The Role of Movement Scaling on Quiet Eye Duration During an Aiming Task

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by

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Introduction

Over the years, researchers have attempted to explain the role of gaze in aiming tasks – most of which have studied coordination between the hand and eye. Many of these studies have examined the role of gaze in near aiming tasks, such as tasks using wrist rotation or tasks in which a stylus is moved from a home position to a target location (Abrams, Meyer, & Kornblum, 1990; Keele & Posner, 1968). In the past few decades, researchers have turned their attention to the role of gaze in tasks where the target is at a distance from the participant. These far aiming tasks have specific relevance to sports and include shooting a gun and throwing a ball.

The role of gaze in far aiming tasks was first examined by Vickers (1992). Vickers used a golf putting task to determine if gaze control differed between high and low handicap golfers, as well as to examine the role gaze played in accuracy. She found that low handicap golfers exhibited longer fixations to fewer targets than high handicap golfers. In addition, she found that accuracy was greatly improved on putts in which the final fixation of the preparatory phase was long (>1700 ms) compared to short (<1700 ms). Vickers (1996a) would later call the duration of this final fixation before initiation of the movement the “quiet eye period”.

Similar to Vickers’ (1992) study, many other studies on quiet eye duration have examined the differences between experts and non- or near-experts. These studies have observed longer quiet eye durations in experts during a basketball free throw (Vickers, 1996a, 1996b; Harle & Vickers, 2001), volleyball tracking (Adolphe, Vickers, & Laplante, 1997), rifle shooting (Janelle et al., 2000), shotgun shooting (Causer, Bennett,
Holmes, Janelle, & Williams, 2010), and billiards (Williams, Singer, & Frehlich, 2002) when compared to non- or near-experts. Additionally, several studies have found that quiet eye duration is significantly longer for successful attempts to hit a target than unsuccessful ones (Causer et al., 2010; Williams et al., 2002). Both findings seem to suggest that the quiet eye period plays an important role in aiming tasks.

Despite evidence for longer quiet eye durations in experts than non-experts and longer quiet eye duration on successful attempts than non-successful attempts at an aiming task, further evidence is required to show that the time period is used in a meaningful way, rather than being an artifact of some other differences between more and less experienced performers. If quiet eye duration is being used to mediate performance, then one would expect that training performers to increase their quiet eye time would be associated with greater accuracy in aiming tasks. The quiet eye duration has been shown to improve performance with training. Volleyball ball-tracking and -passing skills were used to determine whether the quiet eye period could be trained (Adolphe et al., 1997). After a 6-week training program, players were found to have quicker tracking onset times, as well as longer ball tracking durations, than they did pre-training. Most importantly, longer quiet eye periods were observed, and the effects of the training were observed after three years. In another study, Harle and Vickers (2001) attempted to determine whether free throw accuracy could be improved through training to extend the duration of the quiet eye in female university basketball players. Over the course of two seasons, they found an improvement in free throw percentage, citing longer quiet eye durations, especially on successful attempts. It would appear that quiet eye
duration can be trained to improve accuracy in aiming tasks, indicating that some sort of
cognitive processing occurs during the quiet eye period.

After several years of studying the quiet eye phenomenon, Vickers (1996a) introduced the location-suppression hypothesis, which concerned the role the quiet eye period plays in aiming tasks. In the location aspect, she proposed that long duration fixations are made to certain target locations during the preparatory phase of the movement to improve accuracy. This period is thought to be necessary to program the movement parameters, including force, direction, trajectory, and velocity as well as the timing and coordination of the limbs (Newell, Hoshizaki, Carlton, & Halbert, 1979). As movement begins in the impulse phase, slight parameter changes are made, and the movement moves into the execution phase, when visual suppression occurs. The suppression aspect involves an early fixation offset followed by vision-suppression. During this time, the head and eyes move freely, without continued fixation on the target location. It is thought that suppression is necessary to prevent on-line feedback during the movement, which could interfere with the movement plan (Vickers, 1996a, 1996b). Research validating both aspects of Vickers’ hypothesis was needed.

Studies involving billiards, basketball and golf have supported the location aspect of Vickers’ hypothesis (Williams et al., 2002; Vickers, 1992, 1996a, 1996b). Results have shown a longer duration fixation, or quiet eye period, in expert performers when compared to non-experts. While Vickers’ (1996a, 1996b) basketball study supported vision-suppression during the execution phase, other studies in near aiming tasks have shown no evidence of suppression, which suggests instead that fixation on the target location is maintained throughout the movement (Williams et al., 2002; Abrams et al.,
While the location mechanism that results in a longer quiet eye period in experts seems valid, further evaluation of the vision-suppression mechanism is required.

Williams et al. (2002) tested Vickers’ hypothesis using billiards. They manipulated the complexity of the shots to determine if the quiet eye period is reflective of cognitive programming. Williams et al. found support for the location but not the suppression aspect, concluding that the vision-suppression mechanism might only be active in tasks in which the target becomes occluded by a body part or equipment (e.g. the basketball free throw) during the execution phase. In their first experiment, Williams et al. (2002) had participants perform shots at three different complexity levels (easy, intermediate, and hard) until they had performed 10 successful and 10 unsuccessful trials. Williams et al. found the quiet eye period was longer on successful versus unsuccessful attempts, independent of complexity and skill level. In the second experiment, complexity was manipulated using 25% and 50% time-constrained conditions at the intermediate level. Once again, participants performed until they had 10 successful and 10 unsuccessful trials. Williams et al. found that as task complexity increased, quiet eye duration increased. This was especially true on successful trials. It was expected that quiet eye duration would increase if the period was related to cognitive processes, and this was indeed the case, further supporting Vickers’ proposal of the purpose of the quiet eye period; however, the nature of cognitive processing that occurs during the quiet eye period remains unknown.

To my knowledge, no study has examined the quiet eye period with manipulations in practice type until recently. Horn et al. (2010) assessed the duration of the final fixation in a darts aiming task. Participants were assigned to blocked practice,
where all trials to one target are made before the participant moves on to the next, or variable practice, in which the target changes on each trial. Horn et al. also manipulated target movement in the horizontal and vertical plane. If, as Vickers' hypothesis suggests, cognitive programming of the movement parameters occurs during the quiet eye period, it would be expected that quiet eye duration would be longer in variable practice because the parameters of the skill change with each successive shot, and each attempt must be scaled. In blocked practice, the parameters of each shot would remain constant so scaling would only occur on the first throw to the new target in a block. This was found to be the case. Supporting both Vickers' location-suppression hypothesis and their own hypotheses, Horn et al. observed a significantly longer quiet eye duration in participants using variable practice compared to blocked practice, and found the quiet eye period to be longer in the vertical versus horizontal plane. Differences in quiet eye duration during variable and blocked practice could be a result of parameterization and scaling of the movements required for accuracy. Quiet eye duration differences in the vertical and horizontal planes can also be explained by parameterization and scaling. Although the targets were equidistant from the center (bullseye) in both axes, changing targets in the vertical plane required more variation in the movement parameters, since the low and high targets would require different release angles, force and velocity. These larger parameter changes appear to have caused longer quiet eye times.

