VISUAL DISPLACEMENT DURING MANUAL AIMING

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VISUAL DISPLACEMENT DURING

MANUAL AIMING

By

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ABSTRACT

Four experiments were conducted to examine the visual regulation of manual aiming under visually displaced conditions. A secondary purpose of these studies was to examine potential gender differences in behaviour following prismatic displacement. The initial experiment was designed to test a monocular switch of vision as a method of presenting the visually displaced information. This experiment also provided an opportunity to explore manual and ocular asymmetries. The monocular switch had no major influence on the terminal accuracy of the movements. Therefore, the methodology was employed to present visually displaced information in the three subsequent experiments. The second experiment was designed to present visually displaced information at different times during the aiming movements, while the third experiment was designed to remove the displaced information during the movements. In a fourth experiment, a real time movement analysis procedure was used to introduce visual displacement at various kinematic markers. In Experiments 2, 3, and 4, the early presentation and removal of the visually displaced information had the most influence on terminal accuracy. However, these effects were not consistent across gender. Male participants executed their movements based on the information presented prior to the movements. In contrast, female participants were more influenced by the information received during the initial portions of the movements. The results support models of manual control that emphasize the importance of vision in the early portions of the movement for the correction of trajectory errors. The effects involving gender suggest that gender should be included as an independent variable in future research.

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PREAMBLE

The purpose of this thesis is to examine the visual regulation of the corrective processes involved in rapid and accurate aiming. The results of four experiments are reported in two, for submission style, manuscripts. In the first manuscript, three experiments were conducted to examine the effect of visual displacement on the organization and execution of manual aiming. The first experiment was designed to validate the use of a monocular vision switch as a methodology of presenting visually displaced information to the participants during their aiming movements. This experiment also provided an opportunity to explore gender differences in the control of goal-directed movement, as well as manual and ocular asymmetries. The second experiment was designed to examine gender differences in the corrective processes during manual aiming following the presentation of visually displaced information. The third experiment examined gender differences in the corrective processes during manual aiming following the removal of displaced information.

The second manuscript contains the results of a single experiment in which a real time manipulation, based on optoelectronic limb movement data, was used to trigger visual displacement of the movement environment. The purpose of this experiment was to bind the monocular switch perturbation to the kinematic markers indicative of the termination of the pre-programmed sub-movement and the initiation of the concurrently controlled sub-movement. This manuscript is primarily a methodological paper. As such, the experiment involved a smaller sample size and gender was not examined as an independent variable.

To provide a larger theoretical and historical background, an introductory section precedes presentation of the empirical work. In this section, several theories of manual control, and relevant issues pertaining to the experimental protocol are discussed. The final section of the thesis is a general discussion section in which the findings of the four studies are placed in a larger context.

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INTRODUCTION

From A to B: Open-Loop and Closed-Loop Control

Most individuals do not think about how they manage to accurately and rapidly point at an object such as a plane in the sky, but many internal processes and much practice allow individuals to complete such an action without much apparent effort. Simply moving a finger rapidly and accurately from point A to point B requires that the individual plan the movement, and then execute it. Although the movement may seem simple, there is very little agreement about the processes that govern precise control. Many theories have been put forth to explain the qualitative and quantitative characteristics of manual aiming, most involving a combination of open-loop and closedloop control.

Pure open-loop control is associated with a set of previously planned parameters. A completely open-loop movement is completed without alteration of the motor plan. Thus, movement execution occurs independent of internal feedback, or external environmental events that happen during the movement. Completely open-loop movements can lead to a large degree of terminal error if either a response selection error is made, or the movement is perturbed enroute to the target. Response selection errors occur when the parameters chosen prior to the movement are incompatible with the requirements of the goal. Perturbation errors occur when the response chosen was correct for the requirements of the task, but the requirements of the task were changed during the movement. With practice, an individual should be able to improve their preprogramming efforts to optimize outcome, as long as there is at least some terminal

feedback about performance. However, the optimal situation to maximize speed and accuracy is to combine precision planning and the use of response-produced feedback (see Elliott, Helsen, & Chua, 2001, for a review).

Closed-loop control of manual aiming occurs with reference to the external environment and an internal model of correctness during movement. Movements executed under closed-loop processes are usually more accurate than open-loop movements because of this continued referencing to a model of correctness. Of specific interest to researchers in the field of motor control is the length of time necessary to detect error in the limb trajectory using available sensory feedback (usually either visual, or kinesthetic), and then to enact change in the limb's trajectory on the basis of that information. Thus, while closed-loop processing may lead to greater endpoint accuracy, it takes time to detect and correct trajectory errors.

