Measuring Eye Movements While Tracking Accelerating and Decelerating Targets

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Abstract

Humans have an anisotropic perception of motion in depth. An object moving towards the eye is perceived correctly, but when an object is moving away the points closest to the eye appear to be moving faster than the points further away from the eye. This research examined if there is a difference between eye movement patterns during the two directions (forwards and away), how the eye tracks an accelerating or decelerating target, and if the anisotropic response to motion can be improved with practice. Participants were asked to watch a movie of a target moving across a computer screen. The target moved either left to right accelerating from a slow velocity (forwards condition), or right to left decelerating from a fast velocity (backwards condition). Participant's eye velocity and saccades were used to look for differences between the two conditions as well as changes over time (learning). It was found that mean tracking velocity errors differed between the directions, and at different time slices of the videos. Participants learned to make less tracking errors at the highest velocities during the backwards condition. Anticipation differed between the directions, as anticipation was only seen during the backwards condition. Participants learned to make saccades prior to the motion of the target, and the more trials they experienced the greater the learning results. Overall, a number of differences were identified between accelerating and decelerating movement conditions indicating that eye movements may play a role in the anisotropic perception of motion in depth effect.

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Chapter 1 - Introduction

Motion Perception and Directional Sensitivity

The perception of motion is different depending on its direction. An object moving towards the eye in three-dimensional space (3-d) is perceived at its actual constant velocity. Yet an object moving away from the eye appears to be moving at an unequal velocity. The points that are closest to the eye appear as though they are moving faster than the points in the distance. This is known as an anisotropic response to motion in depth (Perrone, 1986).

Anisotropic responses to motion in depth were demonstrated in an experiment carried out by Perrone (1986). Computer generated 2-dimensional images on a screen of 3-d long boxes moved towards or away from the eye. The participants reported if the boxes appeared to be rigid or expand/contract when they were approaching or moving away. The results showed that for the condition with motion towards the eye, the boxes appeared to be rigid. Therefore all points of the boxes appear to be moving at the same velocity. For the condition of motion away from the eye, participants reported the box appeared to contract; the points of the box closest to the eye appear faster than the points further away from the eye.

In everyday life some examples of this effect occurring include when viewing a train coming into a train station, or the receding view from the rear window of a bus. When the train is arriving into the station it appears normal, but when the train is leaving it appears to shrink. Figure 1 shows a train approaching a station.   The train is perceived at its actual size when it is moving towards the eye.

Figure 1: Example of a train approaching a station. Adapted from NZ Rail Photos, 2017, Retrieved from https://nzrailphotos.co.nz/photos/6933/AM-701-arriving-at-Parnell-4.JPG. Reprinted with permission.

However, if the train in Figure 2 was to depart the station it would appear to be shrinking. As the points A and B (closest to the eye) would appear to be moving faster than points C and D.

Figure 2: Example of a train departing from a station. Adapted from NZ Rail Photos, 2017, Retrieved from https://nzrailphotos.co.nz/photos/6933/AM-701-arriving-at-Parnell-4.JPG. Reprinted with permission. Points A and B represent the points closest to the eye.

It is proposed that the human visual system is not suited to perceiving depth for motion away from the eye. From an evolutionary point of view humans are more likely to need to judge the correct velocity of danger moving towards them. Humans do not usually walk backwards so our visual system does not normally view things that are receding (Perrone, 1986).

So why does it occur? If motion has just been reversed, why is it perceived differently? Are the parts of the visual system that are required for backward motion more primitive and different from the ones used for forwards motion? Have humans evolved to perceive forwards motion better than backwards or are there specialised detectors for expansion motion?

Besides the anisotropic response to motion in depth (Perrone, 1986) there are other examples of directional differences in our visual perception.

Direction anisotropy during 2-D motion

Size constancy is the phenomenon where the perceived size of an object does not change when the viewing distance changes. The image on the retina changes but the perceptual system compensates for this size change (Gregory, 1977). The perception of size constancy during forward and backward movement was shown to be greater during forward movement than backwards movement (Gregory & Ross, 1964). Participants moved forwards or backwards, while viewing a circle that shrunk when participants moved towards it, and expanded when participants moved away from it. The variation of sizes were adjusted by the participant until it appeared constant during forwards and backwards movement. The constancy during forward movement showed an anisotropic response to movement in different directions.

Ball and Sekuler (1980) investigated if anisotropies existed for moving targets in the peripheral field by observing reaction times to motion onset. They used stimuli that moved towards a point of fixation, or away from the point of fixation. They found reaction times away from the point of fixation were faster than reaction times towards the point of fixation. This difference or anisotropic response to motion that is towards (centrifugal) or away (centripetal) increased with stimulus eccentricity in the visual field.

A foveofugal drift effect was found by Georgeson and Harris (1978) using various stimuli with motion from side to side. They found counterphase gratings appeared to drift foveofugally or away from a fixation point, rather than foveopetally. This showed a directional asymmetry and an anisotropic response to motion.

Motion sensitivity across the visual field is assumed to be isotropic, that is the same for all directions of movement (left, right, up and down). To test for this Raymond (1994) presented either leftwards or rightwards motion along seven different locations within the visual field. This provided the motion coherence threshold – the minimum amount required for a subject to detect motion, and their sensitivity to motion. The results confirmed motion sensitivity across the visual field is isotropic for foveal or central motion during all directions. However directional anisotropy was found for peripheral motion. When movement is centripetal (moving towards the centre) the motion sensitivity or threshold for peripherally presented stimuli was greater, compared to centrifugal (moving out from the centre).

In order to demonstrate the visual systems' preference for centripetal motion Mateeff et al. (1991) evaluated the spatial error when localising a peripheral event. Subjects were asked to report if a moving target was to the left or right of a reference target when two lights came on near a fixation point. The moving target was either foveopetal (left to right) or foveofugal (right to left). Subjects repeated the task without the light signal present and with the target moving only halfway along its path. They noted the latency of perception of a moving target's position is shorter when a target is moving towards the fovea, than when it is moving away. Reaction time was measured for foveofugal and foveopetal motion using three types of targets – 1) Within-aperture (random pattern of dots of light), 2) En-masse dots, and 3) Single target. Reaction time was shorter for movement towards the fovea when using a single target. However when different, textured stimuli are used the reaction time for movement away from the fovea was shorter.

Anisotropy and Neurophysiology

Anisotropies have also been found in the distribution of cells sensitive to movement. Albright (1989) examined neurons and their preferred directions of motion in the middle temporal visual area (MT) in the Macaque. They found MT neurons with peripherally located receptive fields were directionally selective and showed a centrifugal bias. Therefore there are more MT cells tuned to motion expansion patterns (corresponding to forwards self-motion) compared to motion contraction (backwards self-motion).

The medial superior temporal area (MSTd) has been shown to respond to expanding radial motion that occurs as an observer moves through an environment (Tanaka et al., 1986; Tanaka & Saito, 1989). Duffy and Wurtz (1995) examined whether MSTd neurons that respond to radial motion will respond differently when the centre of motion is not in the centre of the visual field. Most MSTd researchers have found that the majority of the MSTd neurons have large responses to stimuli with the centre of motion in the centre of the visual field and the motion expanding radially outward. Far less neurons in this area are tuned to radially inward motion. Therefore the MSTd neurones seem to be specialised for forward self-motion rather than backwards motion.

Eye movements and the anisotropic response to motion in depth effect (ARMD)

When the anisotropic effect was first discovered by Perrone (1986), it was difficult to record and measure eye movements. When something moves in depth we follow it with our eyes. Several studies (Busettini, Masson, & Miles, 1996; 1997) found that eye tracking is elicited by objects moving in the direct line of sight and moving towards the eye. Could the ARMD effect arise from differences in the way we track towards and away motion?

"Eye movements are a response to a representation of the visual world" (Kowler, 2011, p. 1457). Two ways the visual system perceives the world are with eye movements called smooth pursuit and saccades. The fovea is the part of the retina that is responsible for our perception of high resolution features and fine detail. A lot of eye movements are designed to direct the line of sight of the eye so that the fovea is able to register the area of interest in the visual scene. Smooth pursuit is the slow, smooth tracking of an object foveally. Saccades are the instantaneous jumps of the line of sight that bring the fovea from one location to another. Smooth pursuit and Saccades are both used by the eyes in order to track motion.

While fixating on a stationary target, the eyes use slow eye movements – known as slow control. Slow control maintains fixation by controlling the retinal image velocity, rather than correcting offset errors in fixation. Microsaccades occur during fixation, these are very small jerk like involuntary saccades, and create the offset errors. (Kowler, 2011).

Eye movement patterns seem to be learned based on what objects are relevant. For example, during a driving experiment subjects noticed a stop sign by an intersection but did not notice stop signs in the middle of the block (Shinoda, Hayhoe, & Shrivastava, 2001). Saccades are made to a location before an expected event, e.g. for example cricket players will anticipate the bounce point of a ball (Hayhoe & Ballard, 2005). The roles of eye movements used in the control of daily living were examined by Land, Mennie, and Rusted (1999). They recorded eye movements while people carried out an everyday well-learned task (e.g., making a cup of tea). They found the pattern of fixations and saccades were related to each stage of the task, and the eyes monitored every step of the process.

Eye movements such as saccades and smooth pursuit are used to track targets, and slow control is used during fixation of a target. Smooth pursuit is more likely to be used for lower velocity movement, and saccades are more likely to be used for higher velocity movement. But what happens when the targets that are being tracked are accelerating or decelerating? The ARMD effect involves objects that are moving in depth, and the points closest to the eye when viewing motion appear to be accelerating for objects approaching, and decelerating for objects receding.

Smooth Pursuit Responses during target tracking

The Smooth Pursuit system moves the eyes to try to steady the retinal image of motion (Rasche & Gegenfurtner, 2009). The motion is the stimulus that activates the eye movement, and the system acts as a negative feedback controller (Carl &

Gellman, 1987). Smooth Pursuit eye movements during random target motion were examined to see if they were dependant on moving retinal images by Carl and Gellman (1987). The targets used had different combinations of changes in positions and velocity. Any interactions from saccades were eliminated by only using the pre-saccadic portions of responses. They found the latency of the smooth pursuit response was consistent – approx. 100 milliseconds (msec); the latency increased for lower velocity targets. All participants were able to track targets moving at 5 and 10°/s, some were unable to follow at 20°/s and no subjects were able to track at 40°/s. Because participants were only able to track targets at lower velocities, only the lower velocities were used when introducing a velocity or position step when the participant was already tracking. The response to a target position step was a brief eye acceleration. The accelerations were greater when the position step of the target was away from the direction of tracking, but were lower when the step was in the same direction.

In order to successfully observe motion when a peripheral target moves, the eyes use saccades (a fast eye movement) to correct position error, then the smooth pursuit system to track the object (Braun & Gegenfurtner, 2016). The directional precision while initiating tracking - by using saccades, smooth pursuit, or a combination of the two was examined by Braun and Gegenfurtner (2016). Their results showed pursuit responses after target motion onset improved, irrespective of the targets velocity. Saccades occurred earlier than pursuit responses after target motion onset. Directional precision improved during trials with longer latencies, so the precision was dependant on time since motion onset and not pursuit onset. The directional precision of saccades to static targets was better than to moving targets. Therefore, directional precision is dependent on saccades initially, until the pursuit system improves and takes over.

The visual system does not always seem to be sensitive to acceleration. For example: an apple falling from a tree will accelerate up to the rate of gravity (9.8 m/s^2); however humans will find it difficult to perceive the acceleration (Haarmeier & Thier, 2006). Calderone and Kaiser (1989) investigated the thresholds for the human visual system to detect acceleration and deceleration along the horizontal and vertical axes. Three velocities were used 0.7, 1.2, and 1.7 °/second. Their results showed that acceleration is easier to detect vertically and deceleration is easier to detect horizontally. They also found that the thresholds for acceleration detection are higher than the limits for velocity difference detection.

To see if smooth pursuit assisted the ability to perceive velocity changes Haarmeier and Thier (2006) analysed speed discrimination in participants with normal vision and participants with pursuit disturbances due to neurological diseases. By using just noticeable speed changes they found that the participants with normal vision were able to detect velocity changes while tracking the targets and using smooth-pursuit, than when they were asked to watch a stationery target and judge a moving target's velocity. The participants with pursuit disturbances were insensitive to deceleration and showed a bias for reporting accelerations. This showed the smooth-pursuit system does help detect velocity changes.