Findings from both the Williams et al. (2002) and Horn et al. (2010) studies further support the evidence for Vickers' location-suppression hypothesis, suggesting that the quiet eye period is used for scaling movement parameters, however, a more comprehensive test of the hypothesis is required. The purpose of the present experiment
is to further examine Vickers' hypothesis by manipulating the extent of the change to the target location. As in the study by Horn et al. (2010), changes to the target location in the horizontal and vertical axes will be examined. Additionally however, participants will experience diagonal changes to the target location. This will allow a better examination of the parameters being scaled. If quiet eye duration for the diagonal axis is greater than for the horizontal and vertical axes, it suggests that participants are using the quiet eye period to scale both direction and distance parameters. If however, quiet eye duration in the diagonal axis is greater than the horizontal but not the vertical axis, it suggests that the participants primarily scale for distance parameters in the diagonal axis. It is predicted that target changes in the diagonal axis will elicit longer quiet eye durations than changes in the vertical and horizontal axes. It is expected that vertical changes would yield longer quiet eye durations than horizontal changes. Further extending the Horn et al. study, this present study will manipulate the increments of change in the target location. Each time the participant throws to a new target, it will be in response to a one, two or three increment change on the target grid. It is predicted that larger incremental changes (size of change) would result in longer quiet eye duration (3 > 2 > 1).
Method

Participants

A group of 12 male university undergraduate students from the Department of Exercise Science and Physical Education at Montclair State University volunteered to participate in the study. Participants were recruited through an e-mail sent to all undergraduates in the department. All participants had normal or corrected to normal vision. During data analysis, one participant was found to have a tremor in the eye, so his data was removed. Of the remaining eleven participants (M age = 22.91, SD = 3.39 years), ten were right-hand dominant and one was left-hand dominant. All participants had no previous experience performing the task and were naive to the nature of quiet eye period. Each participant provided written consent before participating in the study.

Research Design

Independent variables. The independent variables were the direction of change in the target location (horizontal (X), vertical (Y), or diagonal (Z)), and the size of the change in the target location (1, 2, or 3 increments on the target grid; see Figure 1).

Dependent measures. Quiet eye duration was measured on each throw by determining the length of the final fixation before initiation of movement in total number of frames and converting it to milliseconds (ms) based on one frame equalling 33.3 ms in NTSC (National Television System Committee) standard. On each trial, throwing accuracy was assessed by measuring radial error to the nearest half of a centimeter (cm) from the center of the intended target to the location on the floor that the dart landed.
Figure 1. Layout of grid with an example target sequence: 1. B4 to C5 (change of 1Z); 2. C5 to C3 (change of 2Y); 3. C3 to F3 (change of 3X); 4. F3 to C6 (change of 3Z); and 5. C6 to D6 (change of 1X).
Statistical analysis. Differences in quiet eye duration across target increment changes (1, 2, or 3 increments) and direction of change in target axis (X, Y, or Z) were assessed by a 3x3 analysis of variance (ANOVA), with the alpha level set at <.05. Meaningfulness was assessed with Omega Squared (Tolson, 1980). The Tukey HSD post hoc test was used to follow-up significant main effects for direction and distance. Post hoc analysis of the significant interaction was accomplished through a series of one-way ANOVAs and Tukey HSD tests. Pearson Product Moment correlations assessed the strength of the relationship between quiet eye duration and throwing accuracy.

Apparatus

The task and target area. The task was to throw soft-tipped sky darts to targets within a 10 x 10 ft grid located on a linoleum floor. The darts are 27 cm long and weigh 0.25 kg. The tip is weighted, and the dart has a long shaft with three fins to ensure the dart is aerodynamic and lands tip down. The grid was made up of six small cross-hairs, two feet apart in the X and Y axes creating a square grid of 36 targets. The columns were labeled A-F, and the rows were labeled 1-6. The throw line was located 16' from the center of the front of the grid (see Figure 1).

Eye movements. Eye movements were recorded using an Applied Science Technologies (ASL) 5000 eye-movement registration system (Bedford, MA, USA). This system uses a headband-mounted eye camera (60 Hz) to measure the line of gaze based on the positions of pupil and cornea relative to a 9-point calibration frame. The system is accurate to within ±1° of visual angle. The headband-mounted system was controlled through the ASL E5000 control unit (Bedford, MA, USA).
Vision-in-action approach. A video camera (Canon, Tokyo, Japan; model ZR800) was placed behind and slightly to the side of the participant in order to determine the initiation of the movement, which was considered to be the end of the quiet eye period. The picture-in-picture function of a digital AV mixer (Panasonic, Osaka, Japan; model WJ-AVE5) was used to synchronize the eye movements with the body movements. These images were then output to a second video camera (Canon, Tokyo, Japan; model ZR80), which recorded the images. Quiet eye was determined from the picture-in-picture output. Once the first frame of the movement had been identified, the frames of the final fixation leading to that frame were counted.

Procedures

Participants took part in a single sky dart throwing session. Each session consisted of 5 practice trials and a calibration period, followed by two sets of 45 condition changes (46 trials per set; 92 total trials). The practice trials allowed the participants to familiarize themselves with the proper throwing technique. Before the first practice trial, participants were instructed how to throw the sky darts. They were directed to (1) have the dart ready to throw in their hand; (2) stand with their feet parallel to each other with a comfortable stance; (3) keep their head up as they visually search for the target; and (4) throw when they are ready, using a single swing of the dart.

The calibration period was used to determine the line of gaze based on the relative position of the pupil and cornea to the calibration frame in the target area. The eye movement headband was placed on the participant. Then, the participant was asked to
stand in their throwing stance facing the target area and hold their head still so the nine calibration points could be set and then calibrated to the eye.

Each session utilized two predetermined throwing sequences. Both sequences were laid out prior to data collection. Each sequence presented every participant with 5 trials of each of the 9 possible conditions (i.e. various combinations of changes in target location taking into account direction and size of change) per set. For each sequence, the order of target locations were designed so the first throw in sequence was the same as the final throw, which allowed us to use any point in the sequence for the first throw. Using predetermined throwing sequences allowed us to control the number of trials per condition, as well as present each participant with a variable practice setting, since they were unaware of their next target.

At the beginning of each trial, the participants were informed of the location of the first target. A combination of incremental and directional changes were made within the grid on each successive throw – for example, if B1 is the first target and E4 is the second, this represents condition 3Z (3 increments back and three across). If the following target is E6, the condition is 2Y (see Figure 1 for example). The overall target sequence was unknown to the participant. Once they had been told which target they were aiming at, they visually searched for the target and tossed the dart at their own pace. Radial error from where the dart landed to the intended target was measured after each throw. Participants took a 5-minute break between the two sets of throws to rest their eye. This break also allowed us to check that the eye was still properly calibrated for the second 46-trial set and re-calibrate if necessary.
Results

Quiet Eye Duration

Quiet eye duration was assessed using a 3 (size of change) x 3 (direction of change) ANOVA with repeated measures. A violation of the assumption of sphericity was detected for distance and direction, but not the interaction. As such, degrees of freedom were adjusted with a Greenhouse-Geisser epsilon factor for distance (0.580) and direction (0.652).

A significant main effect was observed for size of target change, $F(1.16, 11.61) = 21.20, p\leq 0.001, \omega^2 = 0.08$. Tukey HSD post hoc analysis indicated that there was a significant difference in quiet eye duration between three-increment (+0.059 s) changes compared to one-increment changes. There was no significant difference between one- and two-increment changes or two- and three-increment changes. The main effect for size of change is shown in Figure 2.

A significant main effect was also observed for direction of target change, $F(1.30, 13.05) = 204.85, p\leq 0.001, \omega^2 = 0.77$. Tukey HSD post hoc analysis indicated that quiet eye duration was significantly longer for changes in the Z-axis (+0.132 s, +0.127 s) compared to changes in the X-axis and Y-axis, respectively. No differences were seen between the X- and Y-axis. The main effect for direction of change is shown in Figure 3.

