the declaration of Helsinki. The compensation for training and formal experiment was 50HKD/hour. The experiment was approved by the Human Subject and Research Ethics Committee at the Hong Kong University of Science and Technology (HKUST).

5.4.3 Visual Motion Stimuli

To be more focus, we only used the linear translating dots stimulus in this experiment. Chapter 3 already explained the parameters of this stimulus in detail.

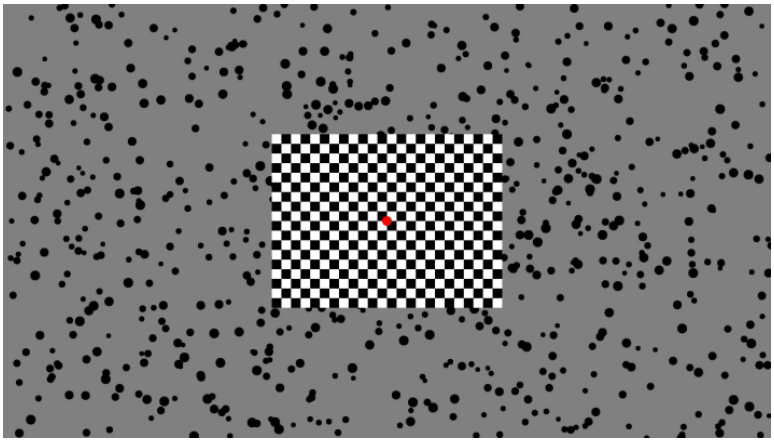


Figure5- 1 Experimental Stimulus

Different from experiment 1, we modulated the speed of the peripheral moving dots hoping to generate different intensity vection. We chose 5°/s and 45°/s left to right translating speed in this experiment.

5.4.4 Electrophysiology

Electrophysiological data acquisition was carried out on a NuAmps 40 channel system (Neuroscan Inc.). There were 32 Ag/AgCl electrodes attaching to a 32-channel Quik-Cap (Compumedical NeuroScan). 30 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) were arranged according to a modified international 10–20 system, and 2 reference electrodes (A1 and A2) were placed on left and right mastoid bones. 4 channels were used for measuring horizontal and vertical Electro-Oculogram. The sampling rate was 1 kHz with 22-bit A/D resolution. Inter-electrode impedance was always kept below 10 kΩ.

5.4.5 Procedure

The test session toke about half an hour. It aimed at detecting subjects' sensitivity to different visual motion stimuli. The test part contained all the stimuli displayed in the formal EEG experiment, that were stimuli with peripheral dots translating left to right at the speed of 5°/s and

45°/s. This test session was similar to the training session in experiment 1. Each trial lasted for 30 seconds. The procedures show as below:

- Brief introduction and educate subjects about vection
- Show welcome page and task introduction on the screen
- Play visual stimulus animation while subjects were asked to indicate their perception using keyboard at the same time
- End of the visual stimulus, subjects were reminded to verbally report their vection intensity

There were five trials for each stimulus, so in total there were ten trials. Between each trial, subjects were asked to close their eye and rest for 1 minute.

After this test, experimenter would look into the intensity as well as the duration data and rejected the subjects on the following criteria:

- Have too weak vection for the weaker visual stimulus (vection duration less than 20% of the whole trial length)
- Have too strong vection for the stronger visual stimulus (vection duration exceeds 80% of the whole trial length)
- The perceived vection intensity of those two stimuli were similar (the difference between the averaged vection intensity was less than one)

Then, qualified subjects would go through the preparation process and entered into the EEG experiment.

The main EEG experiment procedure was similar to experiment 1. The whole experiment consists of two conditions (5°/s linear translating condition and 45°/s linear translating

condition). Total length of each condition was 1600 seconds and divided into sixteen separate trials. All the thirty-two experiment trials were displayed in a random order.

During each experiment block, subjects were instructed to report their perception status using the keyboard. When they have self-motion feeling, they should press left arrow key once and release, while they have object-motion feeling, they should press right arrow key once and release.

After each trial, there was a screen indication remind them to report a vection intensity verbally according to vection scale. Then they were asked to close their eye and rest for two to three minutes until they are good enough to start the next trial.

5.5 Data Analysis

Before analysis, we grouped every two or four trials together to generate one data point. Choosing of the group methods depended on the valid event epoch number in each trial. We grouped them to make sure that for each event, there were more than one hundred valid epochs.

The continuous EEG recorded data was windowed with a pre-stimulus baseline of 50ms before pattern onset, and a 400ms post-stimulus epoch. Then epoch within each perception status was grouped to calculate averaged ERP. The five epochs proceeding as well as following each transition were excluded to avoid contamination of the signal by components related to transitional states and their reporting action.

All the channels were re-referenced to Fz and signal with frequency larger than 30Hz and smaller than 0.1Hz was filtered offline.

The average amplitude and latency of the ERP waveforms was measured at primary visual cortex (average among O1, Oz, and O2) for four different components: N1 (posterior), P2, N2 and P3. These components were measured for each individual (the following are in millisecond, N1: 100-200; P2: 150-200; N2: 200-300; P3: 250-350) using ERPLAB. Then we run between subjects paired t-test to see the change of component amplitude and latency change.

5.6 Result

5.6.1 Between-Subject Analysis

In experiment 1, we found that the vection duration and intensity was positively linear correlated with N1 and N2 component amplitude change (object-motion – self-motion) in significant level ($\alpha<0.05$) or marginal significant level ($0.05<\alpha<0.1$).

In this experiment 2, we found that this correlation still exists in 45°/s condition but not for 5°/s condition. Here section 5.6.1.1shows the scatter plot for all fourteen subjects in 45°/s translating dots condition and the statistical analysis result.

5.6.1.1 45°/s Linear Translating Dots Condition

Figure 5-2 four scatter plots show the relationship between vection duration/intensity and N1, N2 components amplitude change. We could clearly see the correlation between vection duration and component amplitude change (object-motion – self-motion) while for vection intensity, the correlation was relatively weak.

