Estimation of Heading Direction Using Optic Flow

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Background

The purpose of this study was to investigate the effect of the reduction of the uniocular light luminance as well as the effect of unequal retinal image sizes by using uniocular size lenses, on the heading direction judgment using optic flow stimuli. We hypothesized that the accuracy for perceived heading direction will be reduced with use of neutral density filters and size lenses. Also, we further hypothesized that bias in directional heading may be induced by using uniocular neutral density filters or size lens.

Methods

Optic flow stimuli were used to simulate the direction of focus of contraction. The stimuli consisted of a number of white dot presented on a uniform background. The number of the dots was set to 75 dots or 20 dots positioned randomly and contracting to a focus with two reference speeds, namely 2 and 8 degrees per second. The stimuli were presented on a computer screen at eccentricity of +1º, -1º from a central fixation line. Eighteen adults (22- 41 years of age) participated in these experiments. Thirteen participants had neutral density (ND) filter over the right eye and five participants had a 5% size lens over the right the eye. The participant’s task was to identify the direction of focus of contraction (left or right) by using the appropriate keypad.

Results

The results showed that the accuracy was best with the higher dot speed ($P = 0.029$) and there were no interactions between all other stimulus variables. Decreasing the light luminance monocularly with an ND filter did not significantly impact the participant’s accuracy in judging the direction of focus of contraction. No statistically significant differences in accuracy were found in direction judgment with 1 log unit or with 1.5 log unit and without ND filters. However, with introducing a 5 % size lens over the right eye, the participants' accuracy has significantly declined. No significant directional bias was observed neither with neutral density filter nor with size lenses.

Conclusion

Monocular reduction of the light luminance did not affect the accuracy of the perception of focus of contraction of optic flow. However, size differences of the retinal image produced by a size lens significantly reduced the accuracy of judging of focus of contraction of optic flow. There was no bias in the directional responses

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A lot of thanks to my parents (Zaid Eshnina and Kabira Mohamed) for the motivation and support throughout my whole life as well as my brothers (Mosab, Abdulsalam) and my sister (Hana).

Finally, a great thankfulness to my beloved small family, my husband (Abdulbaset) and my three sons (Almontaser, Aiyd, Rowaid)

Dedication

I dedicate this thesis to my lovely dad who always believe in me, motivated me and for his continual support. I hope that I have made you proud.

Thank you, Dad,

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Chapter 1

Introduction

Motion perception is the perception of moving objects which arises due to spatiotemporal changes in the retinal images. Motion perception provides information on both locomotion and movement of the environment. Motion is not directly sensed but indirectly inferred [1,2]. Many brain areas are activated when motion stimuli are presented, and these areas are believed to be visual area five/ Middle Temporal (V5/MT) and Superior Middle Temporal (MST) as shown in **figure 1.1** [3]. We create motion by moving linearly in a stationary environment and this is known as translational motion. Rotational motion can be created by moving both the eyes and head simultaneously.

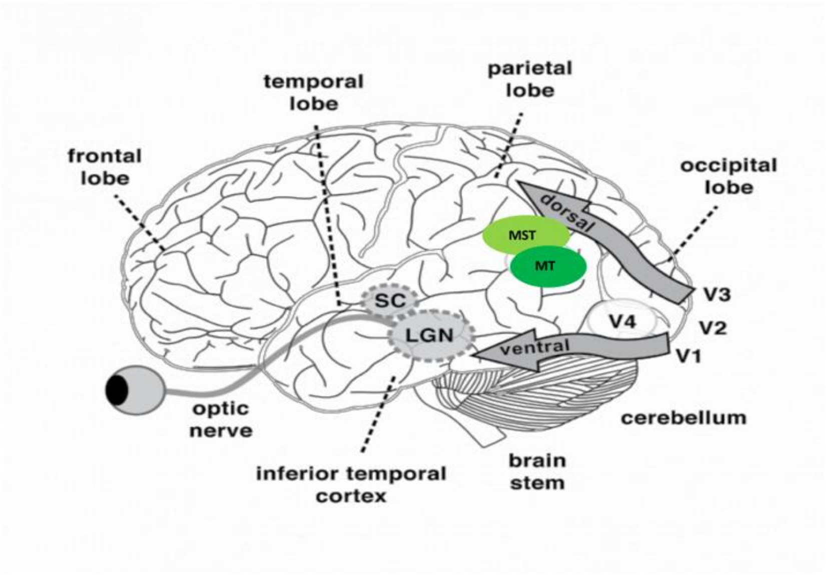

Figure 1-1- Shows the visual areas of brain and the most important area for motion perception MT and MST. Figure adapted from (Montemayor & Haladjian 2015)

1.1 Optic flow

Walking or driving a vehicle through the environment toward a specific destination produces spatial and temporal changes in the subject's retinal image and is referred to as optic flow [5,6,7,8]. Also, moving forward (translation) with a radial expansion of the visual field will create what is called optic flow which provides information about the direction of motion of points in the field as well as the speed [2,4]. The pattern of optic flow creates a heading direction that is important for us to reach our goal in the environment [9,10,11]. Optic flow contains important information regarding the structure of the environment, speed and direction of subject, and it is used to guide locomotion and balance during navigation. Optic flow is important for accurate guiding of human walking through the environment avoiding obstacles[12, 13,14]. Walking in a straight path will create expansion motion of optic flow that originates from what is known as the focus of expansion (FOE) which is located in the center of the expansion motion and is a cue for the subject to identify the heading direction [59,60]. A contraction pattern is a result of moving backward or when the objects move forward in the environment while subject is in static position [27], and the focus of contraction is located in the center of the contraction motion field [59]. The visual system is more sensitive to contraction motion than to expansion motion. Contraction motion easy to identify than expansion motion becase of the dot density will increase at the center more than the periphery and that will help to judge the focus of contraction. Also, the central visual field have greater fuction in the center than the periphery[59]. **Figure 1.2** illustrates the heading directions of the optic flow. “A” represents the expantion optic flow where all the lines expand from focus of expansion (FOE). “B” represents the contraction of optic flow where all the lines move into the midpoint focus of contraction (FOC)[15].

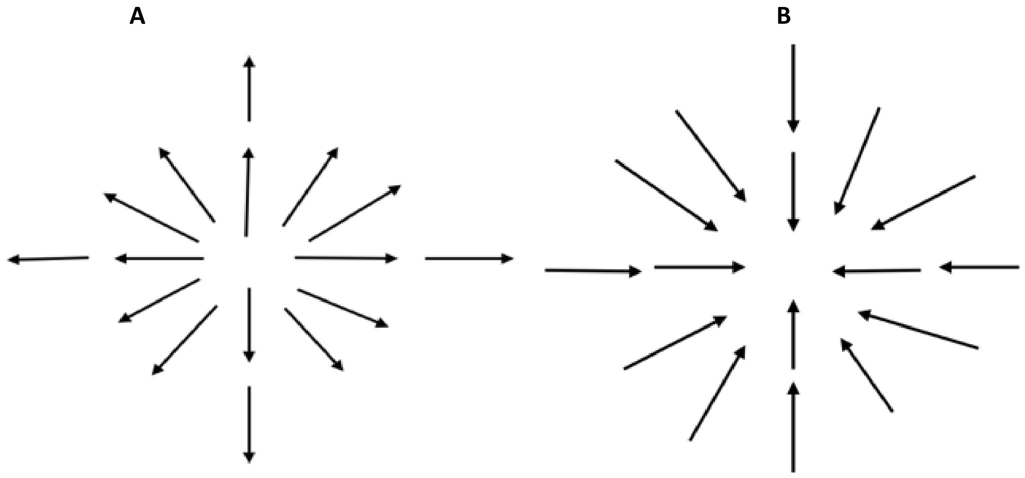

Figure 1-2 The heading direction of radial optic flow. “A" shows the expansion optic flow where all the lines move outward from focus of expansion (FOE). "B" shows the contraction optic flow where all lines are moving inward the midpoint[16].

Previous studies found that the accuracy of judgment of heading direction of optic flow to be less than 1° of visual angle [17,18]. Heading direction is more accurate and straightforward to identify when the direction of gaze is in the same direction of heading. By changing the gaze direction which occurs with eye, head or trunk rotation, the retinal flow of the image on the subject's retina will change and that will lead to difficulty in judging the accuracy of heading direction [9,15].