A two-way 3x3 repeated measures ANOVA also revealed a significant size of change x direction of change interaction, $F(4, 40) = 18.35, p\leq 0.001, \omega^2 = 0.14$. A series of
Figure 2. Differences in quiet eye duration for 1, 2, and 3 increment changes.
Figure 3. Differences in quiet eye duration in response to target changes in the X, Y and Z axes.
simple effects one-way ANOVAs and follow-up Tukey HSD post hoc tests was performed to identify the specific differences within the interaction. When evaluating the interaction with the size of change on the horizontal axis, quiet eye duration was greater for the Z-axis compared to the X- and Y-axes for the one-increment change (Z-X: +0.081 s, Z-Y: +0.084 s), two-increment change (Z-X: +0.142 s, Z-Y: +0.137 s), and three-increment change (Z-X: +0.172 s, Z-Y: +0.160 s). There were no significant differences between quiet eye duration between the X-axis and Y-axis for any of the changes of size. When evaluating the interaction with the direction of change on the horizontal axis, no significant differences in quiet eye were detected relative to size of change along the X-axis. Tukey HSD post hoc analysis was also performed for the interaction of size with direction of change. For changes in the Y-axis, three-increment changes led to significantly greater quiet eye duration (+0.039 s) than one-increment changes. There was no significant difference between one- and two-increment changes or between the two- and three-increment changes. For changes in the Z-axis, three-increment changes led to significantly greater quiet eye duration than both one- and two-increment changes (3-increment − 1-increment: +0.114 s, 3-increment − 2-increment: +0.041 s). Additionally, two-increment changes led to significantly greater quiet eye duration than one-increment changes (+0.073 s). These interactions can be seen in Figure 4 and Figure 5.

Correlation between quiet eye duration and radial error

There was no correlation between radial error and quiet eye duration.
Figure 4. Interaction of direction of change and size of change.
Figure 5. Interaction of size of change and direction of change.
Discussion

The purpose of the present experiment was to provide a more comprehensive test of Vickers' location-suppression hypothesis (1996a). Specifically, the aim was to examine whether the quiet eye period is used to scale movement parameters. It was hypothesized that (1) the larger the size of change between consecutive target locations, the longer the quiet eye duration would be compared to smaller size of change between consecutive target locations ($3 > 2 > 1$); and (2) diagonal changes in target location would produce longer quiet eye duration than changes in the vertical and horizontal axes; similarly, vertical changes would result in longer quiet eye duration than horizontal changes ($Z > Y > X$).

The quiet eye data showed partial support for the first hypothesis. Three-increment changes in target location led to a longer quiet eye duration than one- but not two-increment changes. Additionally, there was no difference between one- and two-increment changes. Partial support was also found for the second hypothesis. Changes in the $Z$-axis resulted in longer quiet eye duration than changes in the $X$- or $Y$-axis, but no difference was seen between the $X$- and $Y$-axis. Additional support for both hypotheses was found based on the interaction of size of change and direction of change. For size of change, $Z$-axis changes led to significantly longer quiet eye duration than $X$- or $Y$-axis changes for all three sizes of change. For direction of change, no difference in quiet eye duration was seen for $X$-axis changes in all three sizes of change. For $Y$-axis changes, only three-increment changes resulted in longer quiet eye duration compared to one-increment changes. However, for $Z$-axis changes, three-increment changes were greater
than both one- and two-increment changes, and two-increment changes led to longer
quiet eye duration than one-increment changes.

Changes in the Z-axis are compound in nature – both X- and Y-axis changes are
made. ANOVA, post-hoc, and meaningfulness results seem to suggest that the compound
nature of the Z-axis is particularly influential on quiet eye duration. Additionally, the
magnitude of the change in the Z-axis magnifies this effect. While one-, two-, and three-
increment changes resulted in similar quiet eye duration in the X-axis and significantly
longer quiet eye duration for three-increment changes compared to one-increment
changes in the Y-axis, changes in quiet eye duration in the Z-axis were different. Quiet
eye duration in the Z-axis seemed to be impacted by each magnitude of change (3>2>1).
This is what would be expected if cognitive processing occurs during the quiet eye
period.

The aforementioned results seem to support the notion that some form of
cognitive programming occurs during the quiet eye period. The only variables that
changed trial-by-trial were the location of the target and the corresponding change in
condition. The main effects show that quiet eye duration was significantly larger for
three-increment changes compared to one-increment changes and in the Z-axis compared
to the X- and Y-axis. It seems logical that the larger the change is between two
consecutive targets, the more parameterization that is required for the movement.
Conversely, smaller changes between two consecutive targets may not be great enough to
cause a significant time delay due to re-parameterizing the movement.
Interestingly, quiet eye duration was similar between the X- or Y-axis. However, quiet eye duration in the Z-axis was significantly greater for all three changes in size. This does not—as previously suggested—support the idea that when participants experience changes in the diagonal axis, they scale distance-based parameters rather than directional parameters. It seems that changes of only one parameter type are not sufficient enough to lengthen quiet eye duration. However, more complex changes—those of both parameter types—lead to longer quiet eye duration, supporting the location aspect of Vickers’ location-suppression hypothesis (Vickers, 1996a). Vickers contended that, in aiming tasks, long duration fixations are used for cognitive processing. This has been supported with findings from other studies. Williams et al. (2002) found quiet eye duration to be longer as complexity increased. Using time constraints, they also found that quiet eye duration is related to the amount of time spent in the response-programming phase. This seems to be indicative of cognitive processing of the task during the quiet eye period. Support for cognitive processing during the quiet eye period was also found by Horn et al. (2010) by manipulating practice-type and the axis of change. If quiet eye duration is reflective of underlying cognitive processes, then longer quiet eye periods would be expected in a variable practice setting versus blocked practice setting. In variable practice, the target changes on each throw so the movement must be re-parameterized; whereas in blocked practice, the target does not change, so the movement does not need to be rescaled trial to trial. Similarly, longer quiet eye duration would be expected for vertical changes compared to horizontal changes because scalable kinematic variables must be parameterized on each trial. Horn et al. found longer quiet eye duration in variable practice, as well as with vertical changes in axis, further
supporting that the quiet eye period is used for cognitive processing. In the present study, movement parameters can be planned and altered through cognitive processing based on the target location. The observation that quiet eye duration was longest for changes in the Z-axis and for changes of 3-increments indicates that these large kinematic changes require longer cognitive processing and that the quiet eye period is the window of time that is used to do this.

The suppression aspect of Vickers' hypothesis contends that there is a fixation offset that occurs at the end of the quiet eye period, followed by vision-suppression. Williams et al. (2002) found little evidence for visual suppression. They suggested that visual suppression may only appear in tasks in which a body part or equipment interfered with the line of gaze to the target. Similar to Williams et al., the line of gaze to the target in the present study was not occluded by the arm or dart. Visual suppression was not seen, supporting Willaims et al. (2002) and in contrast to Vickers (1996a, 1996b).

The results of the current study also show some support for the recent findings of Horn et al. (2010). Using a dart throwing task, Horn et al. found differences in quiet eye duration in the vertical and horizontal axes. They attributed this to greater variation in movement parameters – particularly release angle, force and velocity - in the vertical axis compared to the horizontal axis. The current study also found quiet eye duration differences when changes were made in the Z-axis compared to both the X- and Y-axis. It would appear that these differences can be attributed to parameterization and scaling of the movement. In the Z-axis, the movement must be parameterized in terms of depth and side-to-side change; therefore, it seems logical that the combination of the two would lead to a longer quiet eye duration than either one alone. In contrast to Horn et al., there
were no differences seen between changes in the X-axis (horizontal) and Y-axis (vertical). This discrepancy could result from the nature of the sky dart task compared to the darts task. Perhaps having the target area at a distance from the participant, as well as having it on the floor as opposed to the wall, led to smaller perceived differences between the horizontal and vertical axes in the sky dart task compared to the darts task.

The present research found no correlation between quiet eye duration and accuracy. This is in direct contrast to previous studies in which a positive correlation between quiet eye duration and accuracy was found (e.g. Williams et al., 2002; Causer et al., 2010); however, the finding does support Horn et al. (2010). This can most likely be attributed to the quiet eye period being used in the latter studies as a measure of difficulty in re-parameterizing the movement, rather than being used as a strategy to improve aiming ability. Additionally, the present study used a novel task and was not designed to be a learning study, so no feedback was provided. Both of these factors may have accuracy.