Modeling The Control of Manual Aiming

The control of manual aiming has been empirically studied for over a hundred years, beginning with the investigations of Woodworth (1899). Woodworth had individuals make reciprocal aiming movements on a sheet of paper attached to a rotating drum. By rotating the drum at a constant speed, Woodworth could measure both the spatial accuracy and temporal characteristics of the movements. Woodworth observed that the aiming movements appeared to be completed in two phases. An initial ballistic phase brought the limb into the vicinity of the target, then a secondary or "homing-in" phase brought the effector to the target. The purpose of the secondary phase was to correct for planning or execution errors from the initial ballistic phase of the movement

by using visual or kinesthetic feedback to modify the trajectory of the hand. Evidence of these two control processes emphasized the importance of vision prior to the movement to efficiently plan the movement, and of vision during the later portion of the movement to fine-tune it. Although, Woodworth's (1899) model may appear simple, his ideas have formed the basis for multiple investigations of perception and motor control.

Woodworth's (1899) investigations have resulted in several models of goaldirected aiming including the iterative correction model (Crossman & Goodeve, 1963/1983), the single correction model (Beggs & Howarth, 1972), the impulse variability model (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979), and the optimized dual sub-movement model (Meyer, Abrams, Kornblum, Wright, & Smith, 1988). Although some models share similarities, each model is distinct in its assumptions of the control processes involved in manual movement.

The iterative correction model was initially proposed to explain the speed and accuracy relationship in aiming tasks. This model posits that, provided sufficient time for modification to an erroneous initial movement, the movement is completed in many discrete phases. Each consecutive phase is planned and initiated based on feedback received in the previous phase. Since the correction process is feedback-based, the terminal accuracy is dependent on the number of time consuming corrective movements made during the movement. The limiting factor in the initiation of correction is thus the visual processing time required for the corrections, posited by Keele and Posner (1968), to be between 190 and 260 ms. The iterative correction model was revisited following the introduction of high-speed video, and optoelectronic kinematic evidence that supported

the traditional two-component model. Kinematic evidence indicated that individuals executed reasonably stereotyped movements for the initial portion of the movement path, and then discontinuities in the trajectory of the limb near the end of the movement appeared in the trajectories. The discrete changes in the kinematic profile near the end of the movement also occurred more often than every 200 milliseconds. As an example, Smith and Bowden (1980) studied the effects of delayed and displaced visual information on motor control, and found that inaccurate visual information influenced accuracy even for movements of short duration (< 160 ms).

Provided with the temporal limitations of the iterative correction model, Beggs and Howarth (1972) proposed the single correction model. Similar to the two-component model first proposed by Woodworth (1899), movements were thought to occur in two phases. An initial movement brings the limb into the proximity of the target, while only a single visual feedback-based correction occurred prior to target contact. In contrast to the two-component model (Woodworth, 1899) that emphasizes the importance of vision during the latter portion of the movement, the single correction model emphasizes the importance of vision during the initial portion of the movement to plan the corrective component. Presumably, the vision received prior to the planning and initiation of a correction should be most important regardless of the remaining distance to the target (Elliott et al., 2001). In addition, vision, or the lack of vision following the initiation of the single correction should not have an effect on terminal accuracy because it becomes irrelevant to the control of the rest of the movement. An exception to the irrelevance of this visual information is the use of the endpoint position to aid programming the

subsequent trials. In any case, the relevant cues for the participant prior to planning and initiating the corrective sub-movement are the spatial positions of the target and limb. Thus, the single correction model places importance on the visual detection of the limb and target position to develop a spatial representation of the environment and translate it into a corrective motor response.

The impulse variability model (Schmidt et al., 1979) attempts to explain the speed and accuracy of extremely rapid aiming movements. For example, Schmidt and colleagues (1979) suggest that movements longer than 200 milliseconds in duration allow sufficient time for feedback based corrections, the accuracy of a short duration movement is determined by the amount of muscular force required to produce that movement. The variability of the movement increases proportionally with an increase in muscle force and the associated increase in neural-motor noise. This variability leads to an increase in the spatial variability of the endpoint of the initial impulse, whose distribution over a number of trials should be centered on the target. As the endpoint of the initial impulse becomes more variable, so does the movement endpoint location (i.e., the effective target width increases). Corrections to the initial movement are necessary when this effective target width is larger than the true target width. In other words, when the endpoint of the initial movement falls outside of the target area, a corrective movement is required. However, the modifications only occur with enough time to detect and correct the trajectory error. In the absence of time, the increased variability results in endpoint error. Limitations of this model include issues such as the force variability model only applying to the initial

portions of a movement, and that the force-force relations break down at extremely low and high force demands.