Optic flow (expansion and contraction) is processed in the extra striate area of the visual cortex, specifically in the middle superior temporal MST area, which is located in the superior temporal sulcus (STS) in the dorsal stream [19,54,58]. The MST area is known to be rich in neurons that are highly directionally sensitive and selective for moving visual stimuli, and have large receptive field structure [20,21,22, 23, 24]. According to Morron et al., (2000) in a fMRI study, when a subject viewed an optic flow stimulus, a clear activation can be seen in only temporal occipital cortex without any response in the other areas such as V1[25]. Many factors affect the perception of heading direction from optic flow. One of these factors is age. Previous research has found that older adults perform worse than younger adults in determining direction of heading. Older adults are not fully relying on using optic flow for guiding during navigation, but they rely on viual cues suggesting the possibility of impairment in motion perception[14,26]. Also, there is a positive correlation between age and the heading direction threshold. In older adults, the threshold is slightly higher than for younger adults [17, 27]. Gender is another factor that has an effect on the heading perception discrimination task. It has been found that older men performed better than older women for faster optic flow stimuli. However, the reason why older women had higer threshold than older men not clear, it could be to social factors rather than neural processing[14,27]. Speed and dot density also impact perception of heading direction. Higher dot density in a random dot kinematogram stimulus may improve the performance of younger adults but not for older adults. Higher dot density can give a cue for the location of the focus of expansion and the participant is able to detect it easly[27]. In addition, high dot velocities help subjects to judge their heading direction better than low dot becase of the large displacement of the moving dots that make the focus of expansion easy to determine [28,27].

Brain lesions in occipitoparietal, and/or posterior parietal that comprise MT and MST affect the process of visual motion perception. Lamontagne and other researchers (2010) found that patients with unilateral brain lesions were unable to control their direction of heading during navigation in the physical world when looking at optic flow stimuli through a helmet mounted display (virtual environment). In comparison with the normal healthy group, these patients showed different steering behaviors when their heading corrections were in the wrong direction[15]. Davidsdottir et al., (2008), conducted a study to investigate how unilateral brain damage affects the perception of optic flow and produces navigational veering. They had two groups of patients, one with right brain damage and the other with left brain damage. The participant's task was to walk along a pathway while in a virtual reality setup they saw white random dots projected on two black sides of the hallway to simulate optic flow. They discovered that the group with left brain damage veered to the right side and those with right brain damage veered to the opposite direction (same as normal controls), but they had more deviation than normal. They concluded that unilateral brain injury affected the perception of the optic flow during navigation [29]. These are some factors that affect the perception of optic flow ingeneral, and other factors might affect the perception of optic flow (expension or contraction) are monocularly reduction retinal luminance, differences in the retinal image size.

1.2 Pulfrich Phenomenon

Intraocular differences between the two eyes affect many visual functions [30]. When we see an image binocularly, each eye sees the image slightly different from the other eye due to the approximately 6-cm distance between our eyes. In other words, there is a horizontal image disparity between the two eyes. However, the human brain is capable of fusing the two images into one image with depth. If one of the pathways that connect the images of moving or static objects to the brain is slower than the other then the perception of the moving objects will be different than the reality[31].

This phenomenon was first discovered by Carl Pulfrich in 1922 [32,33]. It is a stereo-illusion effect which is due to the delay of the transmission of the information response from each eye to the brain. This delay could be due to the inter ocular latency differences between two eyes [30,34]. Patients with unilateral ocular diseases or with unilateral optic neuropathies may experience the Pulfrich effect due to the transmission delay between the two visual pathways, and this is called the spontaneous Pulfrich effect. Using ND filter for patients who experience the Pulfrich effect may rebalance the differences between two eyes [30]. The evoked Pulfrich effect can be obtained from a normal subject by introducing a neutral density filter in front one of the eyes. A neutral density filter (ND) produces a reduction in the luminance of the retina and hence because of the luminance differences between the eyes, there is a time delay in processing the image from the affected eye [38,32] or a delay in generation and transmission impulses from the nerves [34].

Normal subjects, will see a pendulum moving in straight line from left to right or the opposite, but when a ND filter (measured in log units) is introduced in front one eye, the percept will be that of an elliptical path. The magnitude of the elliptic path increases with increasing the ND filter value. In addition, the direction of the elliptic path depends upon the eye in front of which the ND filter is placed [35]. Clockwise direction will be obtained when the left eye is affected, and the anticlockwise when the right eye is affected as show in **figure 1.3 A** [35,36]. Increasing the speed of the object will increase the magnitude of the effect [37,32]. According to Diaper and his collegues (1997), the objects that move in a sagittal plane are perceived as moving in a hyperbolic pathway approaching the filtered eye. For example, if the object moves in the sagittal path from the right side and the ND filter is placed over the right eye, subject will perceive the object as moving toward the right side as showen in **figure 1.3 B**[56]. Bias in optic flow may occur when the two optic flow fields have asymmetries in speed of the objects and size of the objects.

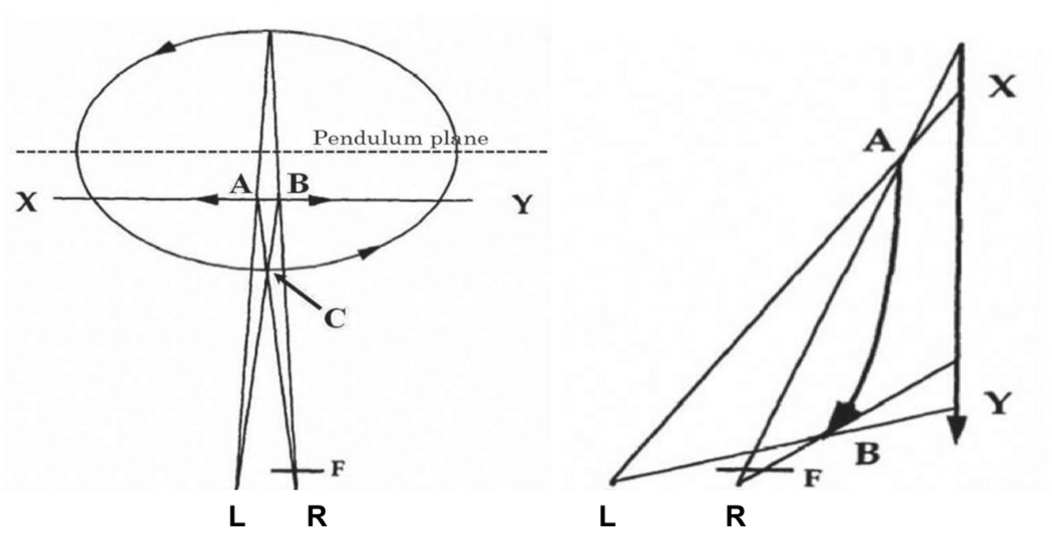

Figure 1-3 "A" Illustration the Pulfrich effect using neutral density (ND) filter over the right eye on horizontal motion from X to Y[30]. "B" shows the effect of ND filter on the sagittal motion from X to Y. Figure adated from (McGowan et al 201)

Patients with asymmetric time delay in the visual pathway have difficulty judging the distance of moving objects while they are driving, specifically when they are looking sideways[39]. Asymmetric delay patients cannot judge the direction of movement of the pedestrians and the position of the passing vehicles[39]. They also perceive the oncoming vehicles approaching them toward the body side of the affected eye [33,35,39]. Enright has noted that, when the right eye is covered with a ND filter, and the observer looked at the left side window, the speed of the oncoming vehicles appears to be faster than the normal speed[40]. Also, the size of the vehicles appears larger and the distance between them appears larger [35,40]. With the use of ND filter over the unaffected eye, normal driving performance is observed. However, the ND filter will work better under photopic conditions than under scotopic conditions, since ND filters reduce the retinal illuminance significantly [31,56]. Further, Sobhanian et al., (2018), examined the Pulfrich phenomenon in normal subjects and patients with Multiple Sclerosis (MS). In the MS patients, the investigators placed the ND filter in front the unaffected eye, and patient's task was to describe the pendulum movement. The patient reported that the movement of the pendulum was less elliptic than when there was no ND filter. The examiner increased the amount of the ND filter until the patient reported that the pendulum movement was linear [41].

We are predicting that reduction in the light luminance in one eye might affect the perception of focus of contraction because of the intraocular differences between the two eyes. The brain will process the image from filtered eye after unfiltered eye making a tranismission delay. This might affect the judgment of focus of contraction as well as producing a directional bias away from the side of the ND filter.

1.3 Size lenses and Aniseikonia

Size lenses have no refractive power, but they produce an enlargement of the retinal image of the eye in all meridians called anisokonia. Introducing the size lens in front one eye will produce size differences in the retinal image [42,43], and the monocular image will appear farther away, being larger. Binoculararly, the shape will be distorted due to binocular disparity which leads to tilt of the viewed scene [55]. Further, when the binocular system fuses the two images, the appearance of the image will be seen as tilted around the vertical axis. The amount of tilt depends on the percentage size of the size lens[44]. We are expecting that by introducing aniseikonia by placing the size lens over one eye, the participants will perceive the moving dots from the eye with size lens as bening larger and further away, than the dots in the other eye, creating the percept of moving dots as a gathering behind the center fixation line which lead to misjudge the focus of contraction. Also, it may be difficult for the participants to judge the heading direction accurately, and it may produce a directional response bias.

We plan to study the effect of the neutral density filters and size lenses on heading perception in normal subjects using optic flow stimuli by introducing monocular neutral density filters and size lens.

1.4 Previous finding

Previous studies found that individuals who experienced the Pulfrich due to either unilateral ocular disease or unilateral optic neuropathies have difficulty judging the position, distance and speed of moving objects [34,45]. Individuls with anisometropia have an unequal refreactive errors that lead to differences in the retinal image size when optically corrected [61]. The difference between Pulfrich and anismetropia is that the Pulfrich has an unequal response time between the eyes, and anisometropima has unequal retinal image size in each eye [61,62].