The results of the present study are related to another mainstream concept in motor learning literature. In motor learning, there is strong support for the concept that variable practice leads to better learning. This is known as the contextual interference effect (Shea & Morgan, 1979). The theoretical reasoning behind the effect is that changes in the practice environment lead to increased cognitive processing, which leads to increased long-term retention and transfer of the skill. Magill and Hall (1990) believed that the contextual interference effect would only be seen when general movement patterns were changed through variable practice. Furthermore, they argued that the contextual interference effect would not be seen when the general movement pattern was
maintained but the movement parameters changed. Nonetheless, there is substantial evidence suggesting that the contextual interference effect is evident in studies using parameter changes rather than movement pattern changes (Sekiya, Magill, & Anderson, 1996; Sekiya Magill, Sidaway, & Anderson, 1994). Horn et al. (2010) found that variable practice led to longer quiet eye duration than blocked practice. While the present experiment was not designed to test directly for a contextual interference effect, the variable practice setting used in the study may lend support to the idea that for aiming tasks, the increased cognitive processing that leads to better learning in prior contextual interference research may occur during the quiet eye period. This could be verified in future studies that measure quiet eye duration during an extended practice and learning study.

Further research is needed to better understand the exact nature of the quiet eye period. First, if quiet eye duration is used to parameterize kinematic variables used in aiming tasks – such as angle of release, velocity, and acceleration, further research could manipulate each variable and measure it’s effect on quiet duration. Second, if quiet eye duration is indicative of cognitive processing, distractions in the visual field could be used to see if quiet eye duration increases as a result of the additional cognitive processing that may occur to overcome the distractions. If the quiet eye period stays the same, will accuracy be reduced? Finally, if the quiet eye period is used to parameterize movements, participants could be trained to understand and focus on the parameters of the movement. It would be expected that quiet eye duration would increase as a result of the training.
Real World Application

Better understanding of how the quiet eye period is used in aiming tasks has real world application in a variety of settings. The most obvious is in sport skills. If athletes are able to understand what the quiet eye period is used for and how to use it to their advantage, then they may be able to extend the limits of human performance in aiming tasks. This could also be true in aiming activities outside of sport. Understanding the cognitive processes thought to occur during the quiet eye period could benefit military groups. In many situations, gunmen in the military are forced to make a decision, aim, and shoot in a very small time frame. Better understanding what the quiet eye period is used for may allow these gunmen to better utilize the limited time to be more accurate.

Conclusion

From the present study, it would appear that cognitive processing, including parameterization of a movement, may occur during the quiet eye period. In the present study, the longest quiet eye duration was seen on trials in which large scale changes were made in the target location (i.e., three-increment or Z-axis). Additionally, this cognitive processing may be related to the cognitive processing that occurs as a result of contextual interference. Despite the results of the present study, future research into the quiet eye period and the processing that may occur is needed.
References


Appendix A

Review of Literature

The quiet eye period is a fairly new concept in motor learning. However, the concepts and theories in which it is based have a long history. The following review of literature on the quiet eye period begins with a brief review of human attention, focusing specifically on visual selective attention. Next, visual search and vision-in-action approaches to expert-novice differences in gaze behavior are discussed, followed by an examination of the role of gaze in aiming tasks. Finally, the quiet eye period is discussed, including theoretical foundations of quiet eye, the location-suppression hypothesis, and the role contextual interference may play in the quiet eye period.

Visual Selective Attention

Human attention has been widely studied by researchers (Hoffman, 1998; Wolfe, 1998). As such, there are a large number of definitions of attention. One definition states that attention is the process in which specific information in the environment is processed to the exclusion of all other information available (Vickers, 2007). In the learning of motor skills, the selection of information, or cues, related to performance is critical. The process through which this information is detected and then selected is called selective attention. When the role of vision is used in directing attention to environmental cues that influence the preparation and/or the performance of an action, this is termed visual selective attention (Magill, 2010).

Visual selective attention can use either top-down (goal-directed) or bottom-up (stimulus-directed) methods to process an object or location. During top-down processing
“the flow of information is from the ‘higher’ to ‘lower’ centers, conveying knowledge derived from previous experience rather than sensory stimulation” (Corbetta & Shulman, 2002, p. 201). Top-down processing is goal-directed. As such, individuals select relevant cues based on experience, knowledge, and goals (Magill, 2010). Bottom-up processing progresses in a “single direction from sensory input, through perceptual analysis, towards motor output, without involving feedback information flowing backwards from ‘higher’ centers to ‘lower’ centers” (Corbetta & Shulman, 2002, p. 201). Bottom-up processing is stimulus driven, in that certain cues pop out and are selected based on their being distinct or meaningful in the environment (Magill, 2010). In most performance situations, a combination of top-down and bottom-up processing is used in the visual search process (Egeth & Yantis, 1997).

Visual Search and Expertise

According to Magill (2010, p. 208), visual search is “the process of directing visual attention to locate relevant environmental cues” in the visual field. Eye movements have been used to evaluate visual search characteristics, based on the concept that point of gaze reflects current focus of attention there is a major limitation to this, which was seen in the following study. Deubel and Schneider (1996) investigated the spatial interaction of visual attention and saccadic eye movements using five participants (ages 20-32). Each participated in four sessions, which consisted of 216 trials per session. In the first experiment, participants were initially fixated on a central crosshair on a monitor. After a short delay, a symbolic cue appeared. The cue indicated a specific target (ST), as well as the side (right or left) it would appear; however, it would not reveal where in a string of distracters the target would appear. The cue was randomly removed from the
screen, signaling to the participant that they should begin a saccade to the ST. They found that visual attention and saccadic eye movements are closely coupled. It was not possible for participants to focus visual attention to one location while preparing a saccadic eye movement to another location. In the second experiment, a similar procedure was used. This time, the target would always appear in the center of the string of distracters. They found that participants were only able to decouple attention from eye movements if there was sufficient time to plan the saccade before decoupling occurs. Several other studies (Hoffman & Subramaniam, 1995; Zelinsky, Rao, Hayhoe, & Ballard, 1997; Henderson, 2003) have corroborated the findings of the Deubel and Schneider study. They found that attention is able to move independent of the eye, but changes in eye movement are - with very few exceptions - always preceded by a shift in attention.

Visual search strategies are used in everyday activities, such as reading or reaching for a cup, and in sports performance. In performance settings, studies examining visual search strategies in tennis (Goulet, Bard, & Fleury, 1989), soccer (Helsen & Pauwels, 1990; Williams, Davids, Burwitz, & Williams, 1994; Williams & Davids, 1998), and driving a car (Chapman & Underwood, 1998) have been used. These studies all used visual search to examine and show differences between visual functions of experts and non-experts in performance settings. Ward and Williams (2003) study using soccer players can be used as an example of how visual search is used in determining expert-non-expert differences.

Ward and Williams (2003) also used visual search to examine the differences between experts and non-experts. They used 137 elite and sub-elite soccer players in various age groups (U-9, U-11, U-13, U-15 and U-17) to examine how visual, perceptual
and cognitive skills develop in relation to age and skill. Four tests – static visual acuity, dynamic visual acuity, stereoscopic depth sensitivity, and peripheral awareness were used to assess visual function. Visual search tests were used to assess perceptual and cognitive skills. This included film-based situations, anticipatory performance, memory recall, and situational probabilities. They found that as early as age 9, elite soccer players demonstrated more advanced perceptual and cognitive skills than their sub-elite counterparts. Despite its use in determining expert-novice differences, there is a major limitation to visual search experiments. Participants look at pictures or video of a skill being performed, and eye movements are recorded. The participants are not performing the skill themselves in a performance setting, so real-world application is limited.