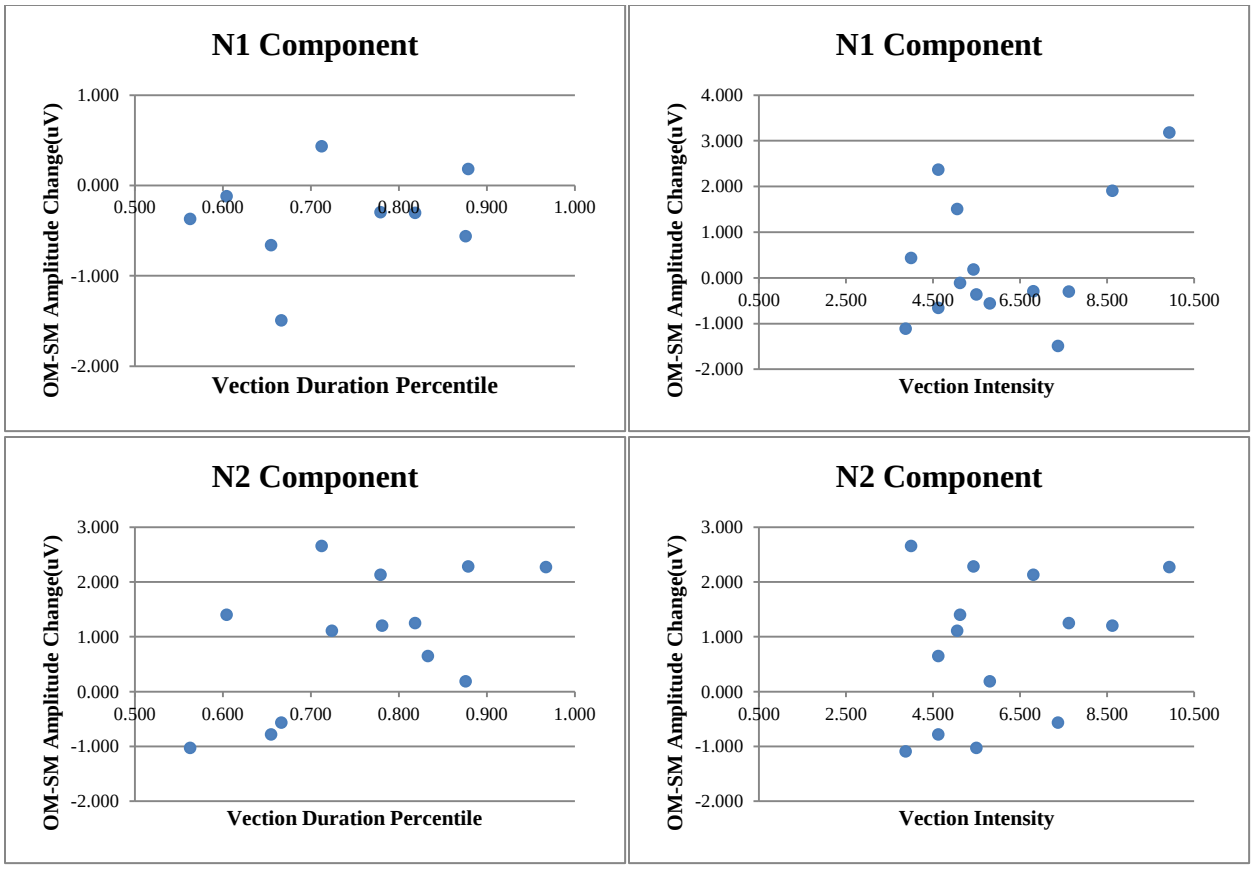


Figure5- 2 Relationship between Vection Duration Percentile/Intensity and N1, N2 Amplitude Change

The following table 5-1 shows the Pearson Correlation Coefficient and related p value of the relationship between vection duration percentile/intensity and N1. N2 component amplitude change (no-vection condition minus vection condition) in 45°/s condition.

Table5- 1 Statistical Result of Pearson Correlation Analysis in 45°/s Translating Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.5876	0.027
		N2	r=0.6415	0.013
Vection Intensity		N1	r = 0.3898	0.17
		N2	r = 0.29	0.31

No significant correlation in intensity may cause our chosen of a specific group of subjects. In experiment 1, all subjects are involved in the EEG experiment without any filtering. However, in this experiment, in order to compare between different stimuli, we chose those subjects with distinguishable intensity for the two stimuli conditions. Subjects with no vection or too strong vection for either of the two stimuli were eliminated during EEG experiment. In the EEG experiment stage, we only kept half of the subjects (14 out of 28).

The following table 5.2 shows the result of correlation between vection duration and components' amplitude change of both experiment 1 and 2. We can see there is high consistency of the N1 and N2 here.

Table5- 2 Correlation Coefficient between Vection Duration and Amplitude Difference Object-motion - Self-motion (Average among O1, Oz, O2)

Correlation Coefficient (Significance Level)	N1	N2
Experiment 1 (14 Subjects)	r = 0.5442 (0.04)	r = 0.316 (0.27)
Experiment 2 (14 Subjects)	r = 0.5876 (0.027)	r = 0. 6415 (0.013)

Table5- 3 Correlation Coefficient between Vection Intensity and Amplitude Difference Object-motion - Self-motion (Average among O1, Oz, O2)

Correlation Coefficient (Significance Level)	N1	N2
Experiment 1 (14 Subjects)	r = 0.6519 (0.01)	r = 0.5145 (0.06)
Experiment 2 (14 Subjects)	r = 0.3898 (0.17)	r = 29 (0.31)

5.6.1.2 5°/s Linear Moving Dots Condition

The following table 5-3 shows the Pearson Correlation Coefficient and related p value of the relationship between vection duration percentile/intensity and N1. N2 component amplitude change (no-vection condition minus vection condition) in 5°/s condition.

Table5- 4 Statistical Result of Pearson Correlation Analysis in 5°/s Translating Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.1395	0.63
		N2	r = -0.0848	0.77
Vection Intensity		N1	r = 0.1391	0.64
		N2	r = -0.2117	0.47

We can see here that the correlation between vection duration/intensity and component amplitude change in 45°/s condition doesn't exist in this 5°/s condition. This may cause by the vection intensity difference or the stimuli parameters difference.

5.6.2 Within-Subject Analysis

There were two experiment conditions, and for each of those two conditions there were 16 repetitions. Time length of each repetition session was 100s.There were at most 200 events in each trial session.

For all the subjects, the data processing procedures were the same as below. After combine EEG data with behavior data, all the data were re-referenced to Fz offline and signal below 0.1Hz and above 30Hz were filtered. Then event epochs were extracted with length of 450ms and 50ms before the reversal action was treated as baseline to do baseline removal. Then, a moving window with 200ms length and 100uV threshold was used to remove eye blink and eye movement artifact.

Five event epochs before and after perception transition were removed from data analysis to avoid action effect. Then all the events in no-vection condition and vection condition were grouped to average and analyze separately.