In recent years, the optimized dual sub-movement model (Meyer et al., 1988) has been the most prominent dual process model of speed accuracy relations and visual regulation. The premise of the model is that a movement is composed of component submovements whose durations are "optimized" to account for the noisy human neuralmotor system. The model accounts for the compromise between the increased neuralmotor noise caused by the increase in force required to complete rapid movements, and the time required to plan and execute corrective sub-movements. In this model, the feedback based corrective sub-movements only occur if the primary sub-movement misses the target. Because of this hypothesized normal distribution of primary movement endpoints around the center of the target, corrections are expected to happen on a given proportion of the total trials. Vision remains important to the accuracy of the movement, but a renewed emphasis falls on the use of kinesthesis for the detection of force variation and error. Although some limitations to the model exist, the optimized dual submovement model combines the best features of each of the other major models (see Elliott et al., 2001).

The Importance of Visual Regulation

The visual system provides information to pre-plan a movement towards a target, as well as feedback about the position of the limb relative to the target during the movement (Elliott et al., 2001). The timing of the visual regulation within an aiming movement, however, is continually disputed in the motor behaviour community.

Traditional two-component models of goal directed aiming (e.g. Woodworth. 1899; Schmidt et al., 1979) emphasize the importance of vision at the end of the movements for on-line control. The visual information received near the target area provides information to guide the limb towards the target. In contrast, the single correction (Beggs & Howarth, 1972), and the optimized sub-movement models (Meyer et al., 1988) posit that the visual information received in the initial portions of the movement would be most beneficial for terminal accuracy. Therefore, the early use of visual information allows the participant to plan and initiate subsequent discrete corrections during the initially preplanned phase of the movement.

The traditional method to study the visual regulation of manual aiming, or more specifically the contribution of the visual closed-loop control, has been to eliminate the visual information and then examine the resulting behaviour. The timing of the occlusion becomes important if an investigator wants to test the various two-component models of manual control. In different experiments, investigators have either adopted a temporal or a spatial criterion for occluding vision.

Temporal Occlusion

Temporal occlusion studies typically compare full vision trials with trials wherein vision is removed at movement initiation, or for a fixed duration prior to movement initiation (Elliott, Carson, Goodman, & Chua, 1991; Meyer et al., 1988; Pratt & Abrams, 1996). Movement initiation is selected as an optimal temporal location to perturb the aiming movement because it is the physical separation between the visual information received during the pre-planning stage of the movement, and the visual information

received during the movement. Upon occlusion, the opportunity to make corrections during the movement based on visual feedback is eliminated. The occlusion of the movement environment can also occur prior to the movement, so that the contribution of pre-movement visual information can be examined (Elliott & Madalena, 1987). Many researchers have used the temporal occlusion technique because of the mechanical and theoretical simplicity of the manipulation. Meyer and colleagues (1988), and Pratt and Abrams (1996) employed a wrist rotation task that eliminated vision of the cursor on an oscilloscope upon movement initiation. Elliott and colleagues (1991) used a WATSMART motion analysis system, and eliminated vision of the stylus when individuals initiated their arm movements. Vision prior-to, and during the movements was found to be important in determining movement accuracy (Elliott et al., 1991).

Researchers using the temporal occlusion methodology, have assumed that the minimal time required for visually based feedback is determined by the time at which there are no differences in the observed errors made under the full vision, and no-vision conditions. The first to establish a time for visual processing was Woodworth (1899). Woodworth (1899) used his rotating drum, occluded vision at movement initiation, and had the participants conduct reciprocal aiming movements to the beat of a metronome. Using this method, Woodworth (1899) estimated the visual processing time to be approximately 450 ms.

Years later, Keele and Posner (1968) estimated the time to be in the range of 190-260 ms. Keele and Posner (1968) reasoned that the visual processing time had to be less than 200 ms, because a simple reaction time to a visual stimulus was shorter than 200 ms.

Keele and Posner (1968) also pointed out that Woodworth (1899), had overestimated the visual processing time because he calculated these latencies over a reciprocal aiming movement, counting the time spent reversing the movement, and thus doubling the required time. Keele and Posner (1968) had participants perform discrete aiming movements within four different time ranges. The results of this study suggested that although, the number of missed targets in the full vision 150-ms condition was equal to that of the no-vision 150-ms condition, a significant difference existed between the two visual conditions in the 250-ms condition. In the first condition, the participants attempted to perform their movements within a 150-ms limit, but were only able to perform them in 190 ms on average. Thus, Keele and Posner (1968) concluded that the visual processing time was between 190-260 ms.. In a series of discrete aiming experiments Zelaznik, Hawkins, and Kisselburgh (1983) estimated the time to be less than the 200 ms suggested by Keele and Posner (1968). The results from each of the four experiments indicated an accuracy advantage for the full vision condition, compared to the no-vision condition, even in movements of 135 ms in duration. Reasons for the discrepancies between the results of Keele and Posner (1968), and Zelaznik and colleagues (1983) may involve the predictability of the visual condition in the subsequent trial, and differences in the measurement of movement accuracy (see Zelaznik et al., 1983) for a review).