1.5 The purpose of the study

The main purpose of the study is to investigate whether monocular reduction of the light luminance, and the retinal image size differences affect judgment of the perception of heading direction using optic flow stimuli.

1.5.1 The research hypotheses:

1- Bias in directional heading will be induced by using uniocular neutral density filters and/or size lenses.

2- The accuracy for perceived heading direction will reduced with neutral density filters and/or size lenses.

1.6 Summary

Optic flow provides information regarding the direction of self -motion and the structure of the surrounding environment. Impairments in motion perception lead to difficulty identifying the direction and speed of self-motion. These impairments can be simulated by monocular reduction of the light luminance of the eye which will affect the perception of moving objects. Positional and motion perception deficits can also be simulated by inducing aniseikonia. In this thesis, we will investigate whether monocular reduction of the light luminance and monocular size lenses affect judging the perception of the focus of contraction when using optic flow stimuli.

Chapter 2

Method

2.1 Subjects

A total eighteen normal subjects participated in the study (9 males and 9 females). Thirteen participants participated in the neutral density filters conditions and five in the size lens condition. The age of the participants ranged from 22 years to 41 years old (mean age 30.6 ± 6.4). All the participants were physically healthy and met all inclusion criteria. The participants were included in this study if their visual acuity in each eye was (0.0 log MAR) or better with or without best correction and their age was within the range 18 to 45 years for both male and female. Also, the contrast sensitivity was 1.80 CS log and above46. For all subjects, both monocular and binocular visual acuity and contrast sensitivity were assessed.

2.2 Screening tests

Monocular and binocular visual acuity was assessed using the Freiburg Visual Acuity and Contrast Sensitivity Test [47]. The participants sat 6 meters away from a computer monitor, and Landolt-Cs were displayed on the Macintosh screen in one of the eight directions. The participants task was to identify the orientation of the gap of the letter C using keypad arrows. The threshold was recorded monocular and binocular with their best correction.

2.3 Display

The stimulus was programed using Psykenamtix software. The stimulus was displayed on an Apple Macintosh screen with resolution of 1024*768 pixels at 60 Hz, and the screen field of view subtended 33.26°*25.25° (horizontal * vertical) at the test distance. The stimulus was presented at a test distasnce of 60 cm from the subject, and the participant viewed the stimulus binocularly. The stimulus was in a square region that subtended 19° of the visual angle. The mean luminance of the screen was 166.38 cd /m^2.

2.4 Stimulus

The stimulus consisted of a Random dot Kinematogram (RDK). The stimulus was presented on the computer screen, with white dots on a gray background at high contrast, and each dot occupied 0.118°. The number of the dots was either 20 or 75 dots, and the speed of the dots was either 2 deg/sec or 8 deg/sec. The inter stimulus interval (ISI) for each trial was 500 ms. The number of the dots and speed were randomized. With these parameters, there were four conditions and these are in **table (2.1).**

Table 2.1

Condition 1	**Condition 2**	**Condition 3**	**Condition 4**
20 dots / speed 2 deg/sec S1D1	75 dots /speed 2 deg/sec S1D2	20 dots / speed 8 deg/sec S2D1	75 dots / speed 8 deg/sec S2D2

Table 2-1shows the four conditions of dots and speed

The dots had 100% coherence and created an focus of contraction of optic flow pattern with an eccentricity (+1^{o} to -1^{o}) of visual angle in the horizontal meridian. The participant was seated with their head in a forehead and chin rest in order to maintain distance fixation. The subject was instructed to fixate on a center line on the screen. In separate visits, the same procedure was repeated, but an uniocular neutral density (ND) filter was placed in front of the right eye (chapter 3 and 4). Five different supjects repeated the psychophysical test using a size lens in front the right eye, and the size of lens used was 5% placed in a trial frame (chapter 3.5-3.7). For each trial the stimulus was presented for 300 ms. The participant was instructed to give a response once the stimulus disappeared to identify the location of the focus of contraction, left or right of the midline, using a two-alternative forced choice (2AFC) procedure. Also, a two-down one- up staircase method was used to measure the direction of heading threshold. After two correct responses, the eccentricity was reduced by 50% and after one incorrect response the eccentricity was increased by 25%. The threshold was obtained by averaging the last four reversals. The smallest step size was 0.01^{o}. All procedures have been reviewed and received ethics clearance approval through the University of Waterloo, Human Research Ethics Committee. The study took place at School of Optometry and Vision Science at University of Waterloo. All participants were informed and indicated consent by signing a consent form before the experiments started. The stimuli and methods were adapted from previous study that measured the pereption of heading direction using optic flow [27]. Some stimulus parameters were modified such as the number of dots, eccentricity of the heading direction, and test distance, and this used contraction rather than expansion for the direction of radial motion in the optic flow patterns. Pilot studies were conducted to determine the optimal stimulus parameters to be used in the main study. We chose the contraction of optic flow as stimuli because identifying the heading direction of the expansion of optic flow was difficult. That was tested on the author and another participant, and the threshold was inconsistent.

Chapter 3

Pilot studies

Pilot study 1

3.1 Neutral density filters

Four normal subjects participated in the study, (three male and one female mean age = 36.2 ± 5.6 years). The purpose of the study was to investigate the effect of speed, dot density, and ND filter levels on perceiving the foucus of contraction using optic flow stimuli. The stimuli consisted of moving dots that are generated in four conditions (number of dots was 75 or 20 and speed was 2 deg /sec or 8 deg/sec) See **table 2.1.** The experiment was conducted for three different repeated measurements for each condition without ND, with 1 log unit ND, and with 1.5 log unit ND filters placed over the right eye.

3.2 Result

An analysis of variance (repeated measures) ANOVA was used to analyze the data, and there were three within subject variables (2 dot densities, 2 speeds and 3 ND filter levels). The main effect was statistically significant for speed (F (1,3) = 15.577, *P*= 0.029). Directional threshold for the lower speed was significantly higher than faster speed threshold. Main effect for dot density and ND filter levels were not statistically significant (F (1,3) = 5.217, *P*= 0.107 and F (2,6) = 5.821, P= 0.07, respectively) although both showed trend ($p \leq 0.1$) towards higher threshold with lower dot density and higher tthresholds with higher ND filters. Also, there were no significant interactions between ND filter and speed (F (2,6) = 0.754, *P*= 0.510), ND filter and dot density (F (2,6) = 0.378, *P*= 0.700), ND filter, speed and dot density (F (2,6) = 0.199, *P*= 0.417) and between speed and dot density (F (1,3) = 0.57 *P*= 0.827). **Figure 3.1** illustrates the main effect of speed on the focus of contraction in the base line no

ND filter. Mean threshold for the last three conditions (low speed high dot density) (high speed low dot density) (high speed high dot density) were $\leq 0.05^{o}$. However, for the first condition (low speed low dot density) the mean threshold was higher 0.14^{o}.

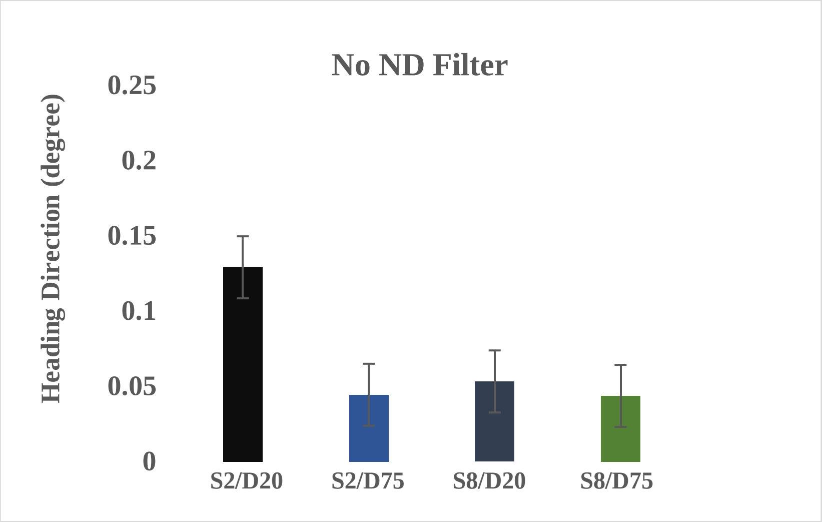

Figure 3-1 Shows the mean threshold and standared error of the mean for the four participants with four conditions with no ND filter. S1D1(dot 20 2deg/sec) S1D2(dot 75 2 deg/sec) S2D1(dot20 8deg/sec) S2D2(dot 75 8deg/sec)

Figure 3.2 illustrates the main effect of speed on the focus of contraction in 1 ND filter. Mean threshold for the first three conditins (low speed low dot density, low speed high dot desnity and high speed low dot density) were quite similar 0.14^{o}, 0.10 and 0.12^{o} respetiviely. The fourth condition was the lowest threshold with 0.06^{o}.