In order to balance between sample size and signal to noise ratio, there were two ways to group trials together. One way was to group every two trials, that is, If we number each trial from 1 to 16, we group 1-2, 3-4, 5-6, 7-8, 9-10, 11-12, 13-14 and 15-16 together. Another way was to group every four trials, that is, if we number each trial from 1 to 16, we group 1-4, 5-8, 9-12, and 13-16 together.

5.6.2.1 Correlation between Vection Intensity/ Duration and ERP Component Amplitude/ Latency

There were several things we were interested during analysis process: Difference in ERP component between no-vection condition and vection condition (average among O1, Oz and O2), difference between left lobe and right lobe (difference in ERP component within same perception status, ERP components difference between objection-motion perception and vection condition across difference lobes), correlation between ERP components properties (latency and amplitude) and vection intensity and duration (behavior index), difference and common properties across subjects.

The following tables summarize the result of all the subjects (relationship between vection duration/ intensity and component amplitude/latency change, difference between left and right lobe).

Table5- 5 Relationship between Vection Duration and Component Amplitude Change

Subject No.	Group Method	Object-motion - Self-motion				Left Lobe - Right Lobe(O1-O2)			
		N1	P2	N2	P3	N1	P2	N2	P3
1	4	-	-	+	+	-	+	-	+
2	4	+	-	+	+	+	+	-	+
3	4	+	+	+	+	+	-	+	+
4	4	+	-	+	+	+	+	+	+
7	2	+	+	+	+	-	+	-	+

9	4	+	-	+	+	+	-	+	-
14	4	-	+	+	+	-	+	-	-
16	4	-	+	-	+	+	-	+	-
17	4	+	+	+	+	+	-	-	-
18	4	-	-	+	+	-	-	-	+
19	2	+	-	+	+	+	+	-	-
24	4	+	-	+	+	+	+	-	+
27	4	-	+	+	+	-	+	-	+
28	4	-	-	+	+	+	+	+	+

+ means positive correlation between vection duration and component amplitude change

- means negative correlation between vection duration and component amplitude change

Pink means significant correlation, yellow means marginal significant correlation

Table5- 6 Relationship between Vection Intensity and Component Amplitude Change

Subject No.	Group Method	Object-motion - Self-motion				Left Lobe - Right Lobe(O1-O2)			
		N1	P2	N2	P3	N1	P2	N2	P3
1	4	-	-	+	+	-	+	-	+
2	4	+	+	+	+	+	-	+	+
3	4	+	+	+	+	+	-	+	+
4	4	+	-	+	+	+	+	+	+
7	2	+	+	-	+	+	+	+	-
9	4	+	+	+	+	+	-	+	-
14	4	+	+	+	+	-	+	-	-
16	4	+	+	+	+	-	+	+	+
17	4	+	+	+	+	-	-	-	-
18	4	+	+	+	-	-	-	+	-
19	2	+	-	+	+	+	+	-	+
24	4	+	-	+	-	-	-	-	-
27	4	-	-	+	+	-	-	-	+
28	4	-	-	-	+	+	+	+	-

+ means positive correlation between vection duration and component amplitude change

- means negative correlation between vection duration and component amplitude change

Pink means significant correlation, yellow means marginal significant correlation

Table5- 7 Relationship between Vection Duration and Component Latency Change

Subject No.	Group Method	Object-motion - Self-motion				Left Lobe - Right Lobe(O1-O2)			
		N1	P2	N2	P3	N1	P2	N2	P3

1	4	-	-	-	-	-	-	+	-
2	4	-	-	-	+	+	+	+	-
3	4	-	-	+	+	+	-	-	+
4	4	+	+	-	-	-	-	+	-
7	2	-	+	-	+	+	-	+	-
9	4	-	-	-	-	-	-	-	+
14	4	-	-	+	-	+	-	-	-
16	4	+	+	+	+	+	+	+	+
17	4	+	+	+	+	+	-	-	-
18	4	-	-	-	-	+	+	-	+
19	2	+	+	+	+	+	-	-	-
24	4	+	-	-	+	+	-	-	-
27	4	+	-	+	-	+	-	-	+
28	4	-	-	+	+	-	+	+	-

+ means positive correlation between vection duration and component amplitude change

- means negative correlation between vection duration and component amplitude change

Pink means significant correlation, yellow means marginal significant correlation

Table5- 8 Relationship between Vection Intensity and Component Latency Change

Subject No.	Group Method	Object-motion - Self-motion				Left Lobe - Right Lobe(O1-O2)			
		N1	P2	N2	P3	N1	P2	N2	P3
1	4	+	-	-	+	+	-	+	-
2	4	-	-	-	+	+	+	+	-
3	4	-	-	+	+	+	+	+	+
4	4	+	+	-	-	+	-	+	-
7	2	-	+	+	+	-	+	+	-
9	4	-	+	-	+	-	+	+	+
14	4	-	+	+	+	+	-	-	-
16	4	+	+	+	-	-	+	-	-
17	4	+	+	+	+	+	-	-	-
18	4	-	-	-	-	-	-	+	+
19	2	-	-	+	+	+	-	-	-
24	4	-	-	+	-	-	+	+	+
27	4	-	-	+	+	+	-	-	+
28	4	-	-	+	-	-	-	+	+

+ means positive correlation between vection duration and component amplitude change

- means negative correlation between vection duration and component amplitude change

Pink means significant correlation, yellow means marginal significant correlation

We can find that compare to relationship between vection duration/intensity and component amplitude change, the relationship between vection duration/intensity and component latency change is of less regular pattern and shows less consistency with the result of experiment 1. So the difference between latency may cause by subjects' variance and of less common rule. We will focus more on amplitude change in the following analysis.

5.6.2.2 Details of Individual Subjects

In the following part, the condition of each subject would be explained in detail, including why some of them were exclude, how their data were grouped, the detail statistical analysis of each subject etc. Considering latency data are less consistent and of great variance, we only show the amplitude change data here.

Subject 1

Four Trials Grouped

For subject 1, in general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

we found there is no significant correlation between vection intensity/duration and the component amplitude change, also no significant correlation between the vection intensity/duration and the amplitude difference among left and right brain lobe (left – right).

Subject 2

Four Trials Grouped

For subject 2, after artifact reduction, there are around 700 events for each block. But because the frequent perception transition and strong vection feeling from ¼th part of the experiment, in 45°/s condition, there are few object-motion events even if we grouped every 4 trials together (for the last block, only 12 object-motion event repetitions there).