Provided with a reasonably accurate visual processing time, Carlton (1981b) set out to independently occlude the visual elements associated with an aiming movement to determine the importance of each individual component for movement accuracy. Carlton

(1981b) had participants complete their manual aiming movements under full vision, novision, target only, stylus only, and target and stylus only conditions. Carlton (1981b) found that vision of the stylus was more important than vision of the target to maintain accuracy and suggested that a short-term visual representation of the environment might exist. With this representation providing the performer with information about the position of the target once vision was occluded.

In order to further examine the possibility of a short-term visual representation, Elliott and Madalena (1987) conducted two experiments to examine the effects of manipulating the time of occlusion prior to movement initiation. In the first experiment Elliott and Madalena (1987), had participants conduct manual aiming trials under full vision, no-vision at movement initiation, and under 2 s, 5 s, and 10 s no-vision delay conditions prior to movement initiation. A significant decrease in movement accuracy was observed for the no-vision delay conditions compared to the situation in which vision was eliminated upon movement initiation. In the second experiment, Elliott and Madalena (1987) attempted to replicate the results of the first experiment, while only exposing the participants to one of the full vision, no-vision, or 2 s delay conditions. As in the first experiment, the results indicated that terminal accuracy significantly decreased following the 2 s delay. The third experiment involved an attempt to reverse the effect of the delay by adding the target information with the use of a drop of phosphorescent paint at the target location. The effect of the delay on terminal accuracy was only partially eliminated. Perhaps as Carlton (1981b) suggested, visual information from the stylus is also required for optimal terminal accuracy.

In contrast to Carlton (1981b) however, Elliott (1988) observed that when participants were continuously presented with the stylus information, the significant decrease in accuracy remained present for delays longer than 2 s. In a second experiment, Elliott (1988) added target information with the use of phosphorescent paint and observed an increase in movement accuracy. The results of Elliott (1988) demonstrate that vision of the stylus is important for reducing terminal error when the potential for the target information remains either in a physical or representational form.

Presented with the underestimation of the importance of the target and stylus information on terminal accuracy in typical full-vision, no-vision paradigms, Elliott and Jaeger (1988) examined the potency of the visual representation under a visually displaced environment. They had participants conduct aiming trials under full vision. novision at movement initiation, and a no-vision 2 s delay condition, under displaced visual information. The participants benefited from the visual information, even when the information provided was visually displaced. In the context of the results from Elliott (1988; Elliott & Jaeger, 1988), the results of Carlton (1981b) may indicate that the vision of the stylus was most important because a visual representation of the target still persisted. Although Carlton (1981b) had participants sit in darkness for 2 s prior to movement initiation in the stylus only condition, the target remained lit by a secondary light from under the table until movement initiation, thus providing further evidence for a lasting visual representation.

Although the decay of the visual representation under normal visual conditions is detrimental to movement accuracy, Elliott, Calvert, Jaeger, and Jones (1990) conducted

an experiment involving pre-exposure to visual displacement to determine if the decay could, in fact, be beneficial. Elliott and colleagues (1990) had participants aiming to a single target under full vision, no vision at movement initiation, no-vision 2 s delay, and no-vision 10 s delay conditions. Once the participants had sufficient practice to complete their movements within 400-500 ms under each of the visual conditions, an adjustable prism was introduced prior to each trial. The prism was adjusted to one of eight positions (up/down, left/right and the four diagonals) prior to the participants' movement. To prevent the participant from making reference to a normalized visual memory representation, participants were pre-exposed to the prism for 2 s prior to movement initiation (Elliott et al., 1990). The results indicate that the decay of the erroneous information was beneficial. Specifically, the longer the participants spent in darkness prior to movement initiation, the more accurate their movement (Elliott et al., 1990).

Spatial Occlusion

Spatial position occlusion studies compare full vision trials with trials where portions of the movement are visually occluded (Carlton, 1981a; Chua & Elliott, 1993; Khan & Franks, 2003; Whiting & Sharpe, 1974). The reasoning behind using spatial occlusion as a manipulation is to examine the importance of vision at various points during the movement (i.e., the start and end of the movement), and thus contrast the predictions of the various models of manual control. For example, in order to examine the optimized dual sub-movement model of control (Meyer et al., 1988), Chua and Elliott (1993) occluded vision of the cursor during the initial half and subsequently the last half of the movement. In addition to the partial vision trials, the participants also performed

trials under full vision and no-vision at movement initiation (for the entire length) conditions. Participants made more accurate movements when vision was available, but vision was most useful for regulation and initiating efficient modifications when it was available in the last half of the movement length. In order to maintain a smooth trajectory, the relevant information was picked up and processed prior to the end of the primary sub-movement (Chua & Elliott, 1993).