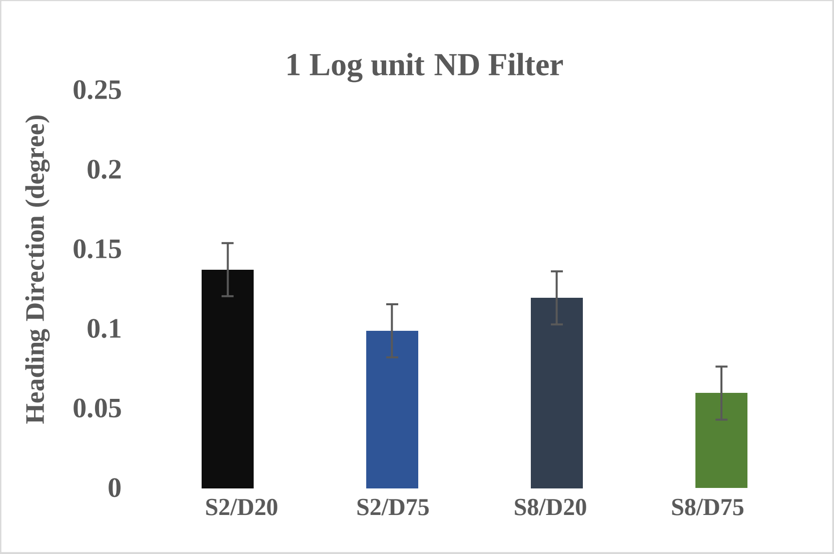

Figure 3-2 Shows the mean threshold and SEM for the four participants and four conditions with 1 ND filter. S1D1 (dot 20 2 deg/sec) S1D2 (dot 75 2deg/sec) S2 D1 (dot 20 8deg/sec) S2D2 (dot 75 8deg/sec)

In 1.5 ND filter experiment, the first three conditions (low speed low dot density, low speed high dot density and high speed low dot density) had higher thresholds (0.21^o, 0.15^o and 0.14^o) respectively than the fourth condition with 0.06^o as show in **figure 3.3**.

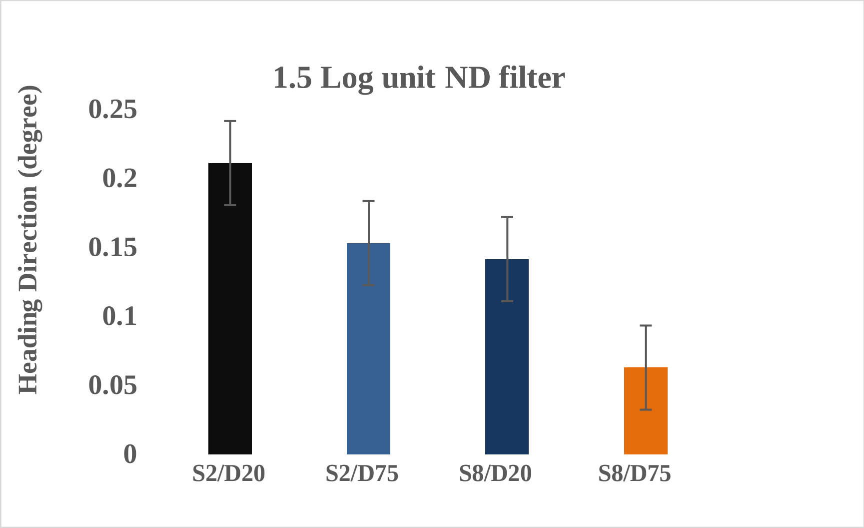

Figure 3-3 Shows the mean threshold and SEM for four participants and four conditions with 1.5 ND filter. S1D1 (dot 20 2deg/sec) S1D2 (dot 75 2deg/sec) S2 D1(dot 20 8deg/sec) S2D2 (dot 75 8deg/sec).

Parameters	20D- 2deg/sec	75D-2deg/sec	20D8deg/sec	75D-8deg/sec
Mean threshold for base line	0.12 ± 0.04	0.04 ± 0.01	0.05 ± 0.02	0.04 ± 0.02
Mean threshold 1ND	0.13 ± 0.02	0.09 ± 0.05	0.11 ± 0.03	0.05 ± 0.02
Mean threshold 1.5 ND	0.21 ± 0.05	0.15 ± 0.03	0.14 ± 0.05	0.06 ± 0.01

Table 3-1Mean threshold and SEM of four conditions of the focus of contraction in the base line, 1ND filter and 1.5 ND filter.

Directional bias response with ND filter

A directional response bias has been analyzed. First the bias value was determined at 50% probability of left or right decision using liner interpolation for each participant, and the data was analyzed separated by filter and by condition. **Figure 3.4 (A, B, C, D)** showed the response directions for four participants at the base line with no ND filter. A one sample *t*-test was used to compare each condition with zero value, and there was no significant bias in all conditions $P > 0.05$. With 1 ND filter over the right eye. Mean value of participants at 50% of directional response in first condition (low dot density and slow speed) was (0.04° ± 0.7) not significantly different from test value (zero) t(3)= 1.185, P =0.321 as showed in **figure 3.5 A**. Mean value of participants at 50% of directional in second condition (high dot density and slow speed) was (0.005° ± 0.02) not significantly different from test value (zero) t(3)= 0.346, P =0.75 as showed in **figure 3.5 B**. Mean value of participants at 50% of directional response in third condition (low dot density and high speed) was (-0.005° ± 0.01) not different from test value (zero) t(3)= -0.577, P =0.60 as showed in **figure 3.5 C**. Mean value of participants at 50% of directional response in fourth condition (high dot density and high speed) was (-0.004° ± 0.02) not different from test value (zero) t(3)= -0.398, P =0.71 as showed in **figure 3.5 D**. Additional analysis was conducted for 1.5 ND filter condition. A one sample *t*-test was used to compare each condition with zero value, and there was no significant bias in any condition $P > 0.05$. Mean value of participants at 50% of directional response in first condition was (-0.05° ± 0.05) not different from test value (zero) t(3)= 1.913, P =0.152 as showed in **figure 3.6 A**. Mean value of participants at 50% of directional response in second condition was (0.0005° ± 0.008) not different from test value (zero) t(3)= 0.005, P =1.00 as showed in **figure 3.6 B**. Mean value of participants at 50% of directional response in third condition was (-0.017° ± 0.06) not significantly different from test value (zero) t(3)= -0.511, P =0.645 as showed in **figure 3.6 C**. Mean value of participants at 50% of directional response in fourth condition was (-0.06^{O} ± 0.161) not significantly different from test value (zero) t(3)= -0.836, *P* =0.46 as showed in **figure 3.6 D**