Traschütz, Zinke, and Wegener (2012) also investigated the ability to detect velocity changes, except their study focused on the ability within foveal or peripheral vision. They found detection depended on eccentricity. The foveal thresholds were lower for acceleration than deceleration, but the peripheral thresholds were higher for acceleration than deceleration.

Sensitivity to acceleration over distances and whether our knowledge of gravity creates anisotropies in the detection of vertical acceleration and deceleration was explored by Mueller, González, McNorgan, Steinbach, and Timney (2016). Their expectation was that the visual system would be better at detecting and pursuing objects that accelerated or decelerated over longer distances, than smaller distances. The visual system is also more likely to need to avoid or intercept something moving downwards due to the effects of gravity, so a bias may have developed due to previous exposure. They found there was more sensitivity to downward acceleration and deceleration, as detection was more accurate for downwards motion than upwards. There was little difference between the acceleration and deceleration conditions during upwards motion. Detection is better for large apertures than small ones, so the distance an object travels does affect perception of vertical acceleration and deceleration. Therefore the visual system does have a bias for downward motion.

The above findings show that the visual system uses both smooth pursuit and saccades to observe target motion, and there are differences between acceleration and deceleration sensitivity. The bias that exists due to previous exposure may also provide an anticipation effect that leads to eye movements anticipating motion.

Anticipation

Motion away in 3-D creates sudden deceleration in 2-D. In the ARMD effect experiments, a target (e.g., edge of the box) is stationary then it is suddenly moving towards the centre over many trials (Perrone, 1986). The observer sees a rapidly decelerating object over and over again. Could this result in anticipation? Anticipatory eye movements occur when the eyes drift in the expected direction of motion before the motion begins. They can lead to variability in velocity at the onset time of target movement. Anticipatory eye movements occur because participants will try to guess when the target will move. Randomising the onset time of target movement does not remove anticipation from occurring, but it does minimise the variability in velocity (Kowler & McKee, 1987). Anticipatory eye movements occurred about 200msec before the onset of target movement during the investigation by Kowler and McKee (1987) that looked at the sensitivity of smooth pursuit to small differences in target velocity. Instead of looking at the accuracy of pursuit (how close the eye matches the velocity of a target) they used the oculomotor difference threshold. The oculomotor difference threshold is the smallest difference in target velocity that produces distinguishable smooth pursuit movement velocities. Because subjects found it difficult to pursue the target effectively at the same time as making perceptual judgements about velocity, they decided to measure oculomotor and perceptual velocity separately. They found the mean eye velocity and variability of eye velocity showed smooth pursuit precision was optimal about 500-800msec after the onset of target motion. The oculomotor difference thresholds were largest during the first 200msec of target motion then declined. About 600-700msec after the start of target motion they reached the perceptual difference threshold (the smallest difference between two velocities that can be detected).

The role of anticipatory eye movements in day to day life may be to compensate for processing delays. Most of the movement that is experienced on a daily basis will be predictable, and anticipatory movements will help with large pursuit errors that are caused by delays (Kowler, 2011).

One way to minimise anticipatory eye movements and predictive behaviour is to use randomised stimuli (Carl & Gellman, 1987). Carl and Gellman (1987) used different types of target motion, including velocity changes and different directions, plus randomised stimulus onset period. They found it was successful and anticipatory responses were minimised.

The above findings show that anticipation does occur and that participants have learnt through practice when targets are likely to move. If perceptual learning of anticipation occurs, then maybe the anisotropic response to motion may change over time. Most psychophysical experiments such as Perrone (1986) use many trials and the stimuli are seen over and over again. So an ARMD experiment done with many trials may produce different perceptual effects over time. We experience forward motion all the time, but backwards motion is less common. Have we learnt to perceive the retinal image motion generated during forward movement differently from the image motion we experience while moving backwards?

Learning

Perceptual learning occurs when practice or training improves the ability to discriminate between objects. Practice has an effect on decreasing the number of errors made (Gibson, 1969).

Ball and Sekuler (1982) investigated if it is possible to train discrimination between the directions of moving targets. They used 8 different directions 0˚ (right), 45˚, 90˚ (up), 135˚, 180˚, 225˚, 270˚, and 315˚. Observers fixated on a dark stationery point in the centre of a display and had to report if the motion observed in two trials were the same or different. Every 50 trials a new array of stimuli was used to avoid participants learning the details of the spatial array of the stimuli (400 bright random dots). Data were collected during seven sessions. Sessions 1, 4 & 7 looked at discrimination performance for all 8 directions and 2, 3, 5 & 6 trained on one direction with 500 same or different judgements (10 x 50 trial blocks). They found discrimination was better for principle directions (up, down, left right) than for the other four directions. Training direction performance improved across sessions and training was not effective for the three directions most different from the trained direction.

In the experiment detailed above by Ball and Sekuler (1982), they also discovered that enhancement of discrimination between directions was shown at a 3-week and 10-week retest without extra training. This showed that discrimination learning lasted for several months and the participants had retained the effects from training.

Within subject performance, changes may occur due to boredom (off target results) or practice (improvement). Ettinger et al. (2003) examined the temporal stability of eye movements within subjects by using test and re-test reliability. The effects from within-sessions results showed the susceptibility of oculomotor tasks to practice effects. They used smooth pursuit, fixation, antisaccade, and prosaccade tasks over two months. They found that oculomotor performance was stable over time. The effects of practice were most consistent during the antisaccade task, because there was a reduced error rate and better spatial accuracy at retest. The participants with the poorest initial performance during the antisaccade task improved the most, so they benefited from the practice. There was a lack of within-session changes so performance was reliable.

Summary and aims of this research

In summary, the visual system has an anisotropic response to motion - the perception of motion differs based on its direction. The visual system uses the smooth pursuit system to observe an object moving initially, then the system uses saccades to catch-up. The goal of this research is to first determine the source of the anisotropic effect – that the perception of motion is different when it is moving towards the eye compared to when it is moving away. Perrone (1986) never looked at eye movements and so the question remains if eye movements are important in the ARMD effect? Could the perceived difference be attributed to different eye movement patterns in the two cases (forwards vs backwards)? The second goal of this research is to investigate if the perception of motion is able to be improved with practice. The research focused on patterns of eye movements and how they differ between the two directions. The question this research tried to answer was: Can the visual system learn to track an accelerating or decelerating target that is moving away or towards the eyes more effectively? If this is a learned behaviour and tracking improves, this could be used as a diagnostic tool to assist cognitive recovery in patients who have experienced a stroke or traumatic brain injury. Previous research (Liston & Stone, 2014; Liston, Wong, & Stone, 2017) has shown how aspects of eye movement responses can be used within a psychometric test to indicate sensorimotor functional status.

To answer these questions, we set up an experiment with an accelerating and decelerating stimulus (moving dot) that mimicked the type of image motion that occurs when people view approaching and receding objects. The eye movements of the participants were recorded and a number of measures (velocity, saccades) were used to look for differences between the two conditions as well as changes over time (learning). Any learning effects were tested by running a group of participants through the experiment twice (in two separate sessions), with double the number of trials and looking for differences in performance compared to the participant’s performance in one session.

Chapter 2 - Experiment

Participants

Seven male and ten female participants took part in this experiment. Participants were aged between 18 to 42. All participants had normal to corrected normal vision. All participants were undergraduate students who received a 1% course credit for one session, or 2% course credit for two sessions. Seventeen participants took part in the study and 11 participants repeated the experiment for a comparison of results over time. One participant had to be excluded because the eye tracker was unable to track their eyes correctly, and their session was aborted after eight trials. Ethics approval was provided by the University of Waikato, School of Psychology Research and Ethics Committee. A copy of the recruitment poster can be found in Appendix A.

Apparatus

This experiment was run on a Dell OptiPlex 760 MT Minitower PC, running Windows XP Professional 32 bit SP2 operating software. The stimuli were displayed on a ViewPixx 2001c LCD monitor with a 57.15cm display (48.5cm width x 30.3cm height), and a resolution of 1920 x 1200 pixels. The screen refresh rate was 60Hz. Right eye movements were tracked and recorded using the EyeLink 1000 Desktop System at a rate of 1000Hz (EyeLink 1000, SR Research, Ltd., Ontario, Canada). Head position and distance to the screen was stabilised using a chin rest. This ensured participants eyes were constantly vertically and horizontally aligned to the centre of the monitor which was 65 cm away. The experiment was held in a windowless room, with only a small lamp on (100W turned away from the participant). This stopped participants from completely dark adapting during the session.

Stimuli

The experiment was run using SR Research Experiment Builder (Version 1.10.1630, @2004-2013, SR Research Ltd). The videos that were displayed were generated using custom software Matlab (R2017A, The Mathworks, Inc.) and saved as .avi files. These were converted to .xvd files so they could be played in the Experiment Builder software used to run the experiment. The main stimulus used throughout this experiment was a dot on a screen that moved either left or right (shown in Figure 3). The motion of the dot was generated by simulating a point in space that was moving towards an observer.

The dot consisted of an intensity profile based on a 2-D Gaussian function with a standard deviation of 5 pixels. The amplitude was set to an intensity level of 255 which corresponds to white in the videos. The background was set to 0 (black). A fixation cross was located at the starting position of the moving dot and the cross had arms that subtended .33 of a degree.

The video displayed either a cross on the left side for 2000 msecs before the target moved to the right (forwards motion condition), or a cross on the right side for 2000 msec before the target moved to the left (backwards motion condition). Each target moved for a total of 1883 msec. An example of the targets position on the screen every 468msecs is shown below in Figure 3.

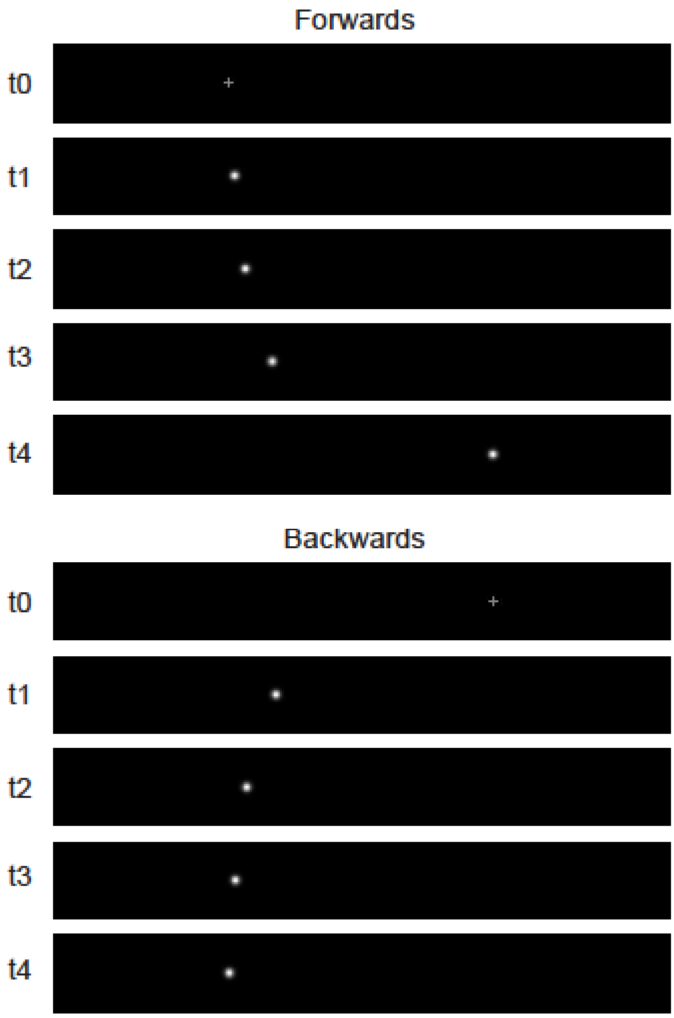

Figure 3: Target position during forwards and backwards video every 468msecs.

Forwards positions are shown at the top and backwards positions are shown at the bottom. t0 represents the static portion of time, when the target was a fixation cross and not moving. t1 represents the position of the dot 468msec after the target changed to a dot and started moving, t2 and t3 represent the position of the dot 936msec and 1404 msec after the dot started moving. t4 represents the final position of the dot at the end of each trial.