Because of this limitation, a better approach to understanding gaze behavior, attention, cognition, and decision-making in performance settings is the vision-in-action approach (Vickers, 1996a). The vision-in-action approach records gaze behavior while the participant is performing a skill in a game-type setting. Since gaze is being recorded while the participant performs a sport skill in a manner that closely mimics a performance situation, perception-action coupling always occurs. Another way in which the vision-in-action approach differs from visual search is that vision-in-action studies, when possible, use sport tasks that have recognized standards of achievement to allow participants to be placed in skill groups objectively (Vickers, 2007).

In one of the earliest vision-in-action studies, Bard and Fleury (1981) compared the eye movements of expert and novice hockey goaltenders. They placed a Plexiglass shield in front of the goaltender and recorded where the goaltender fixated during both wrist shots and slap shots. They found that the fixation points of both groups tended to
focus on the puck and stick. However, the gaze of expert goaltenders was more consistent than novice goaltenders. Like visual search, vision-in-action can be used to examine expert-novice differences.

The body of vision-in-action research has grown in the past two decades. Other studies using the vision-in-action approach have used a variety of sport skills, including golf putting (Vickers, 1992), shooting a basketball free-throw (Vickers, 1996a; Vickers, 1996b; Harle & Vickers, 2001), rifle shooting (Janelle et al., 2000), and billiards (Williams et al., 2002). Further detail of some of these studies can be found in the following sections.

*The Role of Gaze in Aiming Tasks*

There are three categories of gaze control: aiming tasks, interceptive tasks, and tactical tasks. Aiming tasks are also called targeting tasks. These tasks can be near aiming tasks or far aiming tasks. These tasks require the gaze and attention systems to locate a target in the environment and then control the aiming of an object to the target. Aiming tasks can be to fixed targets (e.g. basketball hoop, dart board), abstract targets (e.g. billiards), or targets in motion (e.g. soccer pass). In interceptive tasks, gaze and attention are used to locate the object in space (usually towards the performer/participant). The object must be tracked during the approach and controlled as it is being received. These tasks include catching a baseball or receiving a volleyball pass. Tactical tasks use a combination of the gaze behaviors used in the other two task types, as well as recognizing and reading patterns of movements. These tasks include navigating an obstacle course or
shooting on a goaltender. Aiming tasks are most often used in gaze control research, although some studies have used interceptive or tactical tasks (Vickers, 2007).

Because aiming tasks require gaze and attention to both locate the target as well as control the aiming process to the target, the movement and vision must be coordinated. This is done through perception-action coupling. Perception-action coupling refers to “the spatial and temporal coordination of vision and the hands or feet...in skill performance situations” (Magill, 2010, p. 103). The timing of movement and gaze is critical. Vickers, Rodrigues, and Edworthy (2000) examined the timing between the preparation phase and the quiet eye. Using a dart-throwing task, they found that when to look at the target is just as important as where an individual looks and for how long. Fixating on the target location too early or too late resulted in lower levels of accuracy than when the target was fixated at the most favorable moment – directly before forearm extension. As such, coupling of gaze and movement plays an important role in aiming tasks.

Over the years, researchers have attempted to explain the role of gaze in aiming tasks. Most of this research has been focused on the coordination between the hand and eye, and many of these studies have examined the role of gaze in near aiming tasks. These near aiming tasks include tasks using wrist rotation (e.g., Abrams et al., 1990), as well as tasks in which a stylus is moved from a home position to a target location (e.g., Keele & Posner, 1968). Abrams et al. used a series of experiments in an attempt to determine the role of gaze in near aiming tasks. Participants sat in a booth and held a handle in their right hand, which was behind a wooden shield and not visible to the participant. The handle controlled a cursor on a display in front of the participant. Wrist-
rotation was used to move the handle. Participants were instructed to move the cursor as quickly and as accurately as possible. They were also given other instructions during each experiment, including fixating on a certain point or being told to “do anything they wanted” (p. 251). They found that aimed movements use the oculomotor information about the static position of the eye (fixation) during the impulse phase of the movement, as well as information concerning the dynamic characteristics of eye movements in error correction. They also determined the information that guides the impulse phase is different than the information that controls error corrections.

The Quiet Eye Period

More recently, researchers have turned their attention to the role of gaze in far aiming tasks, or tasks in which the target is at a distance from the participant. Far aiming tasks have specific relevance to sports and include shooting a gun or arrow and throwing or putting a ball.

The role of gaze in far aiming tasks was first examined by Vickers (1992). Vickers used a golf putting task to examine differences in gaze control between high and low handicap golfers, as well as the role gaze played in accuracy. She found that low handicap golfers displayed longer fixations to fewer targets than high handicap golfers. Additionally, she found that accuracy was greatly improved on putts in which the final fixation of the preparatory phase was long (>1700 ms) compared to putts in which the final fixation was short (<1700 ms). Vickers (1996a) would later call the duration of this final fixation before initiation of a movement the “quiet eye period”. In addition to the golf putt, longer quiet eye durations have been observed in experts during a basketball
Evidence for longer quiet eye durations in experts compared to non-experts is not sufficient to suggest that the time period is significant, rather than an insignificant side effect that results from other differences between more and less experienced performers. If the quiet eye period is used to mediate performance, it would be expected that training performers to increase their quiet eye time would be associated with an increase in accuracy in aiming tasks. Research into training the quiet eye period has shown an improvement in performance. Volleyball ball-tracking and -passing skills were used to determine whether the quiet eye period could be trained (Adolphe et al., 1997). A 6-week training program was used to help players to initiate tracking earlier and to elongate their gaze on the ball before a pass was made. After training, players were found to have quicker tracking onset times, as well as longer ball tracking durations. The most important finding of the study was the observation of longer quiet eye periods. Researchers also observed the effects of the training after three years, and accuracy in the trained individuals also improved significantly compared to other top, untrained players.

In another study, Harle and Vickers (2001) tried to determine whether free throw accuracy could be improved through training to extend the duration of the quiet eye in female university basketball players. The training consisted of two sessions per athlete – a video session and a feedback session. During the video session, athletes viewed their quiet eye data compared to an expert model. During the feedback session, the athletes were taught a 3-Step Quiet Eye routine adapted from Adolphe et al. (1997). The routine
consisted of (1) taking their shooting stance with their head up and gaze at the basket; (2) holding the ball in their shootings stance and fixating at a specific location on the basket (either the front, middle, or back of the rim) for 1.5 seconds; and (3) using a quick, fluid motion to shoot the ball. Over the course of two seasons, Harle and Vickers found an improvement in free throw percentage, citing longer quiet eye durations, especially on successful attempts. Based on these findings, it would appear that the quiet eye can be trained to improve accuracy in aiming tasks. A possible explanation as to why training quiet eye improves performance comes from Bernstein’s theory of degrees of freedom (see following section). In far aiming tasks, it could be that training quiet eye limits degrees of freedom by limiting the head and gaze, leaving them concerned only with the action of the hands and the object they will be projecting.

Theoretical Foundations of the Quiet Eye Period

In terms of theory, quiet eye is couched in four theoretical foundations: cognitive psychology, ecological psychology, the dynamic systems approach, and the constraints-led perspective (Vickers, 2007). Each foundation will be discussed throughout the rest of this section.

Cognitive psychology focuses mainly on information processing, particularly how "underlying mental or neural events that support or produce movements" (Schmidt & Lee, 2005, p. 15). It is important to be able to understand how information is stored, as well as how memory and information are processed so learning can occur. Vickers (2007) identified several areas of cognitive psychology that are important to quiet eye, including attention, memory, and focus and concentration.
Ecological psychology is based on the idea that “people perceive the environments in which they perform unaided by...neural representations as suggested by cognitive psychology” (Vickers, 2007, p. 4). Two important aspects of ecological psychology in terms of quiet eye are the optic array and optic flow. Optic array provides visual information to the retina about the environment and the layout of objects in space. Optic flow provides information to the retina from all parts of the environment. Optic flow is important because it is indicative of movement and how visual information is perceived relative to movement.