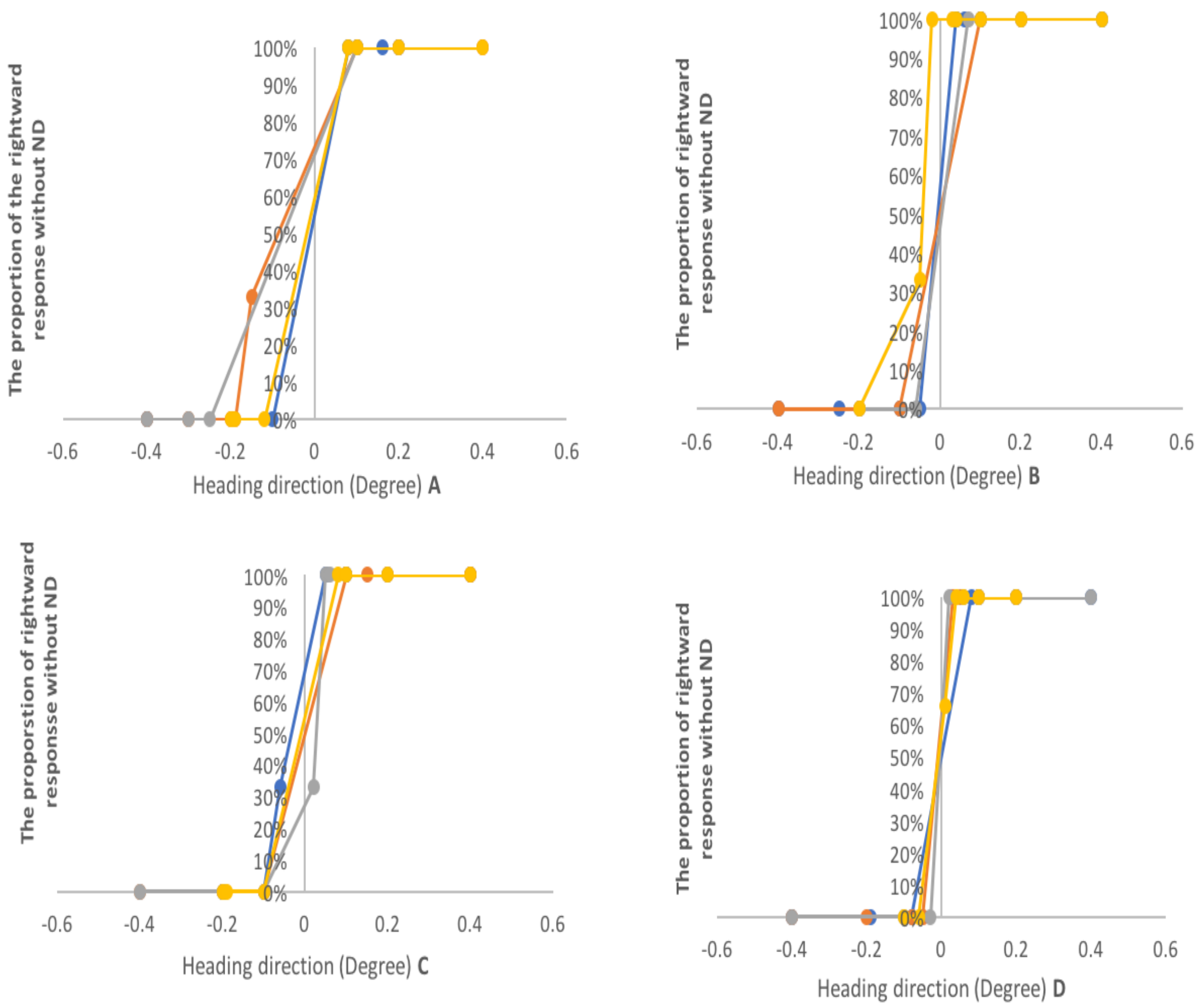

Figure 3-4 Shows the rightward direction responses for four participants without ND filter. "A" condition one (low speed low dot density), B condition two (low speed high dot density), C condition three (high speed low dot density), D condition four (high speed high dot density).

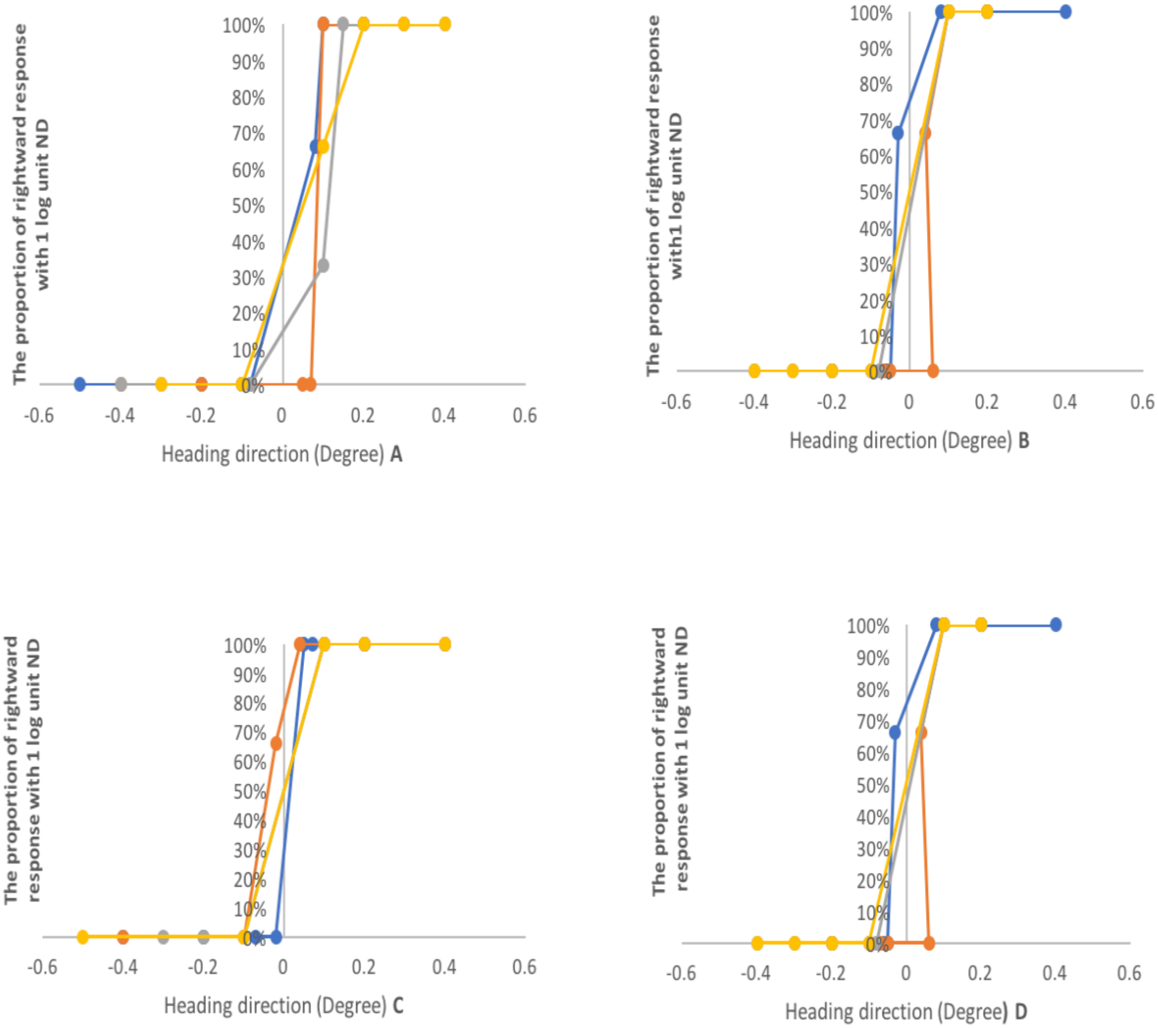

Figure 3-5 Shows the rightward direction responses for four participants with 1 ND filter. A condition one (low speed low dot density), B condition two (low sped high dot density) C, condition three (high speed low dot density) D, condition four (high speed high dot density)

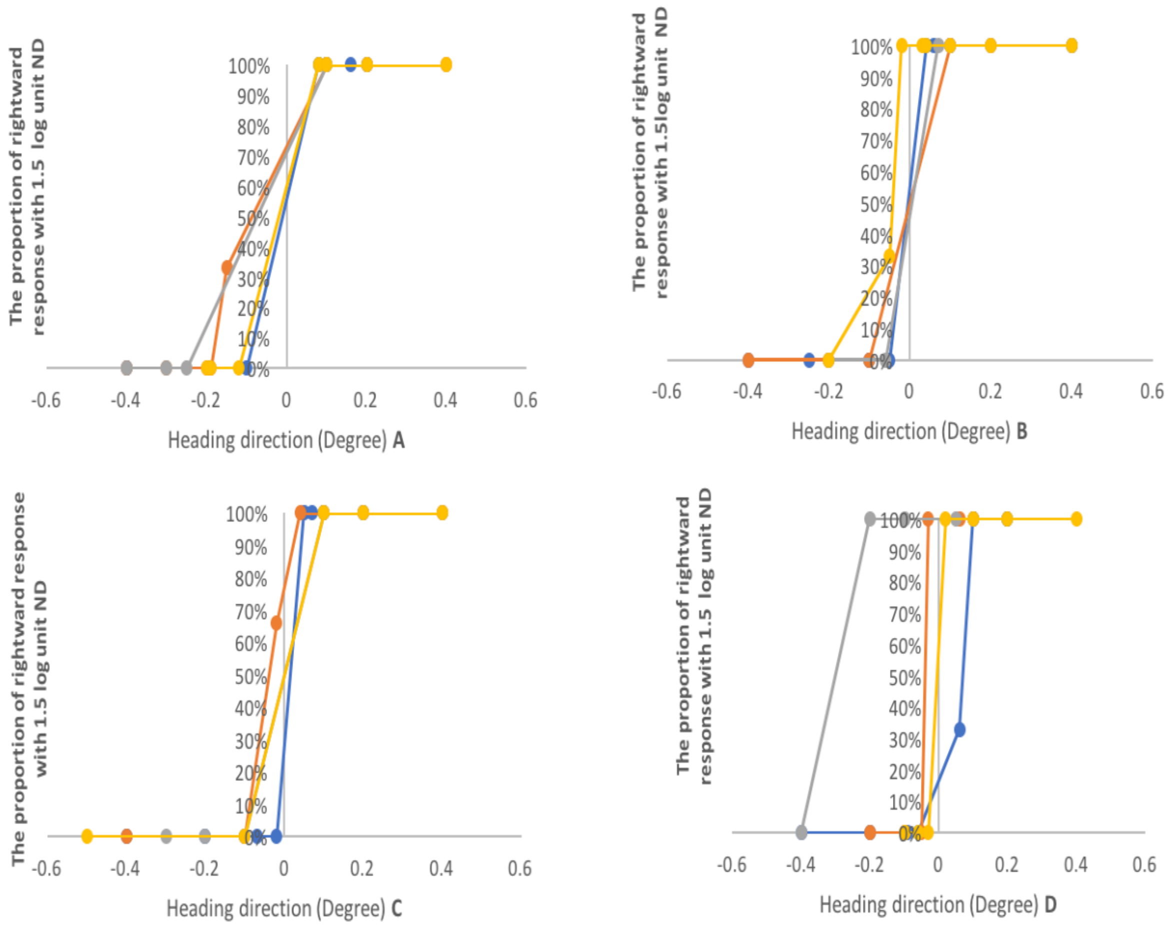

Figure 3-6 Shows response direction for four participants in four conditions with 1.5 ND filter, and the filter over the right eye. A condition one (low speed low dot density), B condition two (low speed high dot density), C condition three (high speed low dot den