The dot position on the screen for each frame was calculated using projective geometry where the X screen position was found from X = f * x/z, where f is the distance to the screen in pixels (2573), x = .05m and z is the position of the dot in depth at the frame time. During the forward motion condition (towards the eye) the dot began at a point 0.5m to the right of the line of sight of the observer and 4m away. The target travelled at a velocity of 2m/sec. The sampling (video rate) was assumed to be 60HZ (16.55 msecs per frame) and the dot moved for 1.88 secs (113 frames). During the backward motion condition (away from the eye), the direction of motion was reversed and the target began at the distance that the approaching dot stopped moving.

In order for the motion to be symmetrical around the centreline of the observer, the middle of the path that the dot travelled over on the screen was centred, so that the target was located at the screen centre (X = 960, Y = 600). This meant that the motion on the screen no longer represented an object moving past the head, but the target still contained an acceleration and deceleration profile that is typically experienced when people track an object moving in depth. This study examined 2-D motion, and how the eye tracks an accelerating or decelerating object. Throughout the thesis these two conditions will still be referred to as ‘forwards’ and ‘backwards’ to show the link to the original ARMD experiment (Perrone, 1986).

Figure 4 show plots of the target velocity over time during the forwards and backwards conditions.

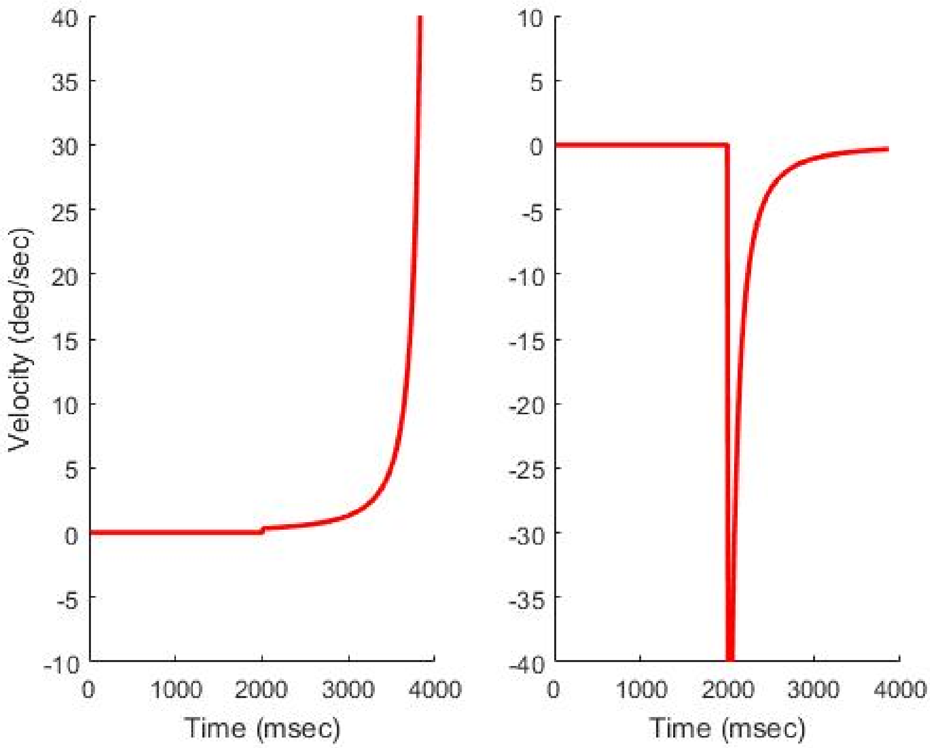

Figure 4: Example of target velocity over time during forwards condition (left) and backwards condition (right).

During the forward condition the target was still for 2000 msec, then the velocity slowly started to increase. During the backwards condition the target was still for 2000 msec, then the target moved at a high velocity and slowed over time.

Design

A within-subjects, repeated measures design was used for all participants. All of the participants viewed the same videos in a randomised order. There were a total of 72 trials, broken up into four blocks of 15 trials then one block of ten trials. Participants also had two practice trials before the experiment started. After the practice trials and each block, a picture of a cartoon would appear on the screen as a mini break. The participant was asked to click the mouse to continue the experiment when they were ready. This break allowed the participant to have a rest, refocus their attention, and allow the eyes to return to random eye movements. A pilot study using the researcher as a participant showed that 15 trials was the maximum number a participant could focus on the video, without their attention wandering, or their eyes becoming fatigued.

Therefore after the participant finished five blocks of trials, they were given a 5 minute break before the second half of the experiment was completed.

Procedure

Each participant was provided with an information sheet which described the experimental process. They were told they would be watching a video of a target moving, and that all they had to do was watch the target move to the best of their ability. After reading the information sheet they were asked to fill out a consent form. A copy of the instruction sheet and the consent form can be found in Appendices B and C. A standard calibration and a validation procedure was then carried out on the eye tracker. Once this was completed a cartoon picture appeared, and the participant was asked to click the mouse to start the experiment. The first practice trial began with the video displayed centrally on the screen. The target appearing indicated the beginning of the video. The video lasted for 3883 msec, then the screen changed to a solid grey colour rgb = (128, 128, 128) for 4000 msec. Once the first trial had ended, the second practice trial began, followed by the next cartoon picture. After the two practice trial blocks, the experimental blocks of either 15 or 10 trials began with cartoon pictures displayed after each block. Every participant experienced 72 trials followed by a five minute break then another 72 trials broken up into practice trials and experimental blocks. In total each participant viewed 144 videos (72 were forwards and 72 were backwards). Eleven participants were invited back to repeat the experiment to provide a comparison of results. The shortest length of time between participation in the experiment was seven days and the longest length of time between participation in the experiment was 15 days.

Data Analysis

The Eyelink data were converted into a readable file (.asc). Data from the experiment were analysed using code written in Matlab (Version R2017a); Mathworks. Eye positions during the period of time that the target was visible until the end of the target moving were used for all analyses (3883 msec). The X position versus times traces were smoothed using a 2-D Gaussian filter (standard deviation = 10 milliseconds). Velocity was derived from change of positions over time ($\frac{P2-P1}{T2-T1}$), where P equals the different positions in pixels and T equals the timestamp of those positions (milliseconds). This velocity (in pixels per millisecond) was converted to degrees per second and this is the unit for velocity reported throughout the thesis.

The main measure of performance was eye velocity. An example of individual velocity results is shown in Figure 5. Blue represents the participant's average eye velocity over all the forwards or backwards trials and red represents the target dot velocity on the screen. The graph on the left represents the forward trials and the graph on the right represents the backward trials. When the blue line is above the red line then the participant's eye velocity is faster than that of the target (leading). When the blue line is below the red line then the participant is slower than the target (lagging). This graph shows when participants eye velocity were faster (leading) or slower (lagging) over the trial, compared to the target dot velocity. The graph also shows the participant's maximum eye velocity per trial.

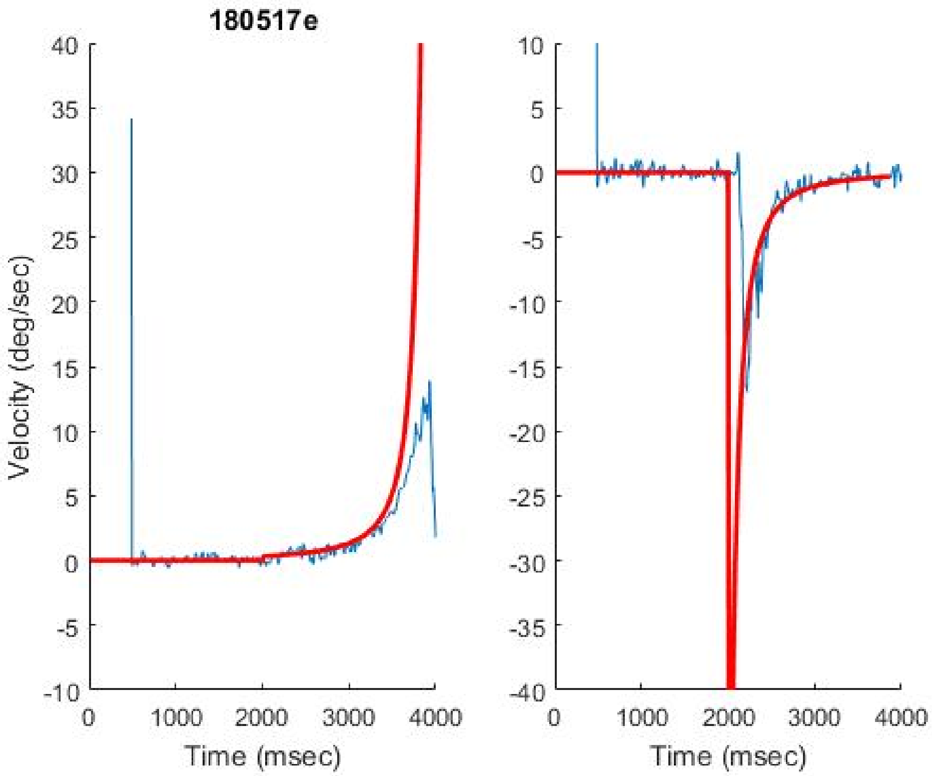

Figure 5: Example of average eye velocity over all trials.

This experiments focus is on the number of mean velocity tracking errors that occurred as velocity changed. Velocity tracking error was defined as eye velocity minus target velocity. This measure was used to address questions such as: Did mean velocity errors reduce if participants repeated the experiment? At what point in time did anticipatory eye movements begin? Did participants' performance change over time and over repeated sessions? Finally did the participants show that they were learning to track motion with less errors as the trials progressed?

Chapter 3 - Results

The velocity of eye movements while pursuing the dot in two conditions (forwards vs backwards) were examined first.

Mean Tracking Errors

The overall mean tracking errors (eye velocity minus target velocity) during three segments were compared for both forwards and backwards conditions. Figure 6 shows the time slices selected during the two conditions.

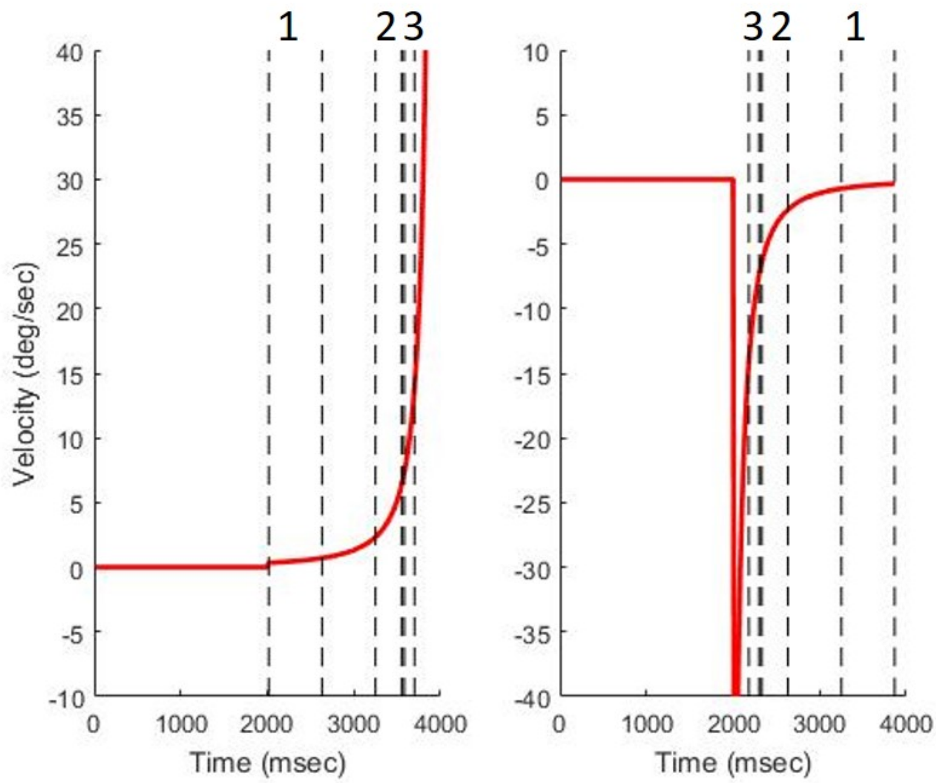

Figure 6: Time segments selected during forwards and backwards conditions. The numbers 1, 2, and 3 show the time period each segment covers.