Prior to Chua and Elliott (1993), and in response to Keele and Posner (1968), Carlton (1981a) conducted a spatial occlusion study designed to investigate the time to process visual information. Carlton (1981a) had participants aim to targets with a shield covering none of the movement, the initial 25 %, 50 %, 75 %, and 93 % of the movement. Carlton (1981a) found a significant increase in the movement time between the 50 %, and the 75 % condition. In addition the rate of errors also increased significantly between the 50 %, and the 75 % no-vision conditions. Film analysis of the movements. indicated that the time between the visual acquisition of the stylus and the movement endpoint was approximately 135 ms. Based on these results, Carlton (1981a) estimated the visual processing time to be approximately 135 ms. However, guiding or correcting the trajectory of the limb from a sudden visual appearance of the stylus, is not similar to the continuous visual guidance of the limb throughout the movement, regardless of the movement duration.

Similar to Chua and Elliott (1993), Khan, and Franks (2003) examined the contribution of vision to the corrective portion of the movement by limiting vision to the initial portions of the movements. Based on the premise that visual information is most

important in the initial portion of the movement, Khan and Franks (2003) had participants aim to a target under no-vision, 50 percent first half vision, 75 percent first portion vision, and full vision conditions. Participants were found to be more accurate and to make more efficient corrections with increasing amounts of vision of the initial portion of the movement (Khan & Franks, 2003). In contrast to Chua and Elliott (1993), their results indicate that the vision of the initial portions of the movement are most important for movement accuracy. The results again demonstrate the robust effect the presence of vision has on the terminal accuracy of manual aiming.

A major limitation of the spatial occlusion paradigm is that it places different constraints on the task, other than those of the typical aiming task. In other words, the control of the movement may differ if the participant knows that the occlusion will occur halfway (Elliott & Allard, 1985; Chua & Elliott, 1993). If the occlusion occurs early or late, the participant may choose to plan a longer/shorter initial movement, and spend a longer/shorter time using online control. In either case, the behaviour would differ from the normal in order to optimize the use of the limited vision.

Clearly, the visual occlusion forces the sensory system to adjust to the unexpected requirements of the task. Thus, the no-vision versus full vision paradigm eliminates the regular interaction of the sensory system, inducing a substitution of processes, or a dependence on open-loop processes. Essentially, the dependence on the primary sensory modality has changed because of the elimination of vision, and therefore the nature of the task itself has changed. In order to reduce this problem, researchers have manipulated multiple environmental elements including the ambient environment, the target, and the

effector without occluding of any of the elements (Heath, Hodges, Chua, & Elliott, 1998; Prablanc, Pélisson, & Goodale, 1986; Proteau & Masson, 1997).

Visual Perturbation

The ambient environment, the target, and the effector each contribute vital information towards the creation of an efficient visual representation of the environment for planning and control of manual aiming movements. Proteau and Masson (1997) examined the contribution of the ambient environment as a source of relevant information during manual aiming. Proteau and Masson (1997) had participants apply pressure to a handle that moved a cursor across a computer screen to a target at the edge of the screen. In an initial experiment, the background moved in the opposite direction to the cursor, creating the visual impression that the cursor was moving faster than it was. In a second experiment, Proteau and Masson (1997) had the background move in the same direction as the cursor, creating the visual impression that the cursor was moving slower than it was. In the first experiment, the participants undershot the target area, and in the second experiment, the participants overshot the target indicating that the ambient environment provides key information about the velocity of the limb.

An additional key source of information for the programming and execution of an aiming movement is the target. Heath et al., (1998) manipulated the target size, and location at movement initiation. Participants executed aiming movements to a target on a digitizing tablet. In one experiment, the size of the target was manipulated to increase in size on 13 % of the trials, and decrease in size on 13 % of the trials. For the remaining trials, the target remained the same size. The intention was to manipulate the on-line

control portion of the movement. By manipulating the size of the target following movement initiation, the intention was for the participants to prepare and execute similar initial movements, then execute secondary movements based on the new task constraints. Heath and colleagues (1998) found that the on-line control portion (the time after peak velocity) of the movement mimicked that of the new task constraints, in comparison to non-perturbed trials where movements were subject to the original constraints. The participants executed faster movements to the larger target, and slower movements to the smaller target in comparison to the non-perturbed trials. The results of Heath and colleagues (1998) support the traditional two-component model of goal-directed aiming. and provide a theoretical basis for the parsing of a discrete aiming movement at peak velocity. In other words, peak velocity seems to serve as a marker for the termination of the initial pre-planned movement, and the beginning of on-line control. In a second experiment, the amplitude of the movement was changed at movement initiation. The results indicated significantly increased times following peak velocity, indicative of an increase in corrective modifications to the movements, or an increase in the on-line control of the movements.