After doing within-subject block analysis, we found that the vection duration and intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 9 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 2

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.7869	0.02
		N2	r = 0.6478	0.08
Vection Intensity		N1	r = 0.8693	0.005

But no significant correlation were found for left-right lobe difference

Subject 3

Four Trials Grouped

For subject 3, after artifact reduction, there are around 500 events for each block (Because the perception transition is more frequent for this subject, the valid events is fewer than others). In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection duration and intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 10 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 3

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.9147	0.001
		N2	r = 0.7194	0.04
Vection Intensity		N1	r = 0.8433	0.009
		N2	r = 0.5833	0.129

However, there is no significant correlation between vection duration or intensity with the amplitude difference among left and right brain lobe (left – right).

Subject 4

Four Trials Grouped

For subject 4, after artifact reduction, there are around 300 events for each block. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 80 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection duration and intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 11 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 4

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N2	r = 0.6061	0.1
Vection Intensity		N2	r = 0.6157	0.1

However, there is no significant correlation between vection duration or intensity with the amplitude difference among left and right brain lobe (left – right).

Subject 5

Subject 5 was eliminated in the test process because he has too strong vection for the 45°/s stimuli condition. His vection condition feeling start several seconds after the stimuli start and it won't fade in the whole trial.

Subject 6

Subject 6 was eliminated in the test process because her vection condition feeling start several seconds after the stimuli start and it won't fade in the whole trial for both 5°/s and 45°/s condition. And her feeling about the intensity of these two stimuli is similar so we can't decide which stimuli is stronger to do further analysis.

Subject 7

Two Trials Grouped

For subject 7, after artifact reduction, there are around 320 events for each block. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that vection duration/intensity correlates with the amplitude change and difference among left and right brain lobe (left – right).

Table5- 12 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 7

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N2	r = 0.5028	0.047
Vection Intensity		N1	r = 0.493	0.052
		N2	r = -0.458	0.074

Table5- 13 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 7

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Left-Right Amplitude Difference	N2	r = -0.4685	0.067

Subject 8

Subject 8 was eliminated in the test process because he has no vection for 45°/s condition and only very week vection for 5°/s condition.

Subject 9

Four Trials Grouped

For subject 9, after artifact reduction, there are around 700 events for each block. in general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

We found that vection duration/intensity correlates with the amplitude change and difference among left and right brain lobe (left – right).

Table5- 14 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 9 for Four Trials Grouped Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.6284	0.095
Vection Intensity		N1	r = 0.6501	0.08

Table5- 15 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 9 for Four Trials Grouped Condition

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Left-Right Amplitude Difference	N2	r = 0.6802	0.06
Vection Intensity		N2	r = 0.7214	0.04

Subject 10

Subject 10 was eliminated in the test process because he has no vection for 5°/s condition and only very week vection for 45°/s condition.

Subject 11

Subject 11 was eliminated in the test process because his perceived vection intensity of those two conditions is of no difference.

Subject 12

Subject 12 was eliminated in the test process because his perceived vection intensity of those two conditions is of no difference.

Subject 13

Subject 13 was eliminated in the test process because she has no vection for 5 °/s and 45°/s condition.

Subject 14

Four Trials Grouped

For subject 14, after artifact reduction, there are around 550 events for each block. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection intensity and duration correlates with the amplitude difference among left and right brain lobe (left – right).

Table5- 16 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 14

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	P3	r = -0.7698	0.025
Vection Intensity		N2	r = -0.7422	0.035
		P3	r = -0.9084	0.001

Also there is marginal significant correlation between vection duration or intensity with the amplitude difference among left and right brain lobe (left – right).

Table5- 17 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 14

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Intensity	Left-Right Amplitude Difference	N1	r = -0.6832	0.06

Subject 15

Subject 15 was eliminated in the test process because his perceived vection intensity of those two conditions is of no difference. And his vection duration is too long (nearly 90% of the trial) in each condition.

Subject 16

Four Trials Grouped

For subject 16, after artifact reduction, there are around 300 events for each block (Because the perception status transition is too frequent for this subject). And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

We found there is no significant correlation between vection intensity/duration and the component amplitude change, also no significant correlation between the vection intensity/duration and the amplitude difference among left and right brain lobe (left – right).

Subject 17

Four Trials Grouped

For subject 17, after artifact reduction, there are around 400 events for each block (Because the perception status transition is too frequent for this subject). And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

We found there is no significant correlation between vection intensity/duration and the component amplitude change, also no significant correlation between the vection intensity/duration and the amplitude difference among left and right brain lobe (left – right).

Subject 18

Four Trials Grouped

For subject 18, after artifact reduction, there are around 600 events for each. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis,

We found there is no significant correlation between vection intensity/duration and the component amplitude change, also no significant correlation between the vection intensity/duration and the amplitude difference among left and right brain lobe (left – right).

Subject 19

Two Trials Grouped

For subject 19, after artifact reduction, there are around 300 events for each block. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found marginal significant correlation between vection intensity/duration and the component amplitude, but no significant correlation between the vection intensity/duration and the amplitude difference among left and right brain lobe (left – right).

Table5- 18 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 14

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N2	r = 0.4506	0.08
Vection Intensity		N1	r = 0.4793	0.06
		N2	r = 0.4682	0.067

Subject 20

Subject 20's sensitivity towards the stimuli is suitable to do the experiment. Her perceived vection is stronger (the duration is longer and intensity is larger) for 45 °/s than 5 °/s condition. But her hair is too long and thick to do the EEG experiment. So this subject was eliminated in the main experiment part.

Subject 21

Subject 21 was eliminated in the test process because his perceived vection intensity of those two conditions is of no difference.

Subject 22

Subject 22 was eliminated in the test process because his perceived vection intensity of those two conditions is of no difference.

Subject 23

Subject 23 was eliminated because her perceived vection for the stronger visual stimulus was too strong and the vection duration exceeded 90% of the trial duration.

Subject 24

Four Trials Grouped

For subject 24, after artifact reduction, there are around 700 events for each. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 19 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 24

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Intensity	Component Amplitude	N2	r = 0.8907	0.003

Subject 25

Subject 25 was eliminated in the test process because her perceived vection intensity of those two conditions is similar; the averaged intensity difference is less than 1.

Subject 26

Subject 26 was eliminated in the test process because she had no vection for the weaker visual stimulus.

Subject 27

Four Trials Grouped

For subject 27, after artifact reduction, there are around 600 events for each. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 20 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 27

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Intensity	Component Amplitude	N1	r = -0.8104	0.01

Also, vection duration also correlates with the amplitude difference among left and right brain lobe (left – right).