For the forwards condition, the first time segment (1) covered between 2017 and 2631 milliseconds. The second time segment (2) covered between

3249 and 3549 milliseconds. The third time segment (3) covered between 3583 and 3699 milliseconds. In order to compare the same target velocities across the two conditions the order of the time segments (1, 2, & 3) were reversed for the backwards condition. For the backwards condition, the first time segment (1) covered between 3252 and 3866 milliseconds. The second time segment (2) covered between 2334 and 2634 milliseconds. The third time segment (3) covered between 2184 and 2300 milliseconds.

The mean and standard deviation of tracking errors during three segments of the movie were obtained and averaged over all participants. The backwards data were flipped to keep the results consistent, so that a negative error meant participants were lagging behind the target.

First Experimental sessions.

The data from the first experimental sessions for all participants were examined first. Figure 7 shows the mean tracking errors during three movie segments for the first experimental session. Blue represents forwards and red represents backwards. If the participant's mean tracking velocity for all trials were faster than the targets velocity then the mean is greater than 0, whereas if the participant's mean tracking velocity for all trials were slower than the target then the mean is less than 0.

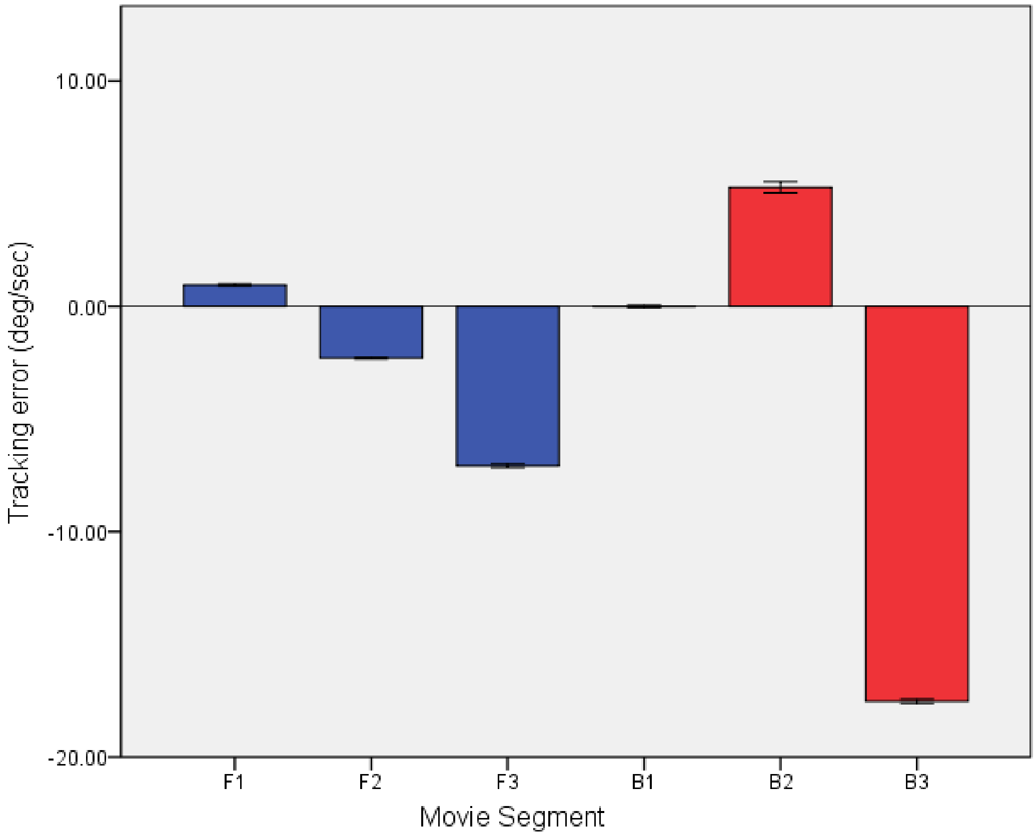

Figure 7: Mean tracking error during 3 segments for forwards and backwards trials for the first experimental session. Above 0 means faster than target, below 0 means slower than target.

For the forwards trials, participants' eye velocity were faster than the target at velocity slice one, by segment two the eye velocity were lagging behind, and by segment three the eye velocity were significantly lagging behind. For the backwards trials, participants' eye velocity were slightly faster than the target at segment one, at segment two the eye velocity were significantly faster than the target, and at segment three the eye velocity were significantly lagging behind the target.

A repeated measures ANOVA was conducted to evaluate if there were significant differences between the calculated mean velocity tracking errors during three segments for the forwards and backwards trials for the first experimental session (Refer to figure 7 above).

Mauchly's test of sphericity (p>0.05) was met for the effect of direction as there were only two conditions. Mauchly's test of sphericity showed that the assumption of sphericity was not met for the effect of different velocities, $x^2(2)$ = 24.746, p =<.001. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=).640.

Unless otherwise stated p=<0.05). There was a significant difference between the two different directions, F (1, 31) = 172.369, p<.001.

There was a significant difference between the means of the different velocities, F (1.281, 39.7) =7998.82, p<.001.

There was a significant difference interaction effect between the direction and the different velocities, F (2, 62) = 2726.191, p<.001. This indicates there were significant differences between the two directions, between the different velocities and between the two directions during different velocities.

Repeat Participants.

In order to see if eye tracking behaviour changed when more trials were run, the mean and standard deviation of tracking errors from participants who ran two sessions with many more trials were examined next.

The mean and standard deviation of tracking errors during three segments of the movie were obtained and averaged over all repeat participants. The backwards data were flipped to keep the results consistent, so that negative error meant participants were lagging behind the target

Table 1 and 2 shows the mean and standard deviation of eye velocity tracking errors during three movie segments for the first experimental session and repeat participants. If the participants' mean tracking velocity for all trials were faster than the targets velocity then the mean is greater than 0, whereas if the participants' mean tracking velocity for all trials were slower than the target then the mean is less than 0.

Table 1*: First session means and standard deviations of eye velocity tracking errors during three segments during forwards and backwards conditions.*

	1	2	3
Forwards			
Mean	0.9484	-2.295	-7.0772
SD	0.29578	0.25278	0.4731
Backwards			
Mean	-0.0022	5.2866	-17.5238
SD	0.30362	1.38376	0.48974

Table 2*: Repeat participant means and standard deviations of eye velocity tracking errors during three segments during forwards and backwards conditions.*

	1	2	3
Forwards			
Mean	0.8793	-2.2116	-6.9814
SD	0.23715	0.25813	0.26819
Backwards			
Mean	0.0645	5.3114	-17.4218
SD	0.50443	1.40123	0.48734

The repeat participants' mean eye velocity tracking errors showed a slight reduction. For the forwards trials, repeat participants' eye velocity were faster than the target at velocity segment one, by segment two the eye velocity were lagging behind, and by segment three the eye velocity were significantly lagging behind. For the backwards trials, repeat participants' eye velocity were slightly faster than the target at segment one, at segment two the eye velocity were significantly faster than the target, and at segment three the eye velocity were significantly lagging behind the target.

Discussion.

The results showed significant differences for first sessions and repeat participants' between the directions and also between the velocity segments that were analysed. Both forwards and backwards results showed that at velocity segment one all participants were faster than the target. At velocity segment two (in the middle of target movement) participants were lagging behind the target during the forwards condition, but in front during the backwards condition. At velocity segment three (at the end of target movement for forward but beginning for backwards) all participants were lagging behind the target for both forwards and backwards conditions, but there were larger errors for the backwards conditions. Repeating the experiment did not alter the results significantly as shown in Table 1 and 2. The slight reduction in the mean tracking velocity errors by repeat participants' may have resulted in some learning/practice effects. The test segments were broken down into a wider range of time slices to see if there was a particular time/target velocity that revealed differences.

Analysis of change in tracking errors at particular target velocities

In order to look for changes in tracking errors over trials, the analysis looked for trends in errors over trials. A scatter plot was generated over the trials (1-36) against the velocity tracking error. A regression line was fit to the scatter plots which produced a slope. Positive slope indicates error was increasing over the trials and a negative slope indicates error was decreasing over the trails. Six different slices for different parts of the movie (during different velocities) were sampled for both forwards and backwards conditions. This looked in more detail at the errors over a wider range of time slices to confirm if there was a particular time/target velocity that showed a difference between the forwards and backwards conditions. Refer to Figure 4 for plots of the target velocity over time during the forwards and backwards conditions

The six different target velocities that were used were 0, 0.5, 1, 2, 5.2 and 10.4° per second. During the forwards video the time slices 1500, 2300, 2820, 3183, 3500, and 3650 represented those velocities. During the backwards video the time slices 1500, 3600, 3067, 2700, 2383, and 2233 also represented those velocities. These velocities were selected using log2 steps when possible to allow for the acceleration/deceleration. The rapid change in velocity between frames at the end (forwards) and beginning (backwards) meant that 5.2°/s and 10.4°/s were the closest to the log 2 steps that were available for selection. Figure 8 shows the different time slices that represented different target velocity for both conditions. The forwards trials are on the left, and the backwards trials are on the right.

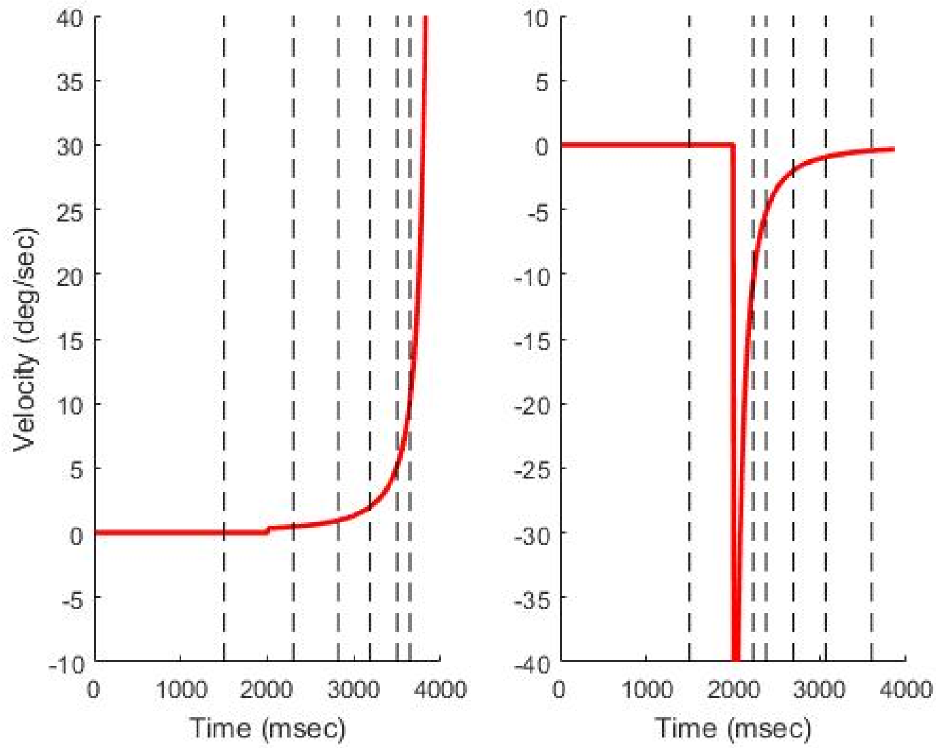

Figure 8: Six time slices representing different target velocities sampled for forwards (left) and backwards (right) trials.

First Experimental sessions.

The data from the first experimental sessions for all participants were examined first. Figure 9 below shows the participant's tracking error changes over trials during their first experimental session compared to the target velocity during six different movie frame slices and speeds. Blue represents forwards and red represents backwards If the participants' tracking error changes were increasing over the trials then the error is greater than 0, whereas if the participants' tracking error changes were decreasing over the trials then the error is less than 0.