3.3 Discussion

In this set of experiments, the main purpose was to choose the appropriate stimuls parametres, and which ND filter was appropriate. The original stimulus parameters have been slightly modified[27]. In this pilot study, the stimuli consisted of contracting optic flow patterns two dot densities (20 and 75 dot per field), two reference speeds (2 and 8 deg/sec) and three filters conditions (none, 1.0 and 1.5 log unit). The result of this study showed that the perception of direction with optic flow (focus of contraction) was significantly affected by speed. Threshold for faster speed was significantly lower than for the slower speed meaning that the perception of focus of contraction was more difficult to identify when the stimulus moving at low speed. The result showed no significant difference in threshold between the dot densities at two reference speed across all ND filters. This result in agreement with previous study[27]. However, Raghuram and Lakshminarayanan (2011) used three dot densities 24, 96 and 400 dots per field of 13.65 by 10.25 degrees and the methodology was used method of limits; in the present study, the dot densities were 20 and 75 dot per field of 19-degree square, and staircase method was used. Although they compared young and old groups and their task was to identify the heading direction of optic flow slimui (expansion)[27], the present result support their finding that the threshold for faster stimuli was lower than for slower stimuli. In their study, dot density did not significantly affect the perception of heading direction overall, but there was an interaction with speed. The participants had similar accuracy at the higher speed with low and hight dot densities, however, as in the trend found in the present study for slower speeds, higher dot density gave an advantage[27]. Raghuram and Lakshminarayanan found a significant interaction between speed, age and gender, older men had lower threshold for fast speed than older women. Also, a significant interaction was observed between dot density, luminance and age where lower threshold observed for younger subjects when the dot density was high at both photopic and scoptopic luminace. Neutral density filters were not statistically significant variables, they did not affect the accuracy or bias judgment of direction of the focus of contraction for optic flow. Overall, there was no statistically significant effect of dot desnity and filters on focus of contraction in this study unlike the previous studies[28]. That could be due to the sample size, we only test four participants in this pilot study and trends support previous studies. Previous studies have shown that the ND filter have an effect on the perception of moving objects. [51,52]. However, most of the studies that used ND filter over one eye, use a pendulum as the stimulus, which is moving in frontal or sagital planes. Our study used optic flow contracting stimulus a group of dots moving coherently from different position into a focus point. No significant bias was observed when a neutral density filter was placed over the right eye. All the directional responses were close to zero, although some conditions showed small biases, these did not reach significance and were not consistent in direction. High speed and high dot density (75 dot density and 8 deg/sec) were selected for the main study. We thought by selecting these parameters the participants will easly identitfy the focus of contraction, and the threshold would be accurte, so we can see the differenc in threshold when ND filter applied.

3.4 Conclusion

1- Perception of focus of contraction for optic flow was affect by speed. Slower speed was difficult for the participants to judge the direction of contraction for optic flow than faster speed.

2- Low and high dot densities did not affect the judgment of position of the focus of contraction.

3- Neutral density filters were not observed to have significant effect on the judgment of either the direction (bias) or accuracy (threshold) although this pilot study was small lacking in statistical power if differences were small.

4- No interaction was observed between all the variables dot density, speed and filter.

Pilot Study 2

3.5 Size lenses

The aim of this study was to investigate the effect of the size difference of the retinal images on perception of focus of contraction using size lenses. Five participants participated in the second experiment, (two male and three females, mean age = 27.4 ±7.8 years). A five percent size lens was used, and the stimulus was consisted of 75 dots that move at speed 8 deg/ sec. The lens was placed over the right eye, and the participants task was to identify the direction of the moving dots either left or right from the center line. The threshold was collected based on staircase method, and the number of presentations were based on the participant's response. We used the same motion perception task and same procedures that are described in the methods chapter 2. A paired sample t- test of mean was used.

3.6 Results

The Shapiro-Wilk test showed that the threshold of focus of contraction was not normally distributed across participants. A Wilcoxon test showed a significant difference between the two measurements with size lens and without size lens on the focus of contraction threshold ($Z = -2.023$, $P = 0.043$) (**figure 3.7).** The mean thresholds for focus of contraction of optic flow for without size lens and with size lens were 0.05^{o} (± 0.03) and 0.09^{o} (± 0.05), respectively.

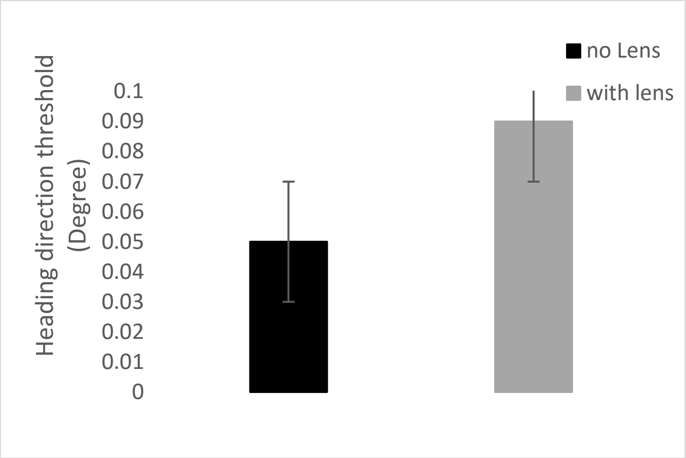

Figure 3-7 shows the mean threshold of five participants for heading direction without size lens and with a 5 % size lens over the right eye. The error bars are the standared error of the mean.

The psychophysical data from five participants were analyzed to find if there was any directional response bias. The value of the response bias had been determined at 50% for each participant. Paired sample *t*-test was used to analysis the data. **Figure 3.8** shows the percentage of the rightward response plotted against the focus of contractionof optic flow without size lens, and we find no directional bias. Mean value of five participants at 50% of directional responses with 5% size lens (0.03^{o} ± 0.073) was slightly higher than the test value (zero). **Figure 3.9** displays the directional responses for five participants with a 5% size lens in front of the right eye, and it showed no statistically significant directional bias t (4) = 1.032, *P* = 0.36.

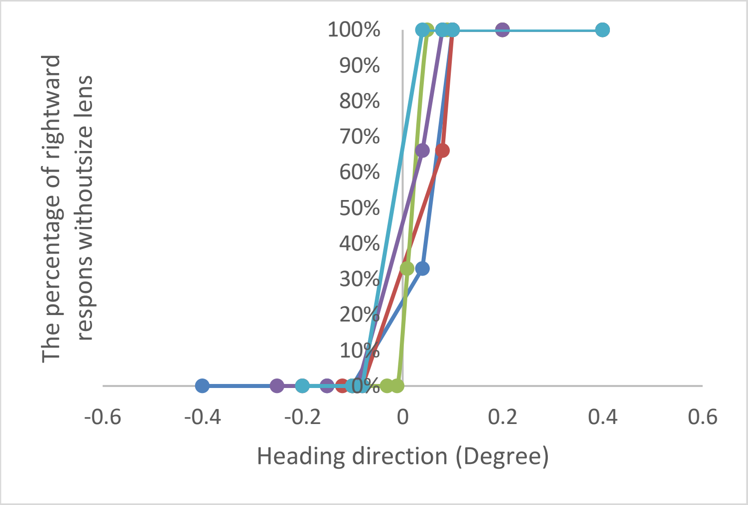

Figure 3-8 show the directional response of five participants without size lenses, and the plus axis is toward the right.

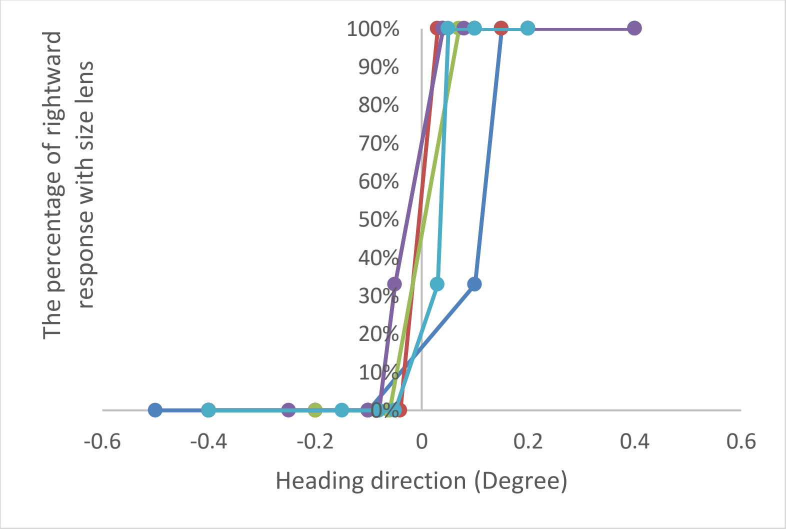

Figure 3-9 shows the five participants with a 5 % size lens over their right eye, and plus axis is towards the right.