The effector is an additional source of information important for the optimal aiming performance. However, the overall importance of this information is the subject of some debate. For example, in a simple manual aiming task with and without vision of the limb. Prablanc et al., (1986) demonstrated that participants could modify their movements as efficiently with or without vision of the limb. Prablanc et al. (1986) had participants execute manual aiming trials to eight different targets under four different

visual conditions. Participants aimed to targets under no-vision, a target only condition, a no-vision 120 ms following the termination of the primary visual saccade, and a no-vision after the first visual saccade towards the target (upon completion of the saccade, a tone sounded, and then vision was removed at hand movement initiation). The results revealed that accuracy differences for the visual conditions only became apparent for longer target amplitudes, and that movements initiated based on foveal information were less efficient than when participants were provided the opportunity to correct the trajectory of the eye to the target during the movement. In other words, the participants maintained an advantage when provided the opportunity to correct the trajectory of the eye, and subsequently the trajectory of the hand during the movement (Prablanc et al., 1986).

The latter three studies demonstrate the importance of the ambient environment, the target and the effector to terminal accuracy. In the absence of visual occlusion, the positive feed-forward contribution of vision to limb control achieved through manipulation of the effector, the target size, or the target distance during the movement creates a dependence on the use of visual online control processes and therefore an examination of the corrective processes (e.g., Heath et al., 1998).

The Displacement of Vision

Another way to perturb the movement environment is through the use of prismatic displacement. The methodology selected for this thesis was a monocular presentation of a Fresnel prism base left and base right to displace the movement environment in the horizontal plane. The benefit of prismatic displacement is that prisms allow the

displacement of the entire visual field including the target, the effector, and the home position (Elliott & Allard, 1985; Elliott & Jaeger, 1988). Thus, prisms perturb the expected interaction between the participant and the visual environment. Specifically, the presence of a prism induces a general incompatibility between the perception of the visual environment and the execution of movement within the workspace. Because of this incompatibility, prisms have been used to examine human adaptive processes, and to prevent ceiling effects on improvement during manual aiming (Elliott & Allard, 1985; Elliott & Jaeger, 1988; Hay, 1979).

While typical prism adaptation experiments involve a pre-exposure phase, an exposure phase, and a post-exposure phase, our methodology was to present the prism for a short-term, and in a randomized orientation, thereby preventing prismatic adaptation. Adaptation to the prisms is usually measured by the strength of the negative after-effect. The negative after-effect is the compensation of the perceptual and motor systems in the opposing direction to the visual displacement. Major contributors to the negative aftereffect are the conscious correction (calibration to the new task constraints), and the assimilated corrective response (alignment to the displacement). The assimilated corrective response, or the alignment process occurs offline and is a permanent adjustment to prism exposure, while conscious correction, or calibration occurs online and is simply a temporary compensation to the environmental perturbation. Each process is distinguishable and separable. Calibration results from the perceptual incompatibility of the visual and motor systems and is reflected by the immediate change in the behaviour of the participant. A process known as first-trial adaptation best reflects the

calibration process (Redding & Wallace, 2003). Redding and Wallace (2003) had participants execute repetitive aiming movements at a target under visual displacement. On the first trial, participants terminated their movements significantly closer to the target than the perceived location of the target would dictate. In other words, if the prism displaced the target from the midline to 10° from the right of the midline, the participants managed to terminate their movements only 5° from the actual target position, indicating that some sort of on-line calibration process had occurred during the trial to adjust for the sensory-motor incompatibility (Redding & Wallace, 2003). In contrast to the calibration process, the alignment of the sensory-motor system is a more permanent adjustment in the spatial mapping and control of the sensory-motor system in response to a continuous and predictable perturbation. Thus, the calibration process may have a feed-forward contribution to the alignment of the sensory-motor system.

The most important process examined in the current thesis is this calibration process. The importance of the calibration process is emphasized in a trial where normal and visually displaced information is mixed randomly and unpredictably together, as employed in the methodology of this thesis. The random presentation methodology is similar to that used by Elliott and Allard (1985), and Elliott and colleagues (1990). In such a random presentation of trials, the only process that should be working is the conscious correction, or the calibration processing. The calibration of the sensory system to a visual displacement is detrimental to the participant if the displacement is in a different direction on the subsequent trial. In this situation, the calibration processes would be beneficial, and the alignment of the sensory-motor system to a specific

displacement would be detrimental. Alternatively, much evidence exists demonstrating that the decay of adaptation following prism exposure is relatively protracted, even after a minimal number of manual aiming trials during exposure (Choe & Welch, 1974). However, the studies demonstrating long periods of decay are experiments employing the traditional prism adaptation methodology (e.g. Choe & Welch, 1974; Redding & Wallace, 2001, 2002, 2003). The random presentation of displacement develops a dependence on calibration, and decreases the value of alignment, and therefore may also decrease the total adaptation to the displaced visual information.