Table5- 21 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 27

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Left-Right Amplitude Difference	N1	r = -0.9388	<0.01

Subject 28

Four Trials Grouped

For subject 28, after artifact reduction, there are around 650 events for each. And the number of self-perception events and no-vection condition events are depending on the vection duration. In general, for each perception status, there are at least 100 events to generate the averaged event-related brain wave.

After doing within-subject block analysis, we found that the vection duration/intensity is linearly correlated with component amplitude change (object-motion – self-motion).

Table5- 22 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 28

Variable 1	Variable 2 (Component)		Pearson Correlation Coefficient	Significance Level
Vection Duration	Component Amplitude	N1	r = 0.816	0.01
		P2	r = -0.6757	0.07
Vection Intensity		N1	r =0.6587	0.08

Also, vection duration also correlates with the amplitude difference among left and right brain lobe (left – right).

Table5- 23 Relationship between Vection Parameters and Component Amplitude Parameters of Subject 28

Variable 1	Variable 2	Pearson Correlation	Significance

	(Component)		Coefficient	Level
Vection Duration	Left-Right Amplitude Difference	P2	r = 0.8246	0.01
		P3	r = 0.7212	0.04

5.7 Discussion

In this experiment 2, we used two translating visual stimuli to generate vection of different intensity, one with the speed of 5°/s, another one with the speed of 45°/s. Finally, we found that the within subject's correlation relationship is not consistent for all the subjects (n=14). For nearly half of the subjects (n=8), there is a correlation for at least one of the two components (N1and N2). For other subjects (n=6), however, we didn't find significant correlation. One major reason maybe we don't have enough repetition to increase signal to noise ratio. Another reason maybe for different subjects, they have different vection threshold so that their perceived vection intensity have different distribution. Even though we have chosen subjects base on some criteria, we couldn't guarantee that the stimuli set is suitable for every subjects to generate vection of similar intensity.

Consistent with experiment 1, we found same correlation between N1, N2 component amplitude change and vection intensity and duration for 45°/s condition between subjects. But for 5°/s, we found no significant correlation. Although we manipulate the subjects, the correlation does still exist, this could double check result of our experiment 1.

5.8 Summary

Following experiment 1, in this study, we studied the effect of linear vection on the visual perception process for individual brain. Linear translating stimuli similar to experiment 1 were used but with two peripheral translating speed 5°/s and 45°/s. Our intention was use these different stimuli to generate different vection intensity within same subject so we could find out the effect of vection intensity on ERP components. Start from this point, we filtered subjects at the test stage and only reserved those subjects having obvious different perception to those stimuli. Finally, we chosen fourteen subjects out of twenty-eight went into EEG experiment.

The result is not good enough for we only found correlation between subject and brainwave activity in 57% of those subjects. This may cause by the limitation of experimental design.

Even we have filtered the subject, we still found that correlation between vection intensity/duration and N1, N2 components. This will further prove the result of experiment 1.

CHAPTER 6: CONCLUSION, LIMITATIONS AND FUTURE WORKS

6.1 Conclusion and Contribution

In this thesis, we studied the effects of vection on brainwave activity at V1. The main finding is that there is a correlation between vection intensity or duration with ERP component (N1 and N2 at occipital lobe) amplitude differences between no vection and linear vection. The higher the vection intensity (or the longer the vection duration), the larger the difference in ERP amplitudes between no vection and vection. This finding could be explained by the well-studied 'feedback regulation' mechanism. Through the 'feedback regulation', activities in V1 will be inhibitede resulting in reduction of N1 and N2 components amplitude of ERP. This finding has potential implications on the potential functional impairment of vection. In other words, normal visual function is expected to be affected in the presence of vection.

To further explain the baseline shift in ERP components amplitude reported in this thesis, a hypothetical explanation using the established cortical 'attention control' mechanism was proposed and discussed. In summary, the combination of these two mechanisms could well explain our finding and implies that the presence of vection significantly affect the brain activities in V1 and could potentially affect normal visual tasks.

This thesis also studied how vection intensity would affect individual brainwave activity. Only 60% of the subjects (n=14) exhibit the correlation relationship between vection intensity or duration and the component amplitude difference between the two vection status. While this could be explained by inter-subject variability, it also indicates a potential variability in susceptibility of visual performance degradation due to vection. In other words, some individuals will be affected more than others. Further research is desirable.

The main contribution of this thesis is that we found a significant correlation between behavior and V1 related brainwave activity under linear vection condition. This is new and original.

Moreover, our study gave a possible speculation on why former studies have inconsistent result on the V1 field. This could further help to enhance our understanding on vection perception.

6.2 Limitations, remaining problems and future work

However, the vection we studied was only horizontal left to right vection, the well-studied up-down, forward-backward vections were not involved in this study. We only used one linear moving stimulus and two speeds in these two studies. Therefore, we can't say that this is the situation for all linear vection condition.

Future studies on other linear vection condition using various stimuli are needed to find whether this correlation is universal for all linear vection condition. If that, an objective ERP vection indicator will be found for further vection studies.

Moreover, considering the limitation of experiment design, we could only draw conclusion that primary visual field activity is affected by vection, but this result need to be double proved and further study by neuroimaging or other high spatial resolution methods are needed to locate more accurate source generator.

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APPENDIX A: NUAMP AMPLIFIER SEPCIFICATION

Analog inputs	40 unipolar (bipolar derivations can be computed)
Sampling frequencies	1000 Hz per channel, software selectable for all channels
Sampling method	40 channels sampled simultaneously
A/D resolution	22 bits
Full scale input range	±130 mV
Input impedance	Not less than 80 MOhm
CMRR	≥100 dB at 60 Hz
Input noise	0.7 μV RMS (4 μV peak-to-peak)
Bandwidth, 3dB down	From DC to 262.5 Hz, dependent upon sampling frequency selected
Interface	Universal Serial Bus (USB), full support for Plug-and-Play technology
Supported electrodes	• Gold, Ag/AgCl, Carbon electrodes with Touch Proof (DIN 42-802) style connectors • QuikCap Ag/AgCl electrodes with Plastic DSUB37F
Digital (TTL) inputs/outputs	Triggering through parallel port and built in trigger points (may not be possible with notebook computer; ask for details)
Quality control of electrode application	• Measurement of contact impedance (at frequency 30 Hz) in impedance mode • Constant monitoring of connection during recording
Isolation	Optical Signal Isolation
Display	16-letter LCD with background light, displaying amplifier status or electrodes with impedance greater than specified cutoff
Power supply and energy consumption	From USB (5V), in active mode current <= 500 mA, in standby mode current <= 20 mA
Electric safety level	According to EN60601-1(type BF), IEC601-1
Size (height x width x depth)	7.8 x 5.9 x 1.6 in. (198 x 151 x 40 mm)
Weight	1.3 lbs (570 grams)

APPENDIX B: TRAINING INSTRUCTION

Project Name: Brain Wave Signature Associated with Visual Motion Perception

Experimenter: ZHENG Jiayue (Joyce), email: jzhengaf@connect.ust.hk

Supervisor: Dr. Richard So, HKUST

Dear participant:

Thank you for participation in this visual perception training session. Please turn off your mobile phones during the whole experiment process.