3.7 Discussion

3.7.1 Experiments utilizing size lenses

In this part, we are investigating whether the intraocular size differences of the images have an effect on the perception of focus of contraction of optic flow. We are expecting that by introducing the size differences in the retinal images by placing a size lens over one eye that will create a difficulty judging the heading direction and producing a directional bias based on where the size lens be placed. Size lenses make the monocular retinal image larger and further away and binocularly the whole view is perceived tilted. For moving dots, the size lens enlarge the dots and make them further away on the magnified side, and the tilt that produced by the lens could affect the accuracy of judgment of heading direction. Our study indicated a significant effect of the size lens on the threshold of heading direction of focus of contraction. The size lens tilted the screen and that could change the perception of the focus of contraction, and affect the accuracy of judging the heading direction of the moving dots. However, no directional bias has been found with using size lens, all participants were slightly bias to the right (positive) but not statistically significantly. There is no previous literature to compare our results. The binocular visual system is capable of fusing the images from the two eyes that are differ in the magnification by 5 percent [54]. The sample size is one of the limitations of no response bias have been found; increasing sample size might lead to a significant directional response. This pilot study was conducted after the main study.

3.8 Conclusion

1- Changing the retinal image size by using a size lens affected the accuracy perception of the location of the focus of contraction optic flow.

2- No directional bias was observed when the size lens placed over the right eye.

Chapter 4

Main Study

4.1 Neutral density filter

The aim of the study was to investigate the effect of a monocular neutral density filter on the focus of contraction judgment. In this part, we kept the number of the dots as 75 and the speed was at the high speed because with these parameters, the participants will accurately judge the direction of the focus of contraction of optic flow. Although its effects were not significant in the pilot studies (chapter 3) the filter was the highest available that did not make the task very difficult for some. 1 unit ND filter was used in this study based on the pilot study even though there was no significant effect of 1 ND filter on the direction of focus of contraction see **appendix A**.

4.2 Procedures

We assessed direction discrimination task of focus of contraction of optic flow as mentioned in the method section in chapter 2. Data from nine new normal participants and data from four participants from the pilot study in chapter 3, neutral density filter section were analysed, (six males and seven females with age range from 22 to 41 years mean age 31.1 ± 6.4). Visual acuity and contrast sensitivity were assessed to measure eligibility for the study.

4.3 Result of the main study

All participants had VA which was -0.1 log MAR or better for each eye, and contrast sensitivity was in the normal range for all participants being 1.80 log unit and above[48]. A paired sample *t* test indicated no statistically significant difference between without ND filter and 1 log unit ND filter on the accuracy perception of focus of contraction *t* (12) = -0.880, *P*=0.39. The mean thresholds for both without ND filter and with 1 log unit ND filter were similar 0.06^o (± 0.04 SD) and 0.08^o ($^\pm$ 0.04 SD). **Figure 4.1** shows the mean threshold of the focus of contraction for no ND filter and 1 log unit ND filter.

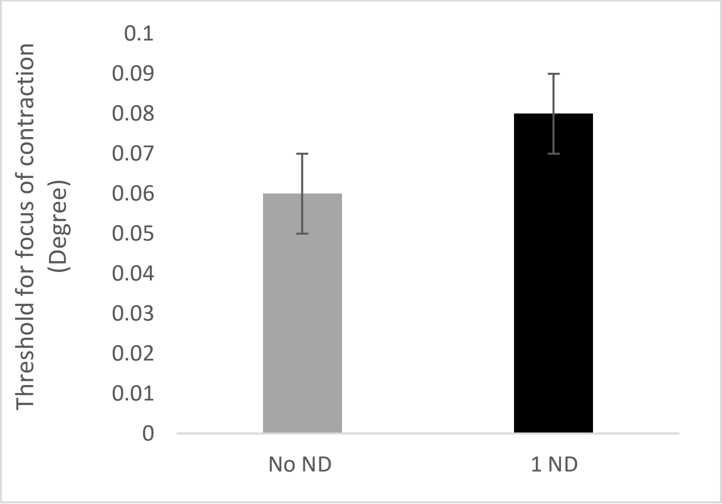

Figure 4-1 Shows the mean absolute value of the threshold of the lateral direction of the focus of contraction for 13 participants without ND filter and with 1 ND log unit filter over right eye. The error bars= SEM.

Additional analysis was conducted to determine if there was any directional responses bias using ND filter over right eye. The value of the response bias was determined at 50% for each participant by linear interpolation. Paired sample *t*-test was used to analyze the data, and it indicated no statistically significant directional response bias between no ND filter and 1 log unit ND filter t (12) = -1.081, *P*= 0.301. **Figure 4.2** show the directional responses to the focus of contraction of 13 participants with no ND filter.

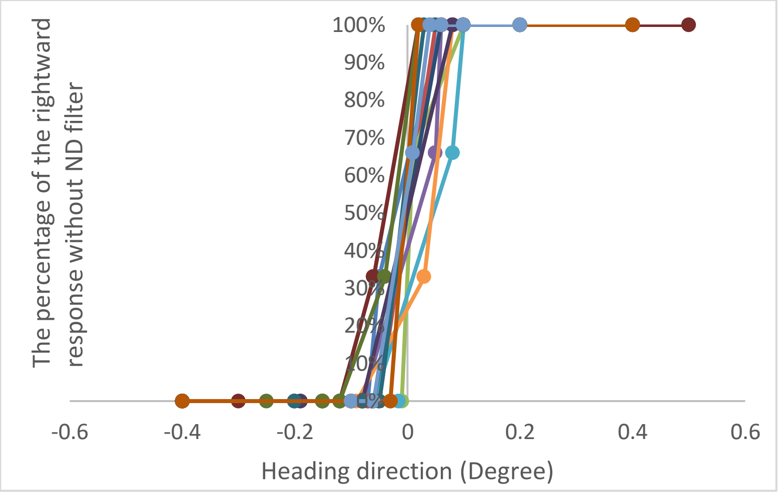

Figure 4-2 Shows the directional response of 13 participants to the position of the focus of contraction with no filter. The positive side indicates rightward.

Table 4.1

	Mean threshold	**Bias value**
No ND filter	**0.06º ± 0.01**	**0.003º ± 0.007**
1 ND filter	**0.08º ± 0.01**	**0.015º ± 0.008**

Table 4-1 Displays the mean threshold and mean bias value with SEM for 13 participants no ND filter and with 1 ND filter.

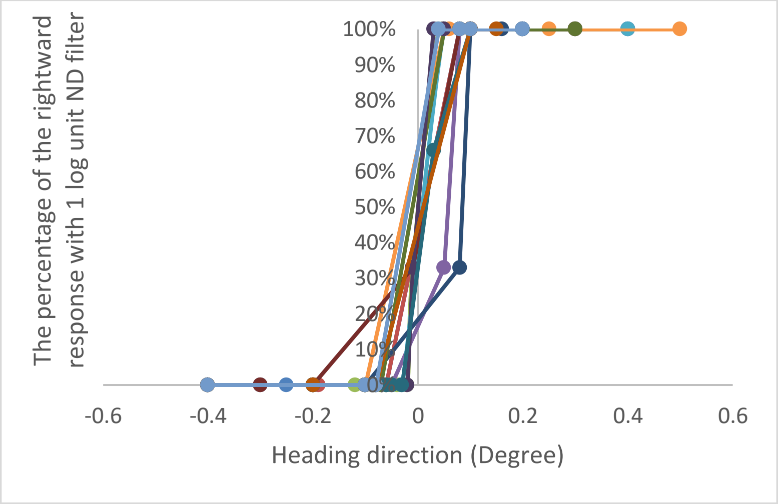

Figure 4-3 Shows the directional response of 13 participants with 1 log unit ND filter over the right eye. positive indicate rightward bias toward the side of the ND filter.

Mean bias value of directional response of the focus of contraction without ND filter 0.0031(± 0.02) and with 1 log unit ND filter (0.015^{o} ± 0.03) were slightly higher than the test value (zero) as showed in **table 4.1.**

4.4 Discussion of main study

4.4.1 Experiments utilizing neutral density filters

The main objective of this study was to investigate the effect of the reduction of light luminance in one eye on the perception of direction of focus of contraction in an optic flow field. Based on the pilot study, since no significant difference of the effect between 1 ND and 1.5 ND filters, 1 log unit ND filter was chosen based on pilot study. High dot density (75) and high speed (8) were chosen based on the pilot study. Although, low speed and low dot density were difficult for the participants to accurately judge the focus of contraction, it might produce a significant difference if the sample size was large enough. Our expectation was that the neutral density filter may affect the accuracy of the focus of contraction since there is different input between the two eyes and it might produce a bias in the directional response. However, our results showed no trend. Our results showed that the participants are able to identify the direction of focus of contraction even with light luminance reduced uniocularly. We observed that the mean threshold for both no ND filter and 1 log unit ND filters were quite similar meaning no statistically significant difference. In addition, there was no difference in the directional response bias of the participants with and without the ND filter. Monocular reduction of the light luminance in normal subjects had no effect on the perception of direction of the focus of contraction using the present parametres.