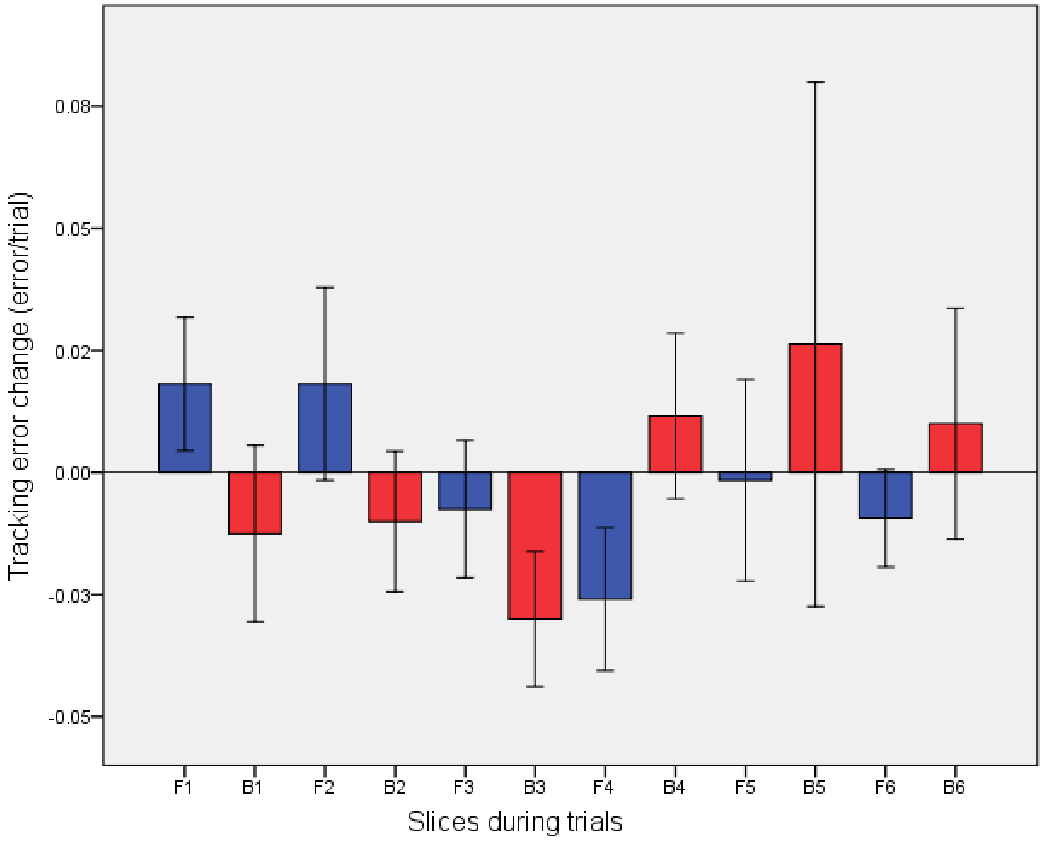

Figure 9: Tracking error changes at 6 different slices during trials for first experimental sessions. If above 0 then error is increasing, if below 0 then error is decreasing.

For the forwards trials participants' tracking errors over trials, increased at the lower velocities until the velocity was between 1 and 2°/s (F3 – F4) then their tracking errors over trials decreased as the target accelerated. Their ability to track the target improved during the 36 trials for that condition, especially when the target was moving at a modest speed (2°/s, F4)

For the backwards trials participants' tracking errors over trials, increased at the highest velocities until the velocity was between 1 and 2°/s, then their tracking errors over trials decreased as the target decelerated. Tracking performance improved over trials for the slower rates (B1 – B3) but nearly always got worse over trials for the high velocity/acceleration part of the movie

(B4 – B6). The error bars were extremely long at 5.2°/s during the backwards condition. This shows a very large amount of variability between participants.

A repeated measures ANOVA was conducted to evaluate if there were significant differences between the changes in tracking errors over trials at six different slices during forwards and backwards trials for first experimental sessions.

Mauchly's test of sphericity (p>0.05) was met for the effect of direction as there were only two conditions. Mauchly's test of sphericity showed that the assumption of sphericity was not met for the effect of different velocities, $x^2(14)$ = 51.6, p =<.001. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.525).

Unless otherwise stated p=<0.05). There was no significant difference between the two different directions, F (1, 31) = 0.003, p=.957.

There was no significant difference between the tracking errors over trials during the different velocities, F (2.626, 81.399) =.491, p=.665.

There was no significant difference interaction effect between the direction and the different velocities, F (5, 155) = .818, p=.539. This indicates on the whole there were no significant differences between the two directions during the different velocities sampled segments.

Repeat Participants.

In order to see if eye tracking behaviour changed even more when a greater number of trials were run, the tracking error changes over trials by participants who ran two sessions with many more trials were examined next.

Figure 10 below shows the repeat participants' tracking error changes during their sessions compared to the target velocity during six different movie frame slices and speeds. Blue represents forwards and red represents backwards. If the participant's tracking error changes were increasing over the trials then the error is greater than 0, whereas if the participants' tracking error changes were decreasing over the trials then the error is less than 0.

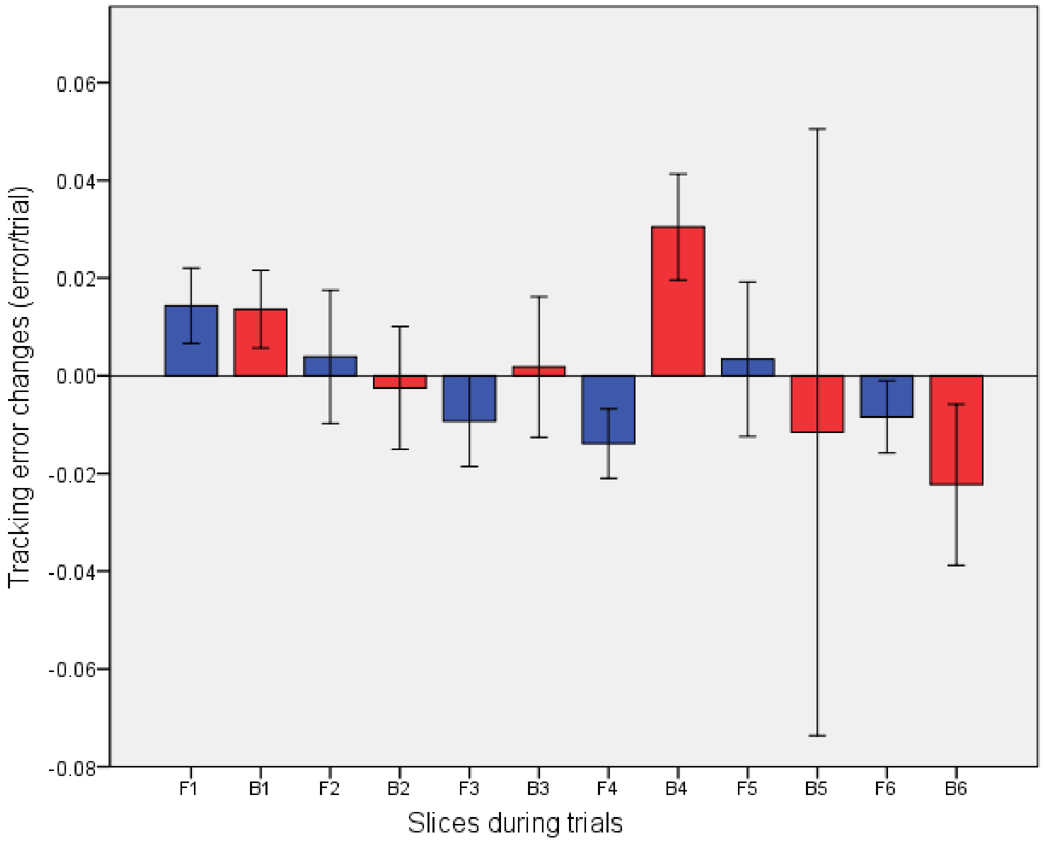

Figure 10: Tracking error change at 6 different slices during trials for repeat participants. If above 0 then error is increasing, if below 0 then error is decreasing.

For the forwards trials repeat participants' changes in tracking errors over trials increased until the velocity was approximately 1°/s, then their changes in tracking errors over trials began decreasing. When the target was at 5°/s participants' changes in tracking errors over trials increased again, then their changes in tracking errors over trials started to decrease. For the backwards trials the participants' changes in tracking errors over trials increased at 0°/s, decreased at 0.5°/s, increased between 1°/s and at 2°/s, then their changes in tracking errors over trials decreased as the target accelerated. The error bars were extremely long at 5.2°/s during the backwards condition. This shows a very large amount of variability between participants.

A repeated measures ANOVA was conducted to evaluate if there were significant differences between the changes in tracking errors over trials at six different slices during forwards and backwards trials for repeat participants

Mauchly's test of sphericity (p>0.05) was met for the effect of direction as there were only two conditions. Mauchly's test of sphericity showed that the assumption of sphericity was not met for the effect of different velocities, $x^2(14)$ =158.204, p =<.001. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.336).

Unless otherwise stated p=<0.05). There was no significant difference between the two different directions, F (1, 43) = .079, p=.780.

There was no significant difference between changes in tracking errors over trials during the different velocities, F(1.68, 72.22) =.512, p=.570. However planned contrasts revealed that the velocity at slice 6 (10.4°/s) was significantly different to slice 1, $F(1, 43) = 10.456$, $p=.002$. Contrasts also revealed that the changes in tracking errors over trials at slice 4 (2°/s) was significantly different between the two directions, $F(1, 43) = 12.284$, $p=.001$.

There was no significant interaction effect between the direction and the different velocities, $F(5, 215) = .510$, $p=.769$. This indicates on the whole there were no significant differences between the two directions during the different velocities sampled slices.

Discussion.

This analysis looked at changes in tracking performance over time by measuring the tracking error change during the 36 trials. The tracking error change was examined at multiple times during the target movement to see if the changes in performance were more obvious at particular parts of the target motion. The first session results showed that when the velocity of the target was slow, the participants' changes in tracking errors over trials decreased during the backwards condition (decelerating target) but increased on occasion during the forwards condition (accelerating target). As the velocity of the target increased the participant's changes in tracking errors over trials increased during the backwards trials, but decreased during the forwards trials. A decrease in tracking error during trials was especially noticed for backward motion at around the 2883msec mark when the target was moving at 5.2°/s and rapidly decelerated. These results indicate participant's changes in tracking errors over trials increased at the start of the forwards condition, and decreased as the trial progressed. Statistically the differences were not significant between directions.

The repeat participant's results showed at slower velocities the changes in tracking errors over trials increased during both the forwards and backwards conditions. As the target velocity increased the participants' tracking errors decreased during the forwards and backwards conditions, except at the point when the target was moving at 2°/s. The results showed a significant difference between the tracking errors over trials at the lowest target velocity compared to the highest target velocity, especially during the backwards condition. There was also a statistically significant difference between the two directions at 2°/s.

The repeat participants' results showed that repeating the experiment lead to participants' decreasing their tracking errors at the highest velocity during the backwards trials. There was also a difference that occurred when the target was at 2°/s between the conditions. When the target was moving forwards participants' tracking errors were decreasing, but when the target was moving backwards participants' tracking errors were increasing. This only appeared when the repeat participant's data were analysed. This provided evidence of a change in behaviour i.e. learning to make less tracking errors at the highest velocity during the backwards condition.

There were large error bars during the 5.2°/s for the backwards condition. This indicates a large amount of variation between participants. This appeared during first experimental sessions and repeat sessions.

These results indicate an anisotropic response to motion during the slower velocities; the tracking performance was different for the forwards condition compared to the backwards condition. This performance difference changed when participants carried out a large number of trials, providing evidence that learning had occurred. The first experimental session's participants increased their tracking errors over trials during the forwards condition, and decreased their tracking errors during the backwards condition. The repeating participant results showed participants' tracking errors increased at 0°/sec, and was close to 0 at 0.5°/sec and 1°/sec.

It was noticed that the velocity of the eye was often not at zero during the static part of the trial, just before the target moved. This indicates a form of anticipation where the participant is starting to move their eyes in the direction of the expected target prior to its arrival on the screen. Figure 11 shows an example of an individual's velocity for forwards trials (left) and backwards trials (right).