The dynamic systems approach refers to how movement patterns are developed through the organization of morphological, biomechanical, and environmental factors as well as task constraints. Central to the dynamic systems approach is Bernstein’s theory of degrees of freedom. Bernstein (1967) described skill acquisition by limiting degrees of freedom, or the number of independent elements that must be controlled by the body in order to produce a coordinated movement. By freezing degrees of freedom, one is able to limit the number of independent elements that are involved in a movement pattern. Through the acquisition of skills, frozen degrees of freedom are “unfrozen”. It is believed that experts are able to freeze and exploit these degrees of freedom in order to perform a movement efficiently.

The constraints-led perspective attempts to integrate ideas from cognitive psychology, ecological psychology, and the dynamic systems approach. Central to the constraints-led perspective is the idea that a combination of organism, environmental, and task constraints, or limits, work together to form the best possible pattern of coordination and control for any given activity (Vickers, 2007).
Location-Suppression Hypothesis

Couched within the four areas previously explained, and after several years of studying the quiet eye phenomenon, Vickers (1996a) introduced the location-suppression hypothesis. In the location aspect of her hypothesis, she proposed that long duration fixations are made to the target location during the preparatory phase of the movement to improve accuracy. This period is thought to be necessary to program the movement parameters of the movement, including force, direction, trajectory, and velocity as well as the timing and coordination of the limbs (Newell et al., 1979). As movement begins in the impulse phase, slight parameter changes are made if necessary, and the movement moves into the execution phase. Vickers contends that the parameters are planned and altered slightly while in the preparatory and impulse phases; during the execution phase, a suppression mechanism is used to block out unnecessary visual interference that results from the movement, such as the ball and hands obstructing the target during the basketball free throw. This suppression is theorized to be necessary to prevent disruption in the movement plan from on-line feedback as the movement begins.

Vickers’ hypothesis outlined two important elements of performance. The location aspect of the hypothesis is related to the duration of final fixation, or quiet eye period, which Vickers described as the final fixation on the target before the initiation of movement. Longer quiet eye periods are believed to be associated with better aiming performance. More importantly, quiet eye seems to be associated with the level of cognitive processing needed for success in aiming tasks. The suppression aspect involves an early fixation offset followed by vision-suppression. During this time, the head and eyes move freely, without continued fixation on the target location. The suppression
aspect of Vickers’ hypothesis is controversial, as other research has shown that many tasks decouple attention from point-of-gaze after the object has been fixated (Stelmach, Campsall & Hardman, 1997). In other words, there is a shift of attention without a subsequent shift in gaze.

Studies involving billiards, basketball and golf have supported the location aspect of Vickers’ hypothesis (Williams et al., 2002; Vickers, 1992, 1996a, 1996b). Results of these studies have shown experts to have a longer quiet eye period compared to non-experts. Although Vickers’ (1996a, 1996b) basketball study supported vision-suppression during the execution phase of the basketball free throw (when the hands and ball occlude the target), other studies in near aiming tasks have shown no evidence of suppression. Instead, they found that fixation on the target location is maintained throughout the movement (Williams et al., 2002; Abrams et al., 1990). While Vickers (1996a) location mechanism that results in a longer quiet eye period in experts seems valid, additional research into the nature of the vision-suppression mechanism is required.

Williams et al. (2002) tested Vickers’ hypothesis in two experiments using billiards. In the first experiment, they manipulated complexity to determine if the quiet eye period is reflective of cognitive programming. Results in the first experiment showed a longer quiet eye duration in skilled performers versus less-skilled performers. In addition, quiet eye duration increased as shot complexity increased and was longer on successful shots versus unsuccessful shots in both skilled and less-skilled performers. These results showed support for the location but not the suppression aspect of Vickers’ hypothesis, concluding that the vision-suppression mechanism might only be active in tasks in which the target becomes occluded by a body part or equipment (e.g. the
basketball free throw) during the execution phase. In a second experiment, Williams et al. used time-constraints to limit quiet eye duration in both sets of performers. They used a 25% constrained condition and a 50% constrained condition. So, if the participants took an average of 5 s to execute their shot in normal conditions, they would have 3.75 s to execute the shot in the 25% constrained condition and 2.5 s in the 50% constrained condition. These constraints led to a shorter quiet eye duration, which resulted in poorer performance in both groups. It was expected that quiet eye duration would decrease if the period was related to cognitive processes, and this was indeed the case, further supporting Vickers' proposal of the purpose of the quiet eye duration.

The Quiet Eye Period and Contextual Interference

Research by Williams et al. (2002) seemed to support the idea that the quiet eye period is used for cognitive processing. Another phenomenon related to cognitive processing is practice schedule. When a practice schedule involves only blocked practice, where all trials to one target are made before the participant moves on to the next target, little cognitive processing is involved because the environment and target stay the same trial to trial. On the other hand, when a practice schedule involves random practice, in which the target changes on each trial, there is a high cognitive load because the target location must be reprocessed every trial. Contextual interference refers to the “interference that results from performing various tasks or skills within the context of practice” (Magill, 2010, p. 376). The amount of contextual interference a task has is based on the practice schedule. Low contextual interference is associated with low practice variability (e.g., blocked practice) while high contextual interference is
associated with high practice variability (e.g., random practice) (Schmidt & Lee, 2005; Magill 2010).

To my knowledge, no study has examined the quiet eye period with practice manipulations until recently. Horn et al. (2010) recently assessed the duration of the final fixation in a darts aiming task. Participants were assigned to blocked or variable practice. Additionally, Horn et al. manipulated target movement in the horizontal and vertical planes. If Vickers’ hypothesis is valid and cognitive programming of the movement parameters does occur during the quiet eye period, it would be expected that quiet eye duration would be longer in variable practice. In variable practice, the parameters of the skill change with each successive shot, and each attempt must be scaled. In blocked practice, however, the parameters of each shot would remain constant so scaling would only occur on the first throw to the new target in a block. This was found to be the case. Supporting both Vickers’ location-suppression hypothesis and their own hypotheses, Horn et al. observed a significantly longer quiet eye duration in participants assigned to variable practice compared to those assigned to blocked practice. Additionally, they found the quiet eye period to be longer in the vertical versus horizontal plane. Differences in quiet duration during variable and blocked practice may result from the parameterization and scaling of the movements required for accuracy. Quiet eye duration differences in the vertical and horizontal planes can also be explained by parameterization and scaling. Although the targets were equidistant from the center (bullseye) in both axes, changing targets in the vertical plane required more variation in the movement parameters, since the low and high targets would require different release angles, force and velocity.
Conclusion

Human attention has been studied extensively in motor learning research. Research into visual selective attention – specifically visual search – has focused on the role of gaze in near aiming tasks. More recently, the role of gaze in far aiming tasks has been examined (e.g., Abrams et al., 1990; Keele & Posner, 1968). A study by Vickers (1992) into the differences in gaze behavior of low-handicap and high-handicap golfers during a putt revealed a long duration fixation just prior to the initiation of the putt. Vickers would later call this duration the quiet eye period (1996a). She found that low-handicap golfers exhibited longer fixations than high-handicap golfers. She also found that accuracy was improved on putts in which the duration of the final fixation was longer compared to putts in which it was short.

Other research studies into the quiet period also revealed expert-novices differences; specifically, that experts exhibited longer quiet eye duration than novices (Vickers, 1996a, 1996b; Adolphe et al., 1997). These studies also found improved accuracy on trials in which quiet eye duration was long compared to trials in which quiet eye duration was short. Similarly, it has been found that quiet eye duration was longer on successful trials compared to unsuccessful trials (Williams et al., 2002; Causer et al., 2010). Later studies on quiet eye duration focused on training to extend quiet eye duration. Studies by both Adolphe et al. (1997) and Harle and Vickers (2001) found that quiet eye duration can be lengthened through training. Together, the early and later studies into the quiet eye period serve as indicators of the quiet eye period being used for cognitive processing. Most recently, findings in studies manipulating complexity
(Williams et al., 2002) and practice (Horn et al., 2010) seem to indicate that cognitive processing of movement parameters occurs during the quiet eye period.