4.5 Conclusion

1- No significant effect of a 1 log unit neutral density filter on the accuracy judgment of direction of the focus of contraction of optic flow.

2- No significant directional response bias was observed.

Chapter 5

Discussion and conclusion

5.1 General discussion

The first objective of this study was to investigate the effect of the dot density, speed and reduction of the retinal luminance uniocular using ND filters on the perception of direction of focus of contraction of an optic flow. Our results indicated that the perception of focus of contraction in optic flow was significantly affected by speed. Low speed was difficult for the participants to accurately judge the direction of focus of contraction [27]. At a higher speed the threshold of the focus of contraction of the participants decreased. Dot density did not significantly affect the perception of focus of contraction of optic flow[27]. Uniocular reduction of the retinal luminance did not significantly impact the perception of the focus of contraction of optic flow, the participants are able to judge the focus of contraction angles even with neutral density filter placed over the right eye. In the first two conditions with 1 ND filter the response bias was slightly to the right (+) and the last two conditions were to the left (-), but there were not statistically significant from the accuracy value (zero). For 1.5 ND filter, the second condition the response bias was more to the right (+), and the other three conditions were to the left (-), but not significant from the accuracy value (zero).

An fMRI study showed that the reduction of the light luminance using ND filter had no effect on the activation of the areas that process motion perception and optic flow, and the study indicated that an activation has been seen in both hemisphere at the higher cortical areas that are processing optic flow while using ND filter over one eye[52]. In their study, they used the expansion and contraction of a concentric ring stimulus. However, in the present study, the stimulus consisted of dots creating the focus of contraction of an optic flow. Both of these stimuli simulate the same motion cortical areas[52]. The second objective was to determine whether the asymmetric image size using size lens will affect the accuracy or bias judgments of heading direction of focus of optic flow contraction or not. A significant effect was observed on the accuracy of heading direction of contraction of optic flow when the 5 % size lens was introduced over the right eye. There is no previous study to compare with our results. The size lens enlarges the retinal image, which is perceived as further away and induces a perceived tilt of the screen around the vertical axis away from the right eye. That could be similar scenario to changing directional of motion. Changing direction during navigation will affect the ability to perceive heading direction of optic flow because that changes the retinal flow image[9]. Similarly, size lens induce tilt, and that shift the view of the screen which affect the judge of the focus of contraction.

5.2 Conclusion

The aim of this study was to investigate the effect of monocular reduction of the light luminance and the differences of the image size on the perception of heading direction.

1- Accuracy for judging the direction of the focus of contraction is better for higher speeds.

2- No effect has been found with reducing the light luminance uniocular using neutral density filters 1 log unit and 1.5 log unit. The participants were able to judge the direction of heading even with ND filters.

3- The accuracy of the focus of contraction was affected by the asymmetrical retinal images using size lens.

4- No directional response bias has been observed with either neutral density filter or the size lenses.

5.3 Future Work

One of the major limitations of the present study is the sample size. In order for better statistical certainty a larger sample size should be used. One can also look for age and gender differences. As a previous study showed, there was a significant difference in gender for speed discrimination task, older women had higher threshold than older men [28]. In addition, there are differences in perception of motion between old and young groups. This can be another area of inquiry. Since no previous study have been conducted on effect of the reduction of retinal luminance or induced aniseikonia in motion perception in general, it is important to study the effects on motion perception as well as effects on heading direction for expansion and contraction across a range of stimulus parameters such as viewing distance, dot size and number of the dots. The ultimate aim of this direction of research is to establish norms for comparison between normal subjects and group patients such as Parkinson disease patients. Parkinson patients frequently show directional bias in their walking[29]. Some of the Parkinson disease patients have unilateral brain damage, and that might cause a transmission or processing delay between the two hemifeilds[29]. An interesting finding in this study is the bias. This brings about many interesting questions. For example, there is widespread evidence that a left-to-right bias could indicate a possible fundamental bias for visual motion, and would explain why all the main characters in the side-scrolling video games popular in the 1980s and 1990s [63]. Lateral motion bias could be associated with heading direction. Heading estimation could be affected by these biases[64]. It is also possible that these could be affected in cases with oculomotor dysfunction. Further research on a combined study for visual motion perception and motor dysfunction is needed for understanding whether the bias is related to motion perception or motor dysfunction.

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Appendix A

Feasibility study using ND filters

The purpose of this study was to examine the effect of the small neutral density (ND) filter on perception of focus of contraction.

Methods:

We used 0, 0.3, 0.6 and 0.9, 1 ND filters over the right eye in one participant. The stimulus was 75 dot run in speed 8 deg/sec, and the number of trials were randomly based on the participant response. We used these ND filters in five different days, one session for each filter.

Result:

The result showed that the accuracy of the threshold was quite similar for all ND filters non, 0.3, 0.6, 0.9, and 1 with 0.04°, 0.04°, 0.05°, 0.03° and 0.06° respectively.

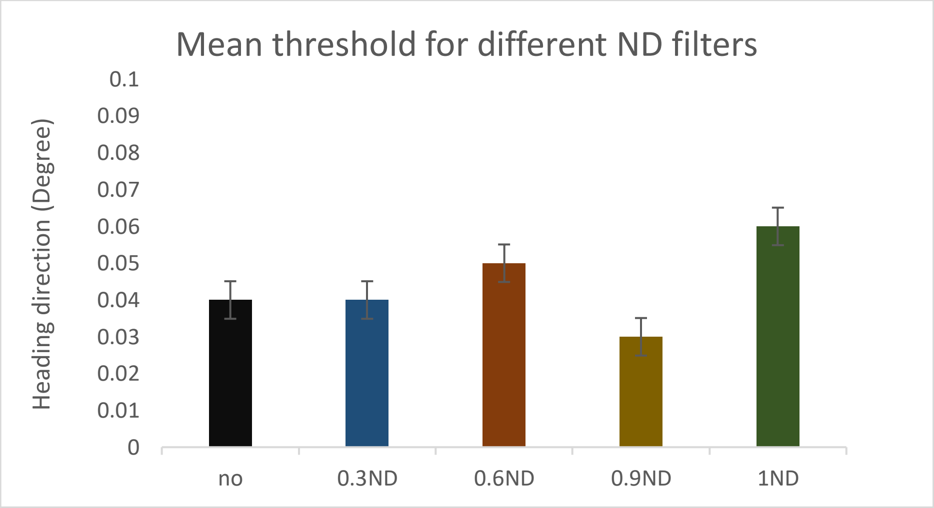

Figure 0-1 The mean threshold for five different ND filters (0 ND, 0.3ND, 0.6ND, 0.9ND and 1 log unit ND filters over the right eye in a single participant. Error bars represent the SEM for threshold measures.

Data for directional response was collected to determine whether there is a bias in directional response or not. Figure A.2 shows the directional response for all ND filters and each line indicate ND filter. No clear directional response bias was observed.

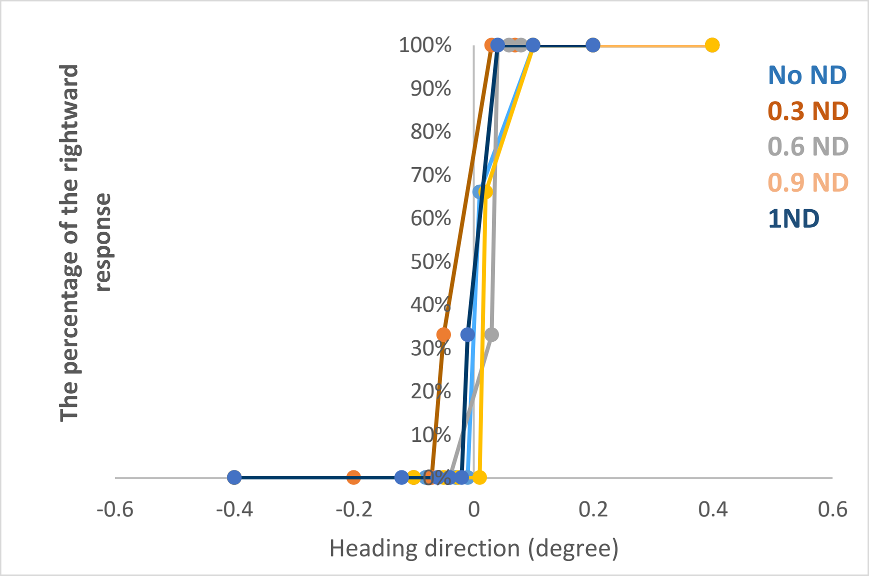

Figure 0-2 Show the directional response for one participant with series of ND filters over the right eye.

Show the directional response for one participant with series of ND filters over the right eye.

Discussion:

In this experiment, all ND filters had no effect on the perception of the focus of contraction. The accuracy threshold for all ND filters were similar meaning participant is able to perceive the direction of focus of contraction. Also, the participant is accurately judging whether the direction of the focus of contraction left or right which produce no bias in the directional response. Overall, reduction of the light luminace monocularly did not impact the perception of focus of contraction and that could be due to a separate visual motion areas processing these two mechanism.