Individual Differences In Manual Aiming

Most models of manual aiming have assumed that the same rules apply to all individuals. However, there is at least some evidence for individual differences in the relative importance of open-loop and closed-loop processes. For example, eighty years after the studies of Woodworth (1899), Hay (1979) studied the manual aiming behaviour of children to examine the development of upper limb control. Hay's (1979) first experiment was a simple aiming movement without vision of the hand, and the second experiment attempted to determine the extent that children use visual guidance during prehension. After the examination of the behaviour of the various age groups, Hay (1979) concluded that the control of manual aiming developed in three main phases. With age, the control of manual aiming developed from a totally ballistic movement, to a combination of a ballistic and a smooth movement, and finally, older children displayed a combination of an initial ballistic and a secondary homing-in phase in their movements. Generally, individuals exhibited changes in the control and guidance of movements with

chronological age. More importantly, the two-component model as described by Woodworth (1899) held for individuals over the age of nine. Additionally, the findings of Hay (1979) support the hypothesis that, with practice, individuals can improve both their pre-planning, and their responses to relevant feedback. Hay's data on the development of manual control fit well with the two-component model and other newer theoretical models on upper limb control.

In order to continue the examination of the development of manual control. von Hofsten and Rösblad (1988) examined the performance of 270 children, placed in nine age groups. The participants aimed to a single target in four different feedback conditions. Participants aimed under full vision, and no-vision conditions, but in a third and fourth condition the children placed their left hand under the aiming board at the target location, then aimed under no-vision and full vision conditions. Von Hofsten and Rösblad (1988) found that while male accuracy with both hands was similar and equal to female right hand performance, female left hand accuracy was significantly worse. This manual asymmetry was present for the younger age groups, but the differences disappeared following 11 years of age.

In this context, Barral and Debû (2002) had male and female 5-year old children point at targets in a cue/no-cue paradigm. The reasoning behind the experiment was that the different developmental rate for children on motor tasks might be moderated by gender, leading to differences in neural architecture and subsequently, differences in the strategy used during the learning and execution of tasks. Barral and Debû (2002) had participants aim as rapidly and accurately as possible to three targets with their left and

right hands. Barral and Debû (2002) found that females had an accuracy advantage for both hands, but their movements were longer, especially when using the left hand. Males were more accurate with their right hand than their left hand. Kinematic evidence indicated that females made corrections to their movements on a large portion of trials, while males executed more ballistic movements, especially when using the left hand. Barral and Debû (2002) suggested that these guidance differences indicate an ability of the females at the age of five to use feedback more rapidly and efficiently. However, this could also indicate a larger dependence on the feedback processes for terminal accuracy.

Consistent with the previous experiments, gender differences have been found to be associated with the environmental context (Laszlo, Bairstow, Ward, & Bancroft, 1980). The task employed by Laszlo and colleagues (1980) was to roll a ball to intercept a stationary, and a dynamic target. The background was manipulated to be blank, or contain task irrelevant wavy lines. The females performed worse than the males but only in the presence of the landmarks. This finding led Laszlo and colleagues (1980) to conclude that females need to reduce salience towards cues in the environment to improve their performances. As a follow-up, Laszlo and colleagues (1980) had males and females perform a sound-tracking task with and without background noise. Similarly, females performed worse with the presence of background noise, while for males the noise was irrelevant. For females, it would seem that the dependence on external cues and on-line correction is detrimental in some cases, and could be beneficial in other situations. In terms of this thesis, this dependence on the external cues, or the

context of the task, may indicate that they engage the calibration and alignment process more than males.

The expectation of gender differences in the calibration processes, and ultimately. the accuracy of the aiming movements are not unfounded. Some gender differences involving prism adaptation have also been observed. Elliott (1982) employed a lefthanded force production task, irrelevant to the primary task of manual aiming with the right hand, and found that the secondary task significantly degraded female adaptation. Perhaps the secondary task interfered with the feedforward, or feedback aspect of the calibration processes, and thus decreased the alignment of the female sensory-motor systems. Elliott (1982) suggested that: "The gender differences should disappear in less feedback dependent tasks such as ballistic pointing."

Teeken et al., (1996) examined gender differences during discrete and reciprocal aiming. Teeken and colleagues (1996) had participants perform 8 cm discrete and reciprocal aiming movements to targets of 32, 12, and 4 mm in diameter. The discrete task involved a single movement to the target, while the reciprocal task was to repeat the movement back and forth as many times as possible within 15 seconds. Teeken and colleagues (1996) found that males performed faster than females for discrete aiming, while both genders performed equally well on the reciprocal aiming task. An overall advantage for discrete aiming tasks seems to exist for males as they were faster, and the accuracy of the movements was similar. The potential for a dependence on feedback processing for females could account for a lengthened movement time in comparison to the male performance.