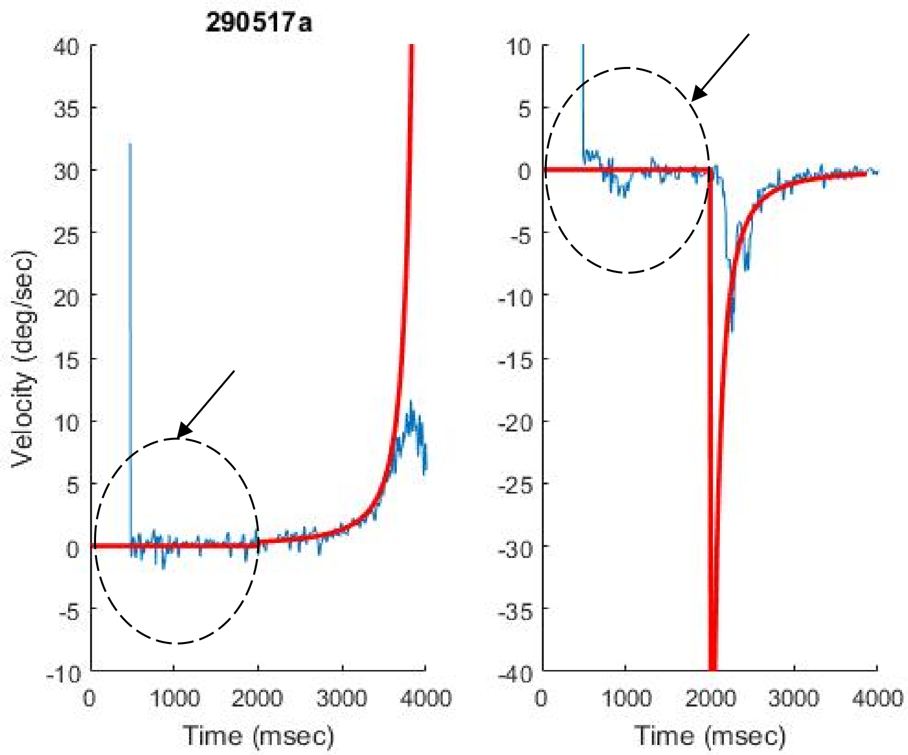

Figure 11: Example of an individual's velocity for forwards and backwards trials.

Between 0 to 2000 msec represents the static part of the trial, yet the participant's velocity was often not at zero.

From these results we wanted to see if there were any differences in anticipation before the forwards and backwards conditions.

Anticipation

Anticipation velocity during three points in time (500, 350, and 250 msec before target movement) were compared to eye velocity during the static portion of time when the cross was displayed. The halfway point of the fixation period was selected, as the control segment to allow for initial saccades when the target appeared. Three points in time were chosen to check if anticipation happened any earlier than had been found in previous research (Kowler, 2011; Kowler & McKee, 1987). Anticipation velocity was calculated by using the difference between the average velocity at interval one (at the start of the fixation period) and the average velocity at interval two (just before the target moved). The times for interval one were between 1000-1500 (500msec), 1000-1350 (350msec), and 1000-1250 (250msec). The times for interval two were between 1501-2000 (500msec), 1651-2000 (350msec), and 1751-2000 (250msec). For the forwards condition if anticipation occurs then the mean velocity tracking error during interval two should be larger than the mean velocity during interval one. For the backwards condition because the target is moving backwards then if anticipation occurs, interval two mean velocity tracking error will also be larger but the error value will be negative. Interval one for both conditions should have a velocity error of zero, since this was the static part of the trial.

First Experimental sessions.

500msec.

Figure 12 shows the mean tracking errors for the first sessions for all participants. Blue represents forwards and red represents backwards. This shows the differences between the results for the two directions.

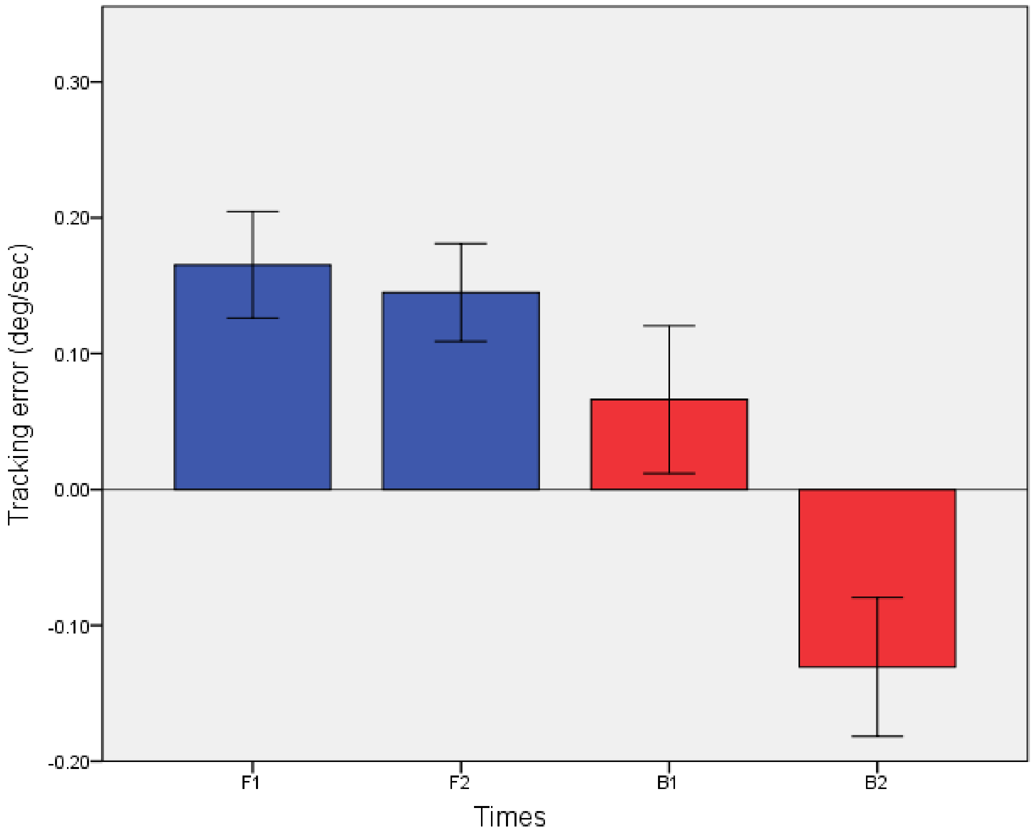

Figure 12: Mean tracking errors for all participants during their first sessions – 500msec.

In the forward case the mean velocity tracking error was slightly positive, but the mean velocity tracking error was almost the same for the early part of the static target period and just before the target moved. During the backwards trials there is evidence that anticipation was occurring, as interval two's mean tracking errors were greater than interval one's mean tracking errors, and negative. The participants were already moving their eyes in the direction of the target even though the actual target was static.

A paired samples t-test was conducted to evaluate if there were significant differences between the calculated mean tracking errors for the first experimental sessions between the two intervals, for each direction.

During the forwards condition, on average participants had a mean velocity tracking error that were slightly lower during interval two ($M = 0.15$, $SE = 0.04$), than the mean velocity tracking error during interval one ($M = 0.17$, $SE = 0.04$). This difference, 0.02, BCa 95% CI [-0.05, 0.95], was not significant $t\ (31) = 0.55$, $p = .584$. During the backwards condition on average, participants had a mean velocity tracking error that were lower during interval two ($M = -0.13$, $SE = 0.05$), than the mean velocity tracking error during interval one ($M = 0.06$, $SE = 0.05$). This difference, 0.19, BCa 95% CI [0.09, 0.30], was significant $t\ (31) = 3.69$, $p = .001$. This indicates on the whole there were significant differences between the two directions for the first experimental sessions.

Anticipation during the 350msec and 250msec just before target movement were also analysed. The results were similar to those found during the 500msec before target movement. There were no significant differences during the forwards condition, but during the backwards condition there were significant differences. This indicated on the whole there were significant differences between the directions during the 500msec to 250msec just before target movement.

Repeat Participants.

In order to see if the anticipation errors changed when more trials were run, the anticipation errors for participants who ran two sessions with many more trials were examined next.

500msec.

Figure 13 shows the mean tracking error for the repeat participants'. Blue represents forwards and blue represents backwards. This shows the significant differences between the results for the two directions.

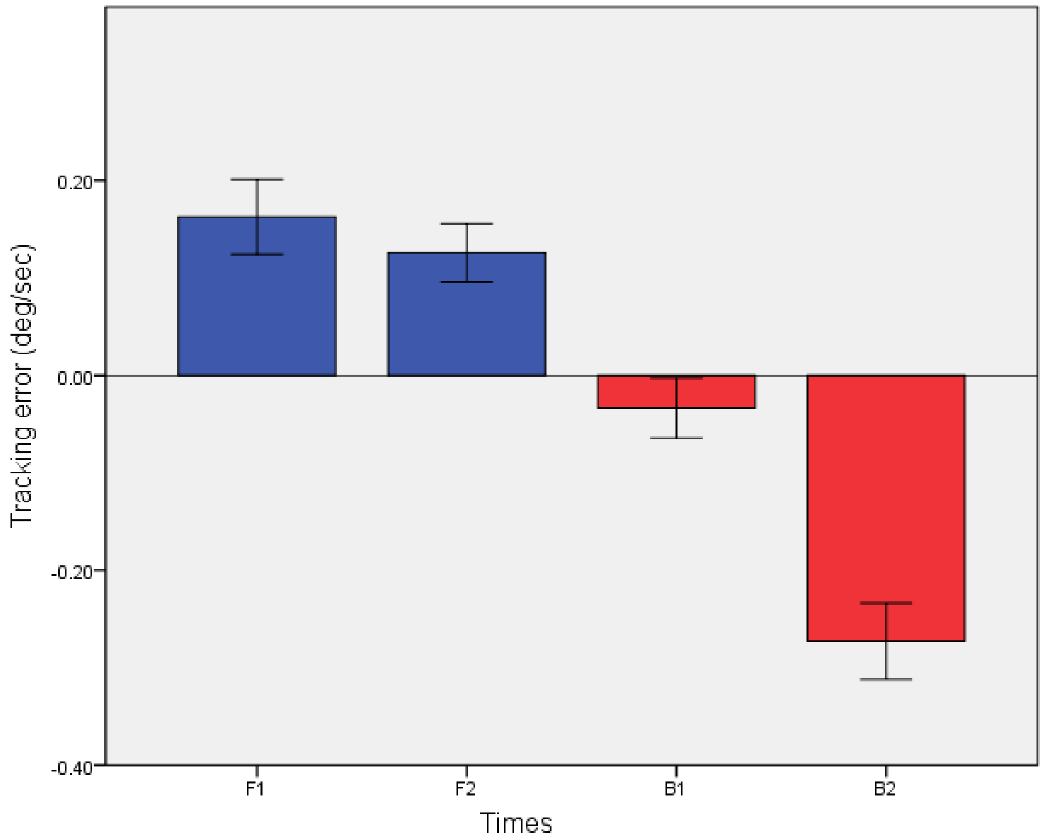

Figure 13: Mean tracking error for the repeat participants– 500msec.

During the forwards trials, repeat participants' were not showing any sign of anticipation occurring, as interval two's mean tracking errors were less than interval one's mean tracking errors. During the backwards trials, anticipation was occurring, as interval two's mean tracking errors were greater than interval one's mean tracking errors, and negative.

A paired samples t-test was conducted to evaluate if there were significant differences between the calculated mean tracking errors for repeat participants' between the two intervals, for each direction.

During the forwards condition, on average participants' had a mean tracking error that were slightly lower during interval two (M = 0.12, SE = 0.03), than the mean tracking error during interval one (M = 0.16, SE = 0.03). This difference, 0.04, BCa 95% CI [-0.19, 0.93], was not significant t (43) = 1.32, p = .195. During the backwards condition, on average participants' had a mean tracking error that were lower during interval two (M = -0.27, SE = 0.04), than the mean tracking error during interval one (M = -0.03, SE = 0.03). This difference, 0.24, BCa 95% CI [0.15, 0.32], was significant t (43) = 5.72, p = <.001. This indicates on the whole there were significant differences between the two directions for the repeat participants. The anticipation effect was stronger for the participants who carried out twice as many trials.

Discussion.

The first experimental session results showed a significant difference in behaviour between the backwards and forwards trials during the final 500, 350 and 250msec before target movement. Overall, the forwards trials during the three timing points analysed did not show a significant difference between interval one's mean tracking error or interval two's mean tracking error. Overall, the backwards trials during the three timing point's analysed showed interval two's mean tracking error were significantly different to interval one's mean tracking error, which suggests that anticipation was occurring up to 500 msec before target movement by most participants, but only during the backwards trials.

The repeat participant results also showed a significant difference in behaviour between the backwards and forwards trials during all three timing points. The differences between interval one's mean tracking error and two's mean tracking error during the backwards trials were the largest seen out of all of the results, so the repeat participants results suggest that repeating the experiment enhanced the anticipation effect.

There was no overall anticipation effect during the forwards trials. One reason for this may be due to the low target velocity at the start of the trial. Participants knew they would be able to keep up with the target so did not need to anticipate movement. During the backwards trials the target velocity was much higher at the start of the trial and they knew they would have trouble tracking it, so participants may have behaved differently. Participants knew that the target would move quickly, so they anticipated the motion and jumped ahead.