This training session aims at giving you an experience of what self-motion (vection) and object-motion are. It will take about 15 minutes.

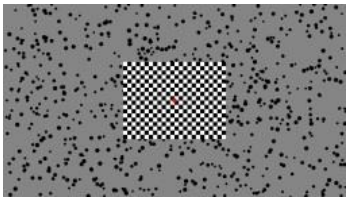
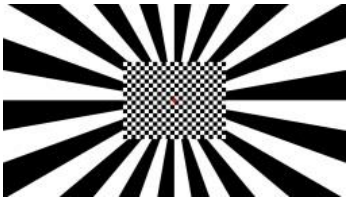
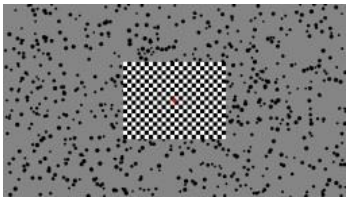
Sometimes what we see will cheat us. This is a situation most of us have experienced; you were in a stationary train. And there is a train just next to you. You were looking at the train. And when that nearby train pulled out the station, you had the illusion that your train was moving in the opposite direction. This is one example of illusion of self-motion (vection).

In the experiment, after you staring at moving patterns for a while, you may feel the moving of the pattern gradually slow down and this is a sign that you are starting to generate the illusion of self-motion.

Then, you may gradually start to feel the TV frame and yourself is tilting or even slowly moving toward the opposite direction in which the pattern are moving.

However, different individuals may have slightly different feelings, and take various length of time to induce the self-motion feelings. So take your time and there is no need to worry if you do not see the phenomenon in the beginning.

In this training session, you will see 3 different visual stimuli shown as following. They all compose of central visual stimuli and peripheral visual stimuli. The **central visual stimuli** are always a 24 ×18 flashing checkerboard. For different conditions, the **peripheral visual stimuli** will be rotating random dots, rotating windmill and linear moving random dots.

	Rotating Dots	Rotating Windmill	Linear Moving Dots
Pattern			

There is a red dot in the center of the screen, you need to stare at that dot all the time and try you best to avoid eye blink and eye movement.

You are asked to report your perception status using the keyboard while staring at the stimuli. **Press left-arrow once and release when you have self-motion feeling, press right-arrow once and release when you have object-motion feeling.** After each trial, you need to report your perceived self-motion (vection) intensity according to the following table to the experimenter and there is a screen hint to remind you.

Perception of self-motion (vection)	Your report
You feel like you are stationary and it is the dots which appear to be moving only.	0
You feel like you are moving a bit in the opposite direction of the dots, but the dots are moving more.	1-4
You feel like you are moving at the same speed as the dots but in the opposite direction of the dots.	5
You feel like you are moving a lot in the opposite direction of the dots and the dots are moving a bit.	6-9
You feel like you are moving in the opposite direction of the dots and the dots appear stationary.	10

You can ask to stop the experiment whenever you feel uncomfortable.

If you have any question about this experiment later, please feel free to contact Joyce at jzhengaf@connect.ust.hk

Thanks again for you participation!

APPENDIX C: EXPERIMENT ONE INSTRUCTION

Project Name: Brain Wave Signature Associated with Visual Motion Perception

Experimenter: ZHENG Jiayue (Joyce), email: jzhengaf@connect.ust.hk

Supervisor: Dr. Richard So, HKUST

Dear participant:

Thank you for participation in this visual perception experiment. Please turn off your mobile phones during the whole experiment process.

This experiment aims at measuring you brain wave when you are in different perception status. The whole experiment consists of three parts: (1) Preparation (2) Brain Wave Measurement (3) Ending. You will get compensation of **50HKD/h** for participation.

Preparation

Firstly, we will help you clean your head in order to remove your scalp oil.

After dried your hair, you can pick up a suitable electroencephalograph (EEG) Cap to wear. I will then inject conductive gel into the electrode space to reduce impedance.

Brain Wave Measurement

In this experiment you will see different visual stimuli moving in different way. All the conditions are shown in the following table.

<table>
<tr><th></th><th>Central Visual Field</th><th>Peripheral Visual Field</th><th>Status</th></tr>
<tr><td rowspan="2">Control Condition</td><td rowspan="5">Flashing Checkerboard</td><td>Grey background</td><td>Stationary</td></tr>
<tr><td rowspan="2">Windmill with 36 alternating black and white stripes</td><td>Stationary</td></tr>
<tr><td rowspan="3">Experiment Condition</td><td>Rotating</td></tr>
<tr><td rowspan="3">700 dots with different size randomly occupy the screen</td><td>Stationary</td></tr>
<tr><td>Rotating</td></tr>
<tr><td>Linear Moving</td></tr>
</table>

There is a red dot in the center of the screen, you need to stare at that dot all the.

You are asked to report your perception status using the keyboard while staring at the stimuli. **Press left-arrow once and release when you have self-motion feeling, press right-arrow once and release when you have object-motion feeling.**

Now we will give you a training session of the definition of self-motion and object-motion.