Further research into the purpose of the quiet eye period is needed in order to better understand the quiet eye period, including determining whether scaling of movement parameters occurs during the quiet eye period. Better understanding of the quiet eye period could lend itself to various sport performance settings, as well as other settings, including military activity.
Appendix B

Research Problem

Statement of the Problem

In aiming tasks, it has been found that performers who exhibit a fixation of long duration just before the initiation of a movement are more accurate than those performers who exhibit a short fixation before the movement begins. Vickers (1996a) called the duration of this final fixation the quiet eye period. Despite extensive research into the quiet eye differences between experts and non-experts (Vickers, 1992, 1996a, 1996b; Adolphe et al., 1997; Janelle et al., 2000; Williams et al., 2002), little research has been done to examine the purpose of the quiet eye period.

The purpose of this study was to examine the hypothesis that the quiet eye period is used to scale movement parameters (e.g., angle of release, velocity, acceleration) using a soft-tipped sky darts aiming task. In the study, 12 male university undergraduates made throws to a variety of target locations. Target location was based on a combination of changes in size and direction. Quiet eye duration and radial error were measured on each throw.

Delimitations

- The participants used in this study were male, university undergraduates. No female participants were used, and using undergraduates presented a limited age range.
• Participants were from the Department of Exercise Science and Physical Education, so they may have had significant experience in motor tasks prior to participation.

• Due to the nature of the equipment, only participants with normal or corrected-to-normal vision were used in the study.

• Target location was manipulated using a series of combinations of directional and incremental changes, and participants were presented with a random practice setting only. The only variables measured were quiet eye duration and radial error.

Limitations

• Testing was done in a laboratory setting, so the transfer of findings to a non-laboratory setting may be limited.

• Participants’ throwing motion was constrained to limit variation between participants.

• Results may be relevant only for sky darts and may not extend to all far aiming tasks.

Assumptions

• The quiet eye period ended with the initiation of the movement

• Participants were able to throw the sky dart the same way in the laboratory as they would outdoors.
• Participants were able optimally motivated and were able to maintain their concentration for the entire session.

Operational Definitions

• **Blocked practice**: A type of practice in which a skill or component of a skill is practiced completely before moving on to another skill or skill component (example: AAAAAABBBBBBBCCCCCCC, where A, B, and C are all separate skills or components).

• **Execution phase**: The phase of movement in which the movement(s) of a skill is completed; in the location-suppression hypothesis (Vickers, 1996a), this is the phase in which visual suppression is believed to occur. In the present study, this period began just after the start of the final backswing of the movement.

• **Far aiming task**: A task in which an object is projected towards a target at a distance from its origin, such as throwing a sky dart.

• **Fixation**: Occurs when the line of gaze is directed towards a single point for a duration of time. In the present study, the length of the quiet eye fixation was determined by identifying the frame in which the movement began and counting the frames of a single fixation that led to it.

• **Impulse phase**: The phase of movement in which the initial movement of a skill is made; in the location-suppression hypothesis (Vickers, 1996a), this is the phase in which slight parameter changes may occur. In the present study, this phase of movement would occur during the initiation of the final backward swing.
• **Line of gaze**: Based on the position of the pupil and cornea, line of gaze is the path that can be drawn between the eye and the focal point, in this case the designated target on the floor.

• **Movement parameter**: In motor behavior, an adjustable scalar quantity (e.g., force, velocity, acceleration) that is used to execute a motor skill.

• **Near aiming task**: A task in which an object is projected towards a target not at a distance from its origin, such as reaching or grasping.

• **Preparatory phase**: The phase of movement that occurs just prior to the initiation of movement of a skill; in the location-suppression hypothesis (Vickers, 1996a), this is the phases in which movement parameters are believed to be planned in order to execute the skill. In the present study, this phase occurred in the moments just prior to the initiation of the final backswing of the movement.

• **Quiet eye period**: First coined by Vickers, it is the duration of the final fixation before the initiation of a movement in an aiming task (1996a); also called *quiet eye duration*.

• **Radial error**: The distance between the desired target location and the point where the projected object lands in an aiming task; is used to assess accuracy. In the present study, this was measured to the nearest 0.5 cm.

• **Scaling**: The process of changing the proportion of movement parameters in order to successful execute a movement when the movement pattern is constant and only the parameters change.
• **Variable practice**: A type of practice in which several skills or components of a skill are practiced in a random order, which is usually unknown to the person performing the skill or skill component (example: ACACCBABCBBACBABCAB, where A, B, and C are all separate skills or components).

• **Vision-in-action approach**: A method used to determine gaze behavior in sport skills. Participants perform skills in a game-like manner while information on gaze behavior is collected.

*Hypotheses*

1. Larger changes in distance in the target location would produce longer quiet eye duration than smaller changes in distance in the target location (3 > 2 > 1).

2. Diagonal changes in target location would result in longer quiet eye duration than changes in the vertical or horizontal axes. In turn, vertical axis changes will yield longer quiet eye duration than horizontal axis changes (Z > Y > X).
CONSENT FORM FOR ADULTS

Please read below with care. You can ask questions at any time, now or later. You can talk to other people before you fill in this form.

Study’s Title: The role of movement scaling on quiet eye duration during an aiming task.

Why is this study being done? This study is being conducted for the thesis of my Master of Arts degree in the Department of Exercise Science and Physical Education at Montclair State University. The purpose is to better understand the visual control of aiming tasks.

What will happen while you are in the study? You will be throwing soft-tipped lawn darts to various targets on the floor. You will be wearing a small camera that tracks where you are looking. You will also be wearing special markers on your body. These markers are the same as used to make video games that will tell us information about your movements. Any video we take of you will only be used in the study for analysis.

Time: Your participation in the study will take about 1 ½ hours. This time will be split into two 45-minute sessions.

Risks: You may experience some discomfort from wearing eye camera headband. You may experience some minor surface scratches to the skin from putting on or taking off the headband. You may feel some minor muscle fatigue and muscle soreness the next day. Use ice to treat any muscle soreness you experience. You may feel some anxiety in performing in front of the experimenter. If you experience any adverse effects, you may stop participation at any time. If these effects continue, contact the University Health Center at (973) 655-4361.
Benefits: You should increase your skill in dart throwing and may learn a strategy to increase aiming accuracy in other aiming tasks.

Who will know that you are in this study? You will not be linked to any presentations. We will keep who you are confidential according to the law.

Do you have to be in the study?
You do not have to be in this study. You are a volunteer! It is okay if you want to stop at any time and not be in the study. You do not have to answer any questions you do not want to answer. However, this study does require that you be videotaped. If you are not okay with being videotaped, that is okay, but we will not be able to use you as a participant.

Do you have any questions about this study? Email Michelle Okumura (okumuraml@mail.montclair.edu) or Rob Horn (hornr@mail.montclair.edu).

Do you have any questions about your rights? Phone or email the IRB Chair, Debra Zellner (reviewboard@mail.montclair.edu or 973-655-4327).
It is okay to use my data in other studies:
Please initial: _____ Yes _____ No

I would like to get a summary of this study:
Please initial: _____ Yes _____ No

*When the investigator is audiotaping, videotaping or photographing individual subjects, add the following two statements:*

*It is okay to (audiotape, videotape, or photograph) me while I am in this study:*
Please initial: _____ Yes _____ No

*It is not okay to (audiotape, videotape, or photograph) me while I am in this study:*
Please initial: _____ Yes _____ No

The copy of this consent form is for you to keep.

If you choose to be in this study, please fill in your lines below.