Based on these results we wanted to see if there were any differences between the saccades during first experimental sessions and repeat sessions. As this may also indicate a change in behaviour and another form of learning across sessions.

Saccades

Because there is an anisotropic response to motion away, the number of saccades during both conditions were analysed and compared. During the backwards condition, the target went from being static to a high velocity within a frame, therefore the eyes were expected to show saccades just before target movement. Saccades were recorded as having occurred when the velocity of eye movement was greater than 30°/second. An example of an individual's velocity results during the 2000msec before target movement is shown in Figure 14.

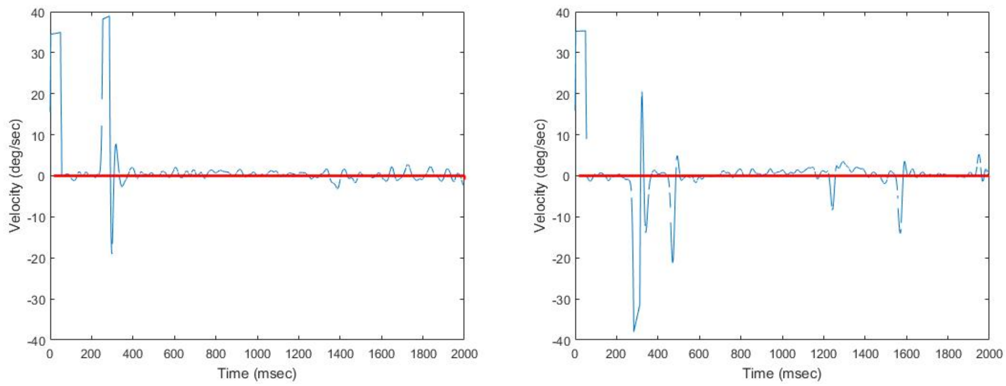

Figure 14: Individual velocity compared to target velocity before target movement during a forwards trial (left) and a backwards trial (right).

Blue represents the participant's velocity over one trial and red represents target velocity. The graph on the left represents a forwards trial and the graph on the right represents a backwards trial. When the blue line is above 30°/s or below -30°/s then a saccade has occurred. The eye velocity traces have been truncated at 40°/s to limit the ranges of the Y axes. The participant in Fig. 14 made one saccade early on during the fixation stage for both a forwards and backwards trial. The number of saccades across trials and participants were very variable with many trials experiencing no saccades at all. Therefore a technique was developed for assessing if any learning was occurring that did not depend on saccade data on every trial. The number of saccades were plotted against the trial number (1-36) as a scatterplot and a linear regression was used to look for evidence of a slope. The slope value returned from the regression (saccade learning slope) was also used to look for differences between the two main conditions (forwards vs backwards). The analysis was carried out at two time intervals during the trial. The two points in time covered 500 msec. Interval one was between 750-1250msec (the middle of the fixation period) and interval two was between 1500-2000msec (just before the target moved). These were considered to be the most likely regions during which the participants would make a saccade.

First Experimental sessions.

Figure 15 shows the mean saccade learning slopes during interval one and two for all first experimental sessions during the forwards (blue) and backwards (red) conditions.

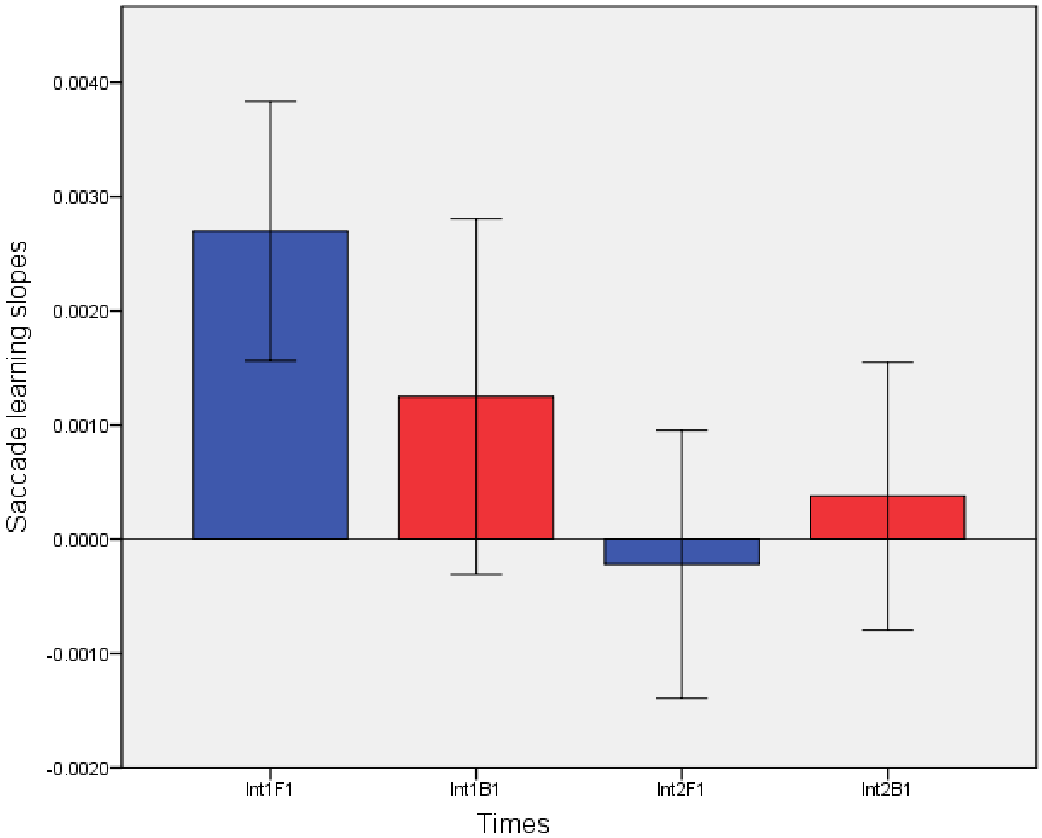

Figure 15: Mean saccade learning slopes at interval one and two during first experimental sessions

A paired samples t-test was conducted to evaluate if there were significant differences between the mean saccade learning slopes for first experimental sessions between the two intervals, for each direction.

The graph shows that for the forwards case during the first interval the slope was positive and significantly different to 0 start (M = 0.0026, SE = 0.0011). This indicates that on average the participants were making more saccades in trials towards the end of their session compared to the beginning. This is evidence for learning when measured using saccade numbers.

During the forwards condition, on average participants' had a mean saccade learning slope that was lower in the second interval (M = -0.00022, SE =

0.0011), compared to the slope in the first. This difference, 0.0029, BCa 95% CI [0.00019, 0.0056], was significant t (31) = 2.19, p =.036. During the backwards condition, on average participants' had a mean saccade learning slope that was lower in the second interval (M =0.00037, SE =0.0011), compared to the first (M =0.0012, SE =0.0015). This difference, 0.00087, BCa 95% CI [0.0027, 0.0044], was not significant t (31) = 0.49, p = .627. This indicates there was a significant difference between the saccade learning that occurred during interval one and two for the forwards condition. Evidence for learning was only apparent during particular intervals (750-1250msec) during the target motion and only for the forwards condition.

Repeat Participants.

Figure 16 shows the mean saccade learning slopes during interval one and two for all repeat participant sessions during the forwards (blue) and backwards (red) conditions.

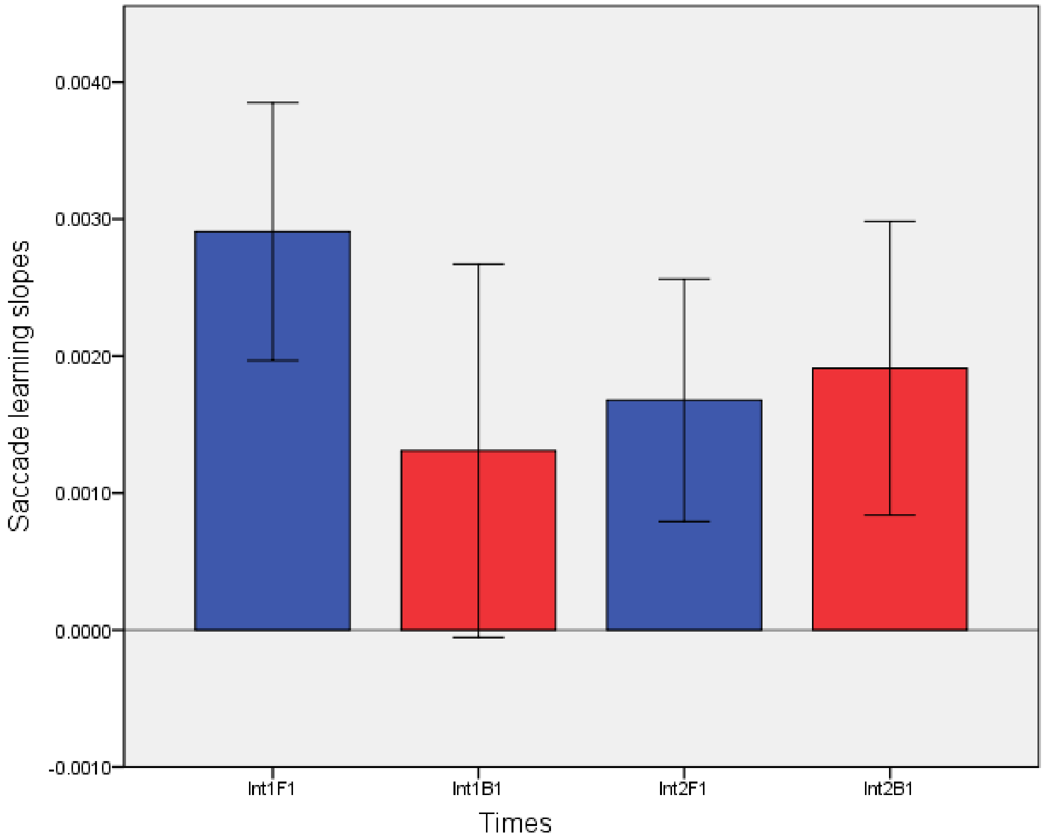

Figure 16: Mean saccade learning slopes at interval one and two for repeat participants.

For participants who carried out twice the number of trials, the saccade learning slopes were positive and significantly different from 0 in nearly all cases.

They have learned to make saccades prior to the motion of the target dot and the more trials they experienced the greater the learning (compare Fig. 15 to Fig 16).

During the forwards condition on average, repeat participants' had a mean saccade learning slope that was lower in the second interval (M = 0.0016, SE = 0.0008), compared to the slope in the first (M = 0.0029, SE = 0.0009). This difference, 0.0012, BCa 95% CI [-0.0009, 0.003], was not significant t (43) =1.14, p =.261. During the backwards condition on average, participants' had a mean saccade learning slope that was higher in the second interval (M = 0.0019, SE =0.001), compared to the first interval (M = 0.0013, SE =0.001). This difference, -0.0006, BCa 95% CI [-0.003, 0.002], was not significant t (43) = -0.44, p = .660. This indicates there no significant differences between the first and second interval, for either direction.

Discussion.

The saccade learning slopes for the first session showed a significant difference between interval one and two during the forwards condition. There was evidence of learning during interval one as the number of saccades the participants made increased as the trials progressed. During interval two the saccade learning slope was negative, so the number of saccades the participants made decreased as the trials progressed. During the backwards condition there was no evidence of learning during either interval when the number of saccades was the measure

The saccade learning slopes for the repeat session participants were all positive for interval one and two, during both forwards and backwards conditions. There was evidence of learning as the number of saccades the participants made increased as the trials progressed. The more trials they experienced the greater the learning effect.

The results showed a difference between the saccade learning slopes between the first sessions and repeat participants. This provided evidence of a change in behaviour i.e. learning to make more saccades prior to the motion of the target when the sessions were repeated. This learning occurred for the forward (accelerating) condition but not for the backwards (deceleration) condition.

Chapter 4 - General Discussion

The purpose of this research was to investigate the anisotropic response to motion in depth (ARMD) – that the perception of motion differs depending on its direction. The research examined eye movements and the way they differ between directions or velocities, and how things change over time with practice (learning).