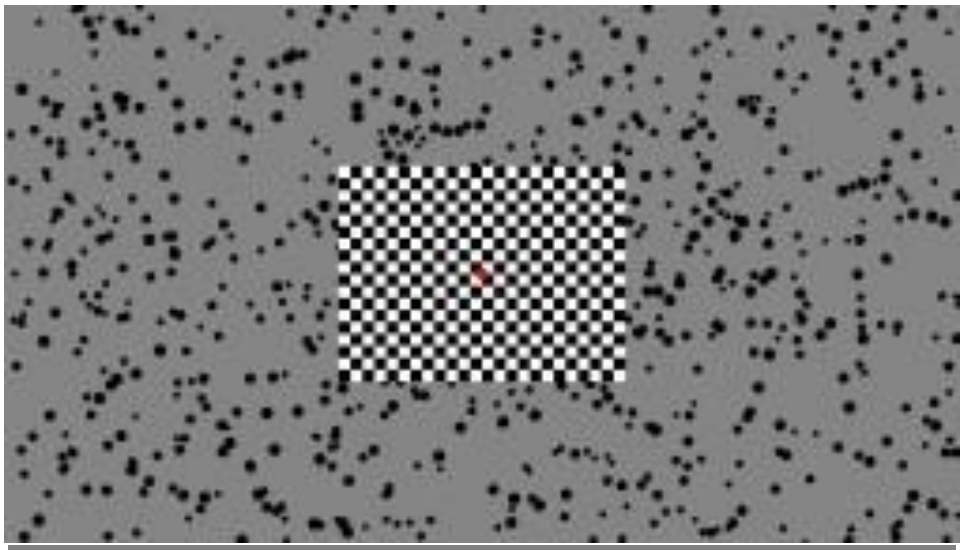
You can ask to stop the experiment whenever you feel uncomfortable.

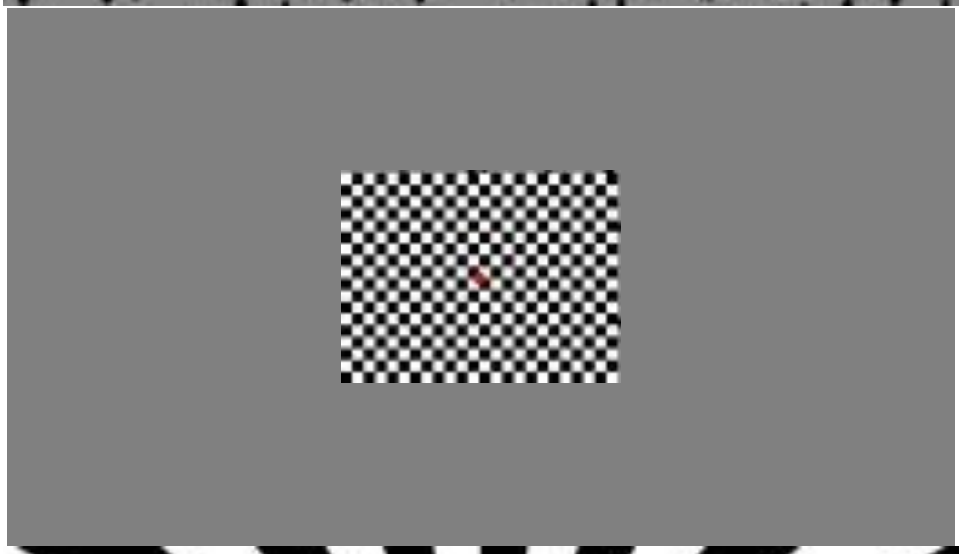
Ending

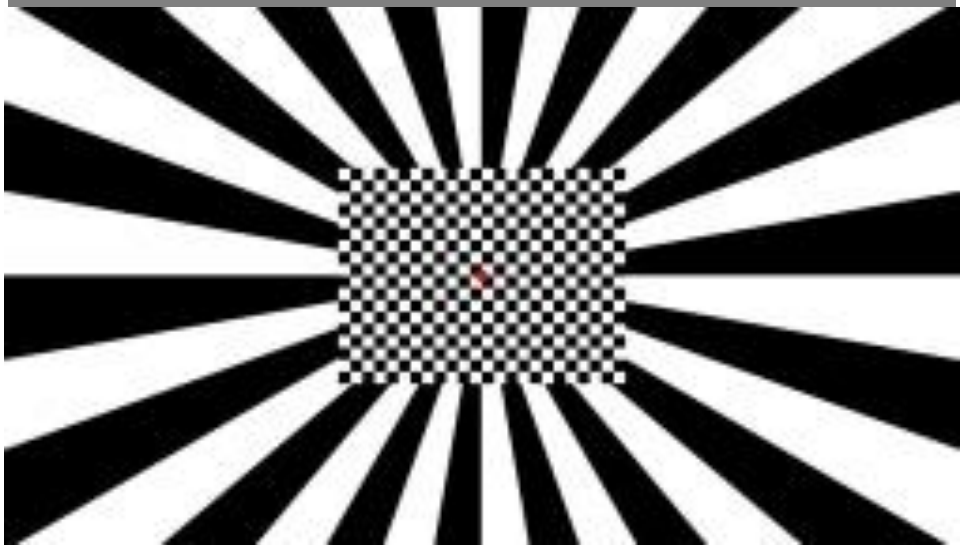
After the experiment, we will help you remove the conductive gel and clean you head.

If you have any question about this experiment later, please feel free to contact Joyce at jzhengaf@connect.ust.hk

Thanks again for you participation!







APPENDIX D: MOTION SICKNESS SUSCEPTIBILITY QUESTIONNAIRE SHORT-FORM (MSSQ-SHORT, KENNEDY ET AL. 1993)

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** ..... Years. *2.* Please State Your Sex (tick box) **Male** [ ]$_1$ **Female** [ ]$_2$

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Scoring the MSSQ- Short

Section A (Child) (Question 3)

Score the number of types of transportation not experienced (i.e., total the number of ticks in the 't' column, maximum is 9).

Total the sickness scores for each mode of transportation, i.e. the nine types from 'cars' to 'big dippers' (use the 0-3 number score key at bottom, those scores in the 't' column count as zeroes).

MSA = (total sickness score child) x (9) / (9 - number of types not experienced as a child)

Note 1. Where a subject has not experienced any forms of transport a division by zero error occurs. It is not possible to estimate this subject's motion sickness susceptibility in the absence of any relevant motion exposure.
Note 2. The Section A (Child) score can be used as a pre-morbid indicator of motion sickness susceptibility in patients with vestibular disease.

Section B (Adult) (Question 4)

Repeat as for section A but using the data from section B.

MSB = (total sickness score adult) x (9) / (9 - number of types not experienced as an adult)

Raw Score MSSQ-Short

Total the section A (Child) MSA score and the section B (Adult) MSB score to give the MSSQ-Short raw score (possible range from minimum 0 to maximum 54, the maximum being unlikely)

MSSQ raw score = MSA + MSB

Percentile Score MSSQ-Short

The raw to percentile conversions are given below in the Table of Statistics & Figure, use interpolation where necessary.