_________________________ _______________
Print your name here       Sign your name here    Date

_________________________ _______________
Name of Principal Investigator   Signature    Date

_________________________ _______________
Name of Faculty Sponsor       Signature    Date
Appendix D

Recruitment Email

I am writing to you to see if you are interested in volunteering to be a participant in a research project. This project is being conducted for my master’s thesis in the Department of Exercise Science and Physical Education at Montclair State University. The project is taking place in room 4005 of University Hall. The purpose is to better understand the visual control of aiming tasks. Your involvement is entirely voluntary and would require about 45-60 min. If interested please e-mail me at okumural@mail.montclair.edu, and I will contact you to set up a time.

Thanks for your time.

Michelle Okumura and Dr. Robert Horn (faculty supervisor)
### Table 1

*Means and Standard Deviations for the Duration (f) of the Quiet Eye Period in Male University Undergraduates During a Soft-tipped Sky Darts Aiming Task*

<table>
<thead>
<tr>
<th>Size of Change</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.79</td>
<td>0.295</td>
</tr>
<tr>
<td>2</td>
<td>8.84</td>
<td>0.440</td>
</tr>
<tr>
<td>3</td>
<td>9.57*</td>
<td>0.600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction of Change</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>7.35</td>
<td>0.444</td>
</tr>
<tr>
<td>Y</td>
<td>7.50</td>
<td>0.402</td>
</tr>
<tr>
<td>Z</td>
<td>11.34*</td>
<td>0.506</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference in M at the p<.05 level.
Table 2

Means and Standard Deviations for the Duration (f) of the Quiet Eye Period for Each Interaction of Size of Change and Direction of Change

<table>
<thead>
<tr>
<th>Size of Change</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction of Change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>7.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.70&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
<td>0.30</td>
<td>0.42</td>
<td>0.65</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>6.90&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>7.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.08&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
<td>0.37</td>
<td>0.42</td>
<td>0.53</td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>9.45&lt;sup&gt;a,b,d,f&lt;/sup&gt;</td>
<td>11.66&lt;sup&gt;a,b,c,f&lt;/sup&gt;</td>
<td>12.92&lt;sup&gt;a,b,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
<td>0.35</td>
<td>0.54</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Note: “a” and “b” indicate a significant difference between direction of change values for the given size of change. “c”, “d”, “e”, and “f” indicate a significant difference between size of change values for the given direction of change.
Table 3

3 x 3 Repeated Measures Analysis of Variance Comparing the Effect of Size of Change and Direction of Change on Quiet Eye Duration

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>52.84</td>
<td>1.16</td>
<td>45.52</td>
<td>21.20*</td>
</tr>
<tr>
<td>Error (Size)</td>
<td>24.93</td>
<td>11.61</td>
<td>2.15</td>
<td></td>
</tr>
<tr>
<td>Direction</td>
<td>338.54</td>
<td>1.30</td>
<td>259.44</td>
<td>204.85*</td>
</tr>
<tr>
<td>Error (Direction)</td>
<td>16.53</td>
<td>1.30</td>
<td>259.44</td>
<td></td>
</tr>
<tr>
<td>Size*Direction</td>
<td>25.16</td>
<td>4</td>
<td>6.29</td>
<td>18.35*</td>
</tr>
<tr>
<td>Error (Size*Direction)</td>
<td>13.71</td>
<td>40</td>
<td>0.34</td>
<td></td>
</tr>
</tbody>
</table>

Note: An "*" indicates significance at the p<.001 level.
Table 4

*Tukey HSD Post Hoc Analysis for Main Effect for Size of Change*

<table>
<thead>
<tr>
<th></th>
<th>One-increment (M = 7.79 f)</th>
<th>Two-increment (M = 8.84 f)</th>
<th>Three-increment (M = 9.56 f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-increment</td>
<td>0.00</td>
<td>1.05</td>
<td>1.78*</td>
</tr>
<tr>
<td>Two-increment</td>
<td>----</td>
<td>0.00</td>
<td>0.73</td>
</tr>
<tr>
<td>Three-increment</td>
<td>----</td>
<td>----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 1.69.
Table 5

*Tukey HSD Post Hoc Analysis for Main Effect for Direction of Change*

<table>
<thead>
<tr>
<th></th>
<th>X-axis</th>
<th>Y-axis</th>
<th>Z-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M = 7.35 f)</td>
<td>(M = 7.50 f)</td>
<td>(M = 11.34 f)</td>
<td></td>
</tr>
<tr>
<td>X-axis</td>
<td>0.00</td>
<td>0.15</td>
<td>3.99*</td>
</tr>
<tr>
<td>Y-axis</td>
<td>-----</td>
<td>0.00</td>
<td>3.84*</td>
</tr>
<tr>
<td>Z-axis</td>
<td>-----</td>
<td>-----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 1.12.
Table 6

*Tukey HSD Post Hoc Analysis for Interaction of Direction of Change with One-increment Size of Change*

<table>
<thead>
<tr>
<th></th>
<th>1X (M = 7.01 f)</th>
<th>1Y (M = 6.90 f)</th>
<th>1Z (M = 9.45 f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1X</td>
<td>0.00</td>
<td>0.11</td>
<td>2.44*</td>
</tr>
<tr>
<td>1Y</td>
<td>-----</td>
<td>0.00</td>
<td>2.55*</td>
</tr>
<tr>
<td>1Z</td>
<td>-----</td>
<td>-----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 0.74.
Table 7

Tukey HSD Post Hoc Analysis for Interaction of Direction of Change with Two-increment Size of Change

<table>
<thead>
<tr>
<th></th>
<th>2X (M = 7.34 f)</th>
<th>2Y (M = 7.51 f)</th>
<th>2Z (M = 11.66 f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2X</td>
<td>0.00</td>
<td>0.17</td>
<td>4.32*</td>
</tr>
<tr>
<td>2Y</td>
<td>----</td>
<td>0.00</td>
<td>4.15*</td>
</tr>
<tr>
<td>2Z</td>
<td>----</td>
<td>----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 0.63.
Table 8

Tukey HSD Post Hoc Analysis for Interaction of Direction of Change with Three-increment Size of Change

<table>
<thead>
<tr>
<th></th>
<th>3X (M = 7.70 f)</th>
<th>3Y (M = 8.08 f)</th>
<th>3Z (M = 12.92 f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3X</td>
<td>0.00</td>
<td>0.38</td>
<td>5.22*</td>
</tr>
<tr>
<td>3Y</td>
<td>-----</td>
<td>0.00</td>
<td>4.84*</td>
</tr>
<tr>
<td>3Z</td>
<td>-----</td>
<td>-----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 0.90.
Table 9

Tukey HSD Post Hoc Analysis for Interaction of Size of Change with Y-axis Directional Change

<table>
<thead>
<tr>
<th></th>
<th>1Y</th>
<th>2Y</th>
<th>3Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(M = 6.90 f)</td>
<td>(M = 7.51 f)</td>
<td>(M = 8.08 f)</td>
</tr>
<tr>
<td>1Y</td>
<td>0.00</td>
<td>0.61</td>
<td>1.18*</td>
</tr>
<tr>
<td>2Y</td>
<td>-----</td>
<td>0.00</td>
<td>0.57</td>
</tr>
<tr>
<td>3Y</td>
<td>-----</td>
<td>-----</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An “*” indicates a significant difference at the p<.05 level. HSD = 0.83.
### Table 10

*Tukey HSD Post Hoc Analysis for Interaction of Size of Change with Z-axis Directional Change*

<table>
<thead>
<tr>
<th></th>
<th>1Z (M = 9.45 f)</th>
<th>2Z (M = 11.66 f)</th>
<th>3Z (M = 12.92 f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Z</td>
<td>0.00</td>
<td>0.61*</td>
<td>1.18*</td>
</tr>
<tr>
<td>2Z</td>
<td>****</td>
<td>0.00</td>
<td>0.57*</td>
</tr>
<tr>
<td>3Z</td>
<td>****</td>
<td>****</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: An "*" indicates a significant difference at the p<.05 level. HSD = 0.96.