The results showed that the mean tracking velocity errors differed between the directions. At lower velocities, participants were faster than the target during both conditions. As velocity increased, participants were faster than the target during the backwards condition, and lagging behind the target during the forwards condition. At the highest velocities participants were lagging behind the target during both conditions, but there were larger mean velocity tracking errors during the backwards condition. The results support the idea that there may be an eye movement-based reason for why the ARMD occurs. Large differences were found between the types of eye movements that observers make while viewing accelerating targets compared to decelerating targets.

The results from looking at changes in tracking errors over trials at specific time slices when the target was moving at either 0, 0.5, 1, 2, 5.2 or 10.4°/second also differed between directions and time slices. During the forwards condition participants tracking errors over trials increased at low velocities until the velocity was between 1-2°/second, then the tracking errors over trials decreased. Repeating the experiment changed the results at 5°/s as participants tracking errors over trials increased during the forwards condition, yet participants' tracking errors over trials decreased during the first session. During the backwards condition participants' tracking errors over trials decreased during the lower velocities and increased during the higher velocities. Repeating the experiment changed the results as participants' tracking errors over trials increased at lower velocities and decreased during the highest velocities. This provided evidence that learning had occurred. As participants who experienced more trials showed a decrease in tracking errors. Therefore the visual system was able to improve its ability to track a fast target more effectively. There was a statistically significant difference between the two directions at 2°/s, as repeat participants' tracking errors over trials decreased during the forwards condition and increased during the backwards condition. These anisotropic findings between directions were consistent with Perrone (1986). Smooth pursuit eye movements were observed at the lower velocities and saccades became more common as the velocity increased. The participants were able to track up to 10°/s, although they lagged behind the target during both directions. These findings were consistent with Carl and Gellman (1987). They investigated Smooth pursuit eye movements during random target motion. They found the latency of the smooth pursuit response was approx. 100msec after target motion. Their participants were able to track targets moving at 5 and 10°/s.

The anticipation results showed that there was a difference between the forwards conditions and the backwards conditions. During the forwards condition there was no significant difference between the mean tracking error at interval one (start of fixation period) and the mean tracking error at interval two (end of fixation). However the tracking error during interval two decreased compared to the tracking error at interval one, which indicates participants were showing less eye velocity tracking errors just before the target moved. In other words their eye velocity error was closer to zero at interval two. During the backwards condition there was a significant difference between interval one and interval two. At interval one there was very little eye tracking errors. By interval two, the mean eye tracking errors had increased significantly, so participants were anticipating the target movement and starting to move their eyes in the expected direction of the target. When the repeat sessions results were analysed the findings showed that repeating the experiment decreased mean eye tracking errors for both interval one and interval two during the forwards condition, and for interval one during the backwards condition. But repeating increased the mean eye tracking errors for interval two during the backwards condition. Repeating the experiment led to a greater anticipation effect. Anticipation was found to occur at 500msec, 350msec, and 250msec. These findings were consistent and expanded on those in (Kowler, 2011; Kowler & McKee, 1987) which found that anticipation occurred at 200msec. Anticipation may have only occurred during the backwards condition due to the high velocity at the start of the trial. Because participants expected a lower velocity during the forwards condition, and they were able to follow the target at the beginning of the trial, participants did not need to anticipate the motion.

The saccade results showed a significant difference in the saccade learning slopes observed during the first session and the repeat participants' sessions.

There was an increase in the amount of saccades participants' made during the sessions. This was particularly apparent for those who came back for a repeat session. This showed evidence for learning when saccade numbers were measured. These results were consistent with Ettinger et al. (2003) as there was an indication of test-retest reliability and improvement with practice. During the first session the saccade learning slope showed less saccades during the backwards condition, compared to the forwards. Repeating the experiment increased this effect for both forwards and backwards conditions

The implications of this research have shown there is an anisotropic response to motion depending on its direction, but it can be improved with practice. Participants were able to follow a moving target at the lower velocities with less tracking errors during the forwards condition. Participants were lagging behind the target at lower velocities during the backwards condition but faster than the target when the velocity was between 2° and 5°/s. At higher velocities the eye cannot catch up but the eyes also cannot track sudden deceleration well either. When something moves away from the eye at a high velocity, the eye will overshoot and move faster than the target. This means that the velocity of objects in the world may be misperceived when deceleration occurs on the retina. These results therefore have implications for how the brain deals with navigating through the world.

Limitations of this research

A main issue of this study is the lack of control over participant's behaviour. If participants received feedback on velocity tracking errors each trial, or an indication of how on target they were there may have been less tracking errors or more learning effects shown. The lack of control may have also changed variability within the trials or between the participants.

If a wider range of velocities were used instead, then there may have been a clearer indication of the effect of velocity and the effect of direction. If a target moving to the right was accelerating or decelerating, and the target moving to the left was accelerating or decelerating then results could have compared how much effect the direction had, and how much effect was from the differing speeds. This would have also provided evidence that it was only the high velocity that caused anticipation to occur. As acceleration may have appeared for both directions if the target was decelerating. This may have shown that there is a velocity threshold for anticipation to occur.

Learning effects may have been different if only one direction was used for participants. By seeing only one direction multiple times during a session it may have improved the errors with practice. Comparisons could have been made for repeat participants if they were exposed to the other direction during the repeat session.

Suggestions for further research

The experiment only looked at eye movements occurring in a single eye. When objects move in depth, the eyes undergo vergence movements (Busettini et al., 1996; 1997). Monitoring the eye movements of both eyes could provide information about what happens when both eyes follow an object moving in depth. It is possible to monitor eye movements while participants are wearing virtual reality helmets and so an experiment could be done using virtual reality to fully examine the role of eye movements during motion in depth.

The timing points where anticipation occurs could be further investigated. This research has shown that anticipation only occurred during the decelerating backwards condition. Previous research (Kowler, 2011; Kowler & McKee, 1987) found that anticipation occurred 200msec before target motion, but this research found that anticipation was also occurring up to 500msec before target motion. This may have occurred earlier due to the velocity at the start of the condition. Future research could investigate the velocity that is required to alter the timing of anticipation occurring, and the velocity threshold that is required to observe anticipation.

Liston and Stone (2014) developed an eye movement tracking tool named the Comprehensive Oculometric Behavioral Response Assessment (COBRA) that can be used within clinical practice as an assessment or screening tool. By randomising target motion they were able to obtain pursuit initiation, tracking, direction, and speed tuning metrics. These metrics can be used with disorders that affect visual processing. COBRA was used with participants who had experienced traumatic brain injury (TBI) and compared to participants who had not experienced an injury (Liston et al., 2017). They found COBRA assessed the visual impairments in patients with TBI and quantified the areas where visual degradation had occurred. Hill, Coats, Halstead, and Burke (2015) reviewed the effectiveness of using active pursuit eye movements for rehabilitation interventions in patients who have experienced a stroke. They found that using pursuit based rehabilitation interventions instead of traditional scanning interventions using saccadic eye movements was better at improving outcomes. They noted that the effectiveness of using eye movement interventions is dependent on the extent of the damage in the right hemisphere as well as the visual acuity of the patients.

Based on the findings above future research could investigate whether the videos used in this experiment could be used within a rehabilitation intervention with participants who have an impairment in sensorimotor function. By using different directions and different velocities patients would experience targets that appear in their foveal and peripheral line of sight. They would also experience targets that accelerate or decelerate, so they would be required to use smooth pursuit as well as saccadic eye movements. Accurate eye movement responses would be recorded and a randomised design would reduce bias, as suggested by (Hill et al., 2015).

Conclusion

This research enabled insights into the ARMD effect and the role that eye movements play. There was a difference between tracking errors during different directions and different velocities. Evidence for learning was shown by tracking errors decreasing, anticipatory eye movements changing over time and more trials, and the number of saccades observed changing over time and more trials.

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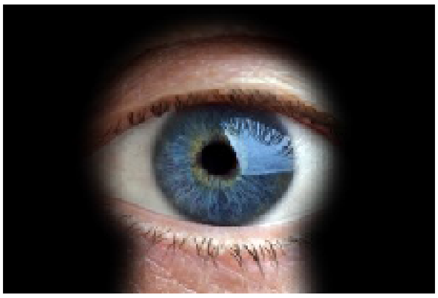
Appendices

Appendix A

Eye tracking Research



We are looking for participants to take part in a study examining eye movements while viewing accelerating and decelerating targets..

What does the study involve?

You will be invited to attend a 1 hour experimental session at the University of Waikato Perception lab. You will be asked to track a moving target on a screen with your eyes. While doing this task your eye movements will be recorded with an eye tracker.

Course credits are available as below.

For each hour of participation students can earn 1%, with a maximum of 4%.

PSYC103(HAM & TGA) (up to 4%)
PSYC226(HAM & TGA) (up to 2%)
PSYC229(HAM & TGA) (up to 2%)
PSYC317(HAM & TGA) (up to 2%)
PSYC208(HAM & TGA) (up to 4%)
PSYC227(HAM & TGA) (up to 2%)
PSYC307(HAM & TGA) (up to 4%)
PSYC319(HAM & TGA) (up to 4%)

Who can I contact to volunteer or to find out more?

Email Jo at joballnz@hotmail.com to find out more, she will provide further information and answer any questions you have.

This study has been approved by the School of Psychology Research and Ethics Committee, and is being conducted by Jo Luckie in partial fulfilment of the requirements of the MAppPsy, supervised by Associate Professors John Perrone and Robert Isler. All information collected will remain confidential.

Eye Tracking Research
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Appendix B

Tracking a moving target that is accelerating or decelerating.

Information Sheet

You will be asked to track a moving target on a screen with your eyes. While doing this task your eye movements will be recorded with an eye tracker.

The session will last for approximately one hour, breaks will provided and you will receive course credits as per below:

For each hour of participation students can earn 1%, with a maximum of 4%.

PSYC103(HAM & TGA) (up to 4%)	PSYC208(HAM & TGA) (up to 4%)
PSYC226(HAM & TGA) (up to 2%)	PSYC227(HAM & TGA) (up to 2%)
PSYC229(HAM & TGA) (up to 2%)	PSYC307(HAM & TGA) (up to 4%)
PSYC317(HAM & TGA) (up to 2%)	PSYC319(HAM & TGA) (up to 4%)

This research is being conducted by Jo Luckie in partial fulfilment of the requirements of the MAppPsy, supervised by Associate Professors John Perrone and Robert Isler. All information will be treated with the strictest confidence and the data will only be accessed by the researcher and her supervisors. The data will be stored on a secure server. Data will be kept for a minimum of 5 years. The findings will be written up as a Thesis.

You can withdraw from the experiment at any time without penalty, and you will still receive course credits for participating. If you have any questions about the study please contact either Jo Luckie (joballnz@hotmail.com) or Associate Professor John Perrone (jpnz@waikato.ac.nz).

This research project has been approved by the School of Psychology Research and Ethics Committee of the Faculty of Arts and Social Sciences, University of Waikato. Any questions about the ethical conduct of this research may be sent to the convenor of the Research and Ethics Committee (currently Dr Rebecca Sargisson, phone 07 557 8673, email: rebeccas@waikato.ac.nz).

Appendix C

Ψ School of Psychology

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

CONSENT FORM

A completed copy of this form should be retained by both the researcher and the participant. [Note: you may delete or reword any items that are not relevant to your research and add items that are relevant to your research – **please ensure that the crest and logo above appear on the top of the page]**

Research Project: Tracking a moving target that is accelerating or decelerating

Please complete the following checklist. Tick (✓) the appropriate box for each point.	**YES**	**NO**
1. I have read the Participant Information Sheet (or it has been read to me) and I understand it.		
2. I have been given sufficient time to consider whether or not to participate in this study		
3. I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet		
4. I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without penalty		
5. I have the right to decline to participate in any part of the research activity		
6. I know who to contact if I have any questions about the study in general.		
I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.		
I wish to receive a copy of the findings via email		
My email address is:		

Declaration by participant:
I agree to participate in this research project and I understand that I may withdraw at any time. If I have any concerns about this project, I may contact the convenor of the Psychology Research and Ethics Committee (Dr Rebecca Sargisson, phone 07 557 8673, email: rebecca.sargisson@waikato.ac.nz)

Participant's name (Please print): ______________________

Signature: ______________ Date: ______________

Declaration by member of research team:
I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it. I believe that the participant understands the study and has given informed consent to participate.

Researcher's name (Please print): ______________________

Signature: ______________ Date: ______________