Alternatively a close approximation is given by the fitted polynomial where y is percentile; x is raw score
$y = a.x + b.x^2 + c.x^3 + d.x^4$
a = 5.1160923 b = -0.055169904
c = -0.00067784495 d = 1.0714752e-005

Table of Means and Percentile Conversion Statistics for the MSSQ-Short (n=257)

Percentiles Conversion	Raw Scores MSSQ-Short		
	Child Section A	Adult Section B	Total A+B
0	0	0	0
10	.0	.0	.8
20	2.0	1.0	3.0
30	4.0	1.3	7.0
40	5.6	2.6	9.0
50	7.0	3.7	11.3
60	9.0	6.0	14.1
70	11.0	7.0	17.9
80	13.0	9.0	21.6
90	16.0	12.0	25.9
95	20.0	15.0	30.4
100	23.6	21.0	44.6
Mean	7.75	5.11	12.90
Std. Deviation	5.94	4.84	9.90

Table note: numbers are rounded

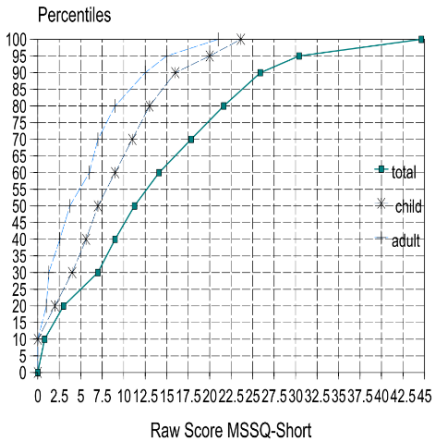


Figure: Cumulative distribution Percentiles of the Raw Scores of the MSSQ-Short (n=257 subjects).

Reference Note

For more background information and references to the original Reason & Brand MSSQ and to its revised version the 'MSSQ-Long', see:
Golding JF. Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness. **Brain Research Bulletin**, 1998; 47: 507-516.
Golding JF. (2006) Predicting Individual Differences in Motion Sickness Susceptibility by Questionnaire. **Personality and Individual differences, 41:** 237-248.

APPENDIX E: EXPERIMENT TWO INSTRUCTION

Project Name: Brain Wave Signature Associated with Visual Motion Perception

Experimenter: ZHENG Jiayue (Joyce), email: jzhengaf@connect.ust.hk

Supervisor: Dr. Richard So, HKUST

Dear participant:

Thank you for participation in this visual perception experiment. Please turn off your mobile phones during the whole experiment process.

This experiment aims at measuring you brain wave when you are in different perception status. The whole experiment consists of three parts: (1) Preparation (2) Brain Wave Measurement (3) Ending. You will get compensation of **50HKD/h** for participation.

Sometimes what we see will cheat us. This is a situation most of us have experienced: you were in a stationary train. And there is a train just next to you. You were looking at the train. And when that nearby train pulled out the station, you had the illusion that your train was moving in the opposite direction. This is one example of illusion of self-motion (vection).

In the experiment, after you staring at moving patterns for a while, you may feel the moving of the pattern gradually slow down and this is a sign that you are starting to generate the illusion of self-motion.

Then, you may gradually start to feel the TV frame and yourself is tilting or even slowly moving toward the opposite direction in which the pattern are moving.

However, different individuals may have slightly different feelings, and take various length of time to induce the self-motion feelings. So take your time and there is no need to worry if you do not see the phenomenon in the beginning.

Preparation

Firstly, I will help you clean your head in order to remove your scalp oil.

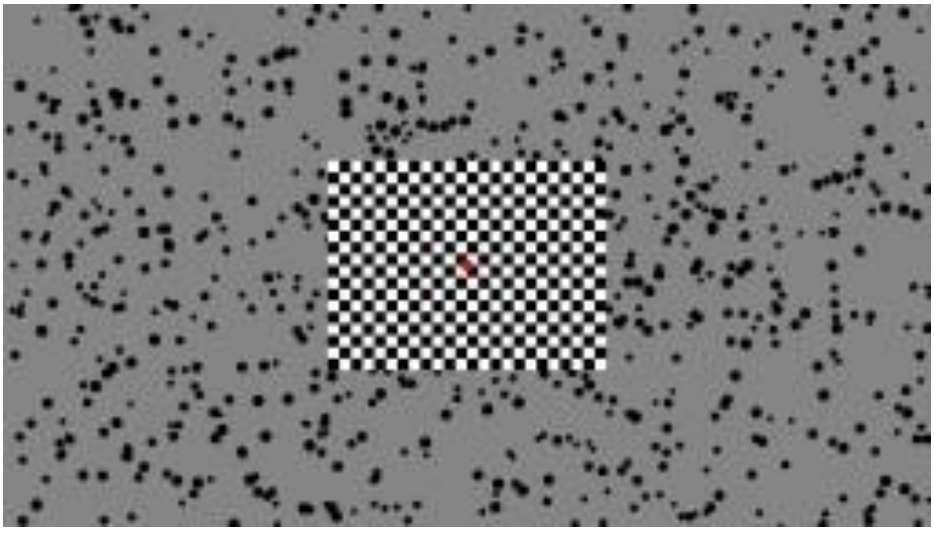
After dried your hair, you can pick up a suitable electroencephalograph (EEG) Cap to wear. I will then inject conductive gel into the electrode space to reduce impedance.

Brain Wave Measurement

In the whole experiment you will see one visual stimulus moving in different way. It is composed of central visual stimulus and peripheral visual stimulus. The **central visual stimulus** is always a 24 ×18 flashing checkerboard, and the **peripheral visual stimulus** is random dots translating at different speed.

There is a red dot in the center of the screen. You need to be relaxed and stare at that dot all the time and try you best to avoid eye movement.

The picture of the stimuli is shown below.



You are asked to report your perception status using the keyboard while staring at the stimuli. **Press left-arrow once and release when you have self-motion feeling, press right-arrow once and release when you have object-motion feeling.** After each trial, you need to report your perceived self-motion (vection) intensity according to the following table to the experimenter and there is a screen hint to remind you.

Perception of self-motion (vection)	Your report
You feel like you are stationary and it is the dots which appear to be moving only.	0
You feel like you are moving a bit in the opposite direction of the dots, but the dots are moving more.	1-4
You feel like you are moving at the same speed as the dots but in the opposite direction of the dots.	5
You feel like you are moving a lot in the opposite direction of the dots and the dots are moving a bit.	6-9
You feel like you are moving in the opposite direction of the dots and the dots appear stationary.	10

You can ask to stop the experiment whenever you feel uncomfortable.

Ending

After the experiment, we will help you remove the conductive gel and clean you head.

If you have any question about this experiment later, please feel free to contact Joyce at jzhengaf@connect.ust.hk

Thanks again for you participation!