As previously discussed, a potential exists for participants to engage in different strategies based on their gender. Drinkwater (1968) used a pilot's altitude reporting task to examine the decision making of male and female civilian pilots. The participants were shown 30 transparencies consisting of the images of three flight instruments, and were asked to decide if the instruments did or did not match. Drinkwater (1968) found that females initially responded slowly, but correctly, and then sped up their responses with practice. In contrast, males responded rapidly, but incorrectly, then became more accurate with practice. Initially, the response strategies differed between genders, and then following practice the performance outcomes were similar. Because daily tasks are repeated multiple times prior to testing in the laboratory, the strategy differences between genders found by Drinkwater (1968) may not be evident unless the task employed is novel and does not incorporate well-practiced movements.

Additional reproducible gender differences have been found using the Purdue pegboard performance task (Peters, Servos, & Day, 1990). The task involves placing as many 3 mm rods into as many of the target holes as possible within 30 s. The task consistently favours women, and the results are robust and reproducible. However, the differences seem to be accounted for by finger size (Peters et al., 1990). The physically smaller female fingers provide an advantage in the execution of the task.

In another study that eliminated the physical characteristics of the participants as the cause for the gender differences, Nicholson and Kimura (1996) examined the recall and execution of movements of both speech and manual movements. In a first experiment. Nicholson and Kimura had participants repeat uni-syllabic, and multi-
syllabic words $(g^{,} b^{,} d^{;} g^{,} b^{,} d^{,})$. Males demonstrated an advantage on the unisyllabic words, and females were faster at executing multiple-syllabic words. The second experiment involved an examination of gender differences on single finger-tapping, and multiple finger-tapping tasks. Males maintained an advantage for executing single-taps, while females maintained an advantage for executing multiple-taps. The results of both experiments indicate that males had an execution advantage, while females maintained an advantage for programming a sequence of movements. Along the same lines, Rahim, and Sharma (1991) attempted to determine if performance advantages existed on an 8-button movement pattern task. Participants were to recall and execute movement patterns of varying difficulty, in response to a light pattern generated by the target array. Females performed the movements faster than males, and the difference increased as the difficulty of the movement pattern increased. Similar to Nicholson and Kimura (1996), Rahim and Sharma (1991) found that females were faster at the execution of multiple component movements, while males were faster at executing a single component in isolation. Whether gender differences arise because of hardware, cultural influences, or strategy, is relatively unknown and unexplored.

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Gender Differences And Visual Displacement

During Manual Aiming

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ABSTRACT

This study examined the contribution of the visual system to the control of upper limb movements, and the spatial and temporal limitations of the visual corrective process. A secondary purpose of the study was to examine gender differences in limb control following displacement of the visual field. An initial experiment was conducted to test a monocular switch as a method of presenting prismatic displacement rapidly. The results revealed minimal effect of the monocular switch on movement time and the endpoint error. Following this control experiment, prismatic displacement was introduced at the initiation of and during the movement. In the third experiment, the prism was first presented prior to movement initiation, and then removed at the beginning of or during the movement. The participants were most influenced by the early presentation or removal of the prism, and females were significantly more affected than males. It appears that females depend more on environmental context during the sensory-motor calibration processes than males.

Gender Differences And Visual Displacement During Manual Aiming Although there is little doubt that vision plays a prominent role in the regulation of goal-directed movement, there is still a great deal of controversy in the motor behaviour community about when the visual information is most important. The visual system provides information to pre-plan a movement towards a target, as well as feedback about the position of the limb relative to the target during the movement (Elliott, Helsen, & Chua, 2001). Traditional two-component models of goal directed aiming (e.g. Woodworth, 1899) emphasize the importance of vision at the end of the movement for on-line control. Following an initial ballistic impulse, visual information received near the target area provides information to guide the limb towards the target. In contrast, the single correction model (Beggs & Howarth, 1972), the iterative correction model (Crossman & Goodeve, 1963/1983), and the optimized sub-movement model (Meyer, Abrams, Kornblum, Wright, & Smith, 1988) posit that the visual information received in the initial portions of the movement would be most beneficial for terminal accuracy. Presumably, the early use of visual information allows the participant to plan and initiate subsequent discrete corrections during the pre-planned phase of the movement.

The traditional method to study the visual regulation of manual aiming, or more specifically the contribution of the visual closed-loop control, has been to eliminate the visual information and then examine the resulting behaviour. The timing of visual occlusion becomes important if an investigator wants to test the various two-component models of manual control. Consequently, investigators have usually either adopted a

temporal or a spatial criterion for occluding vision. In the case of a temporal criterion, the elimination of vision occurs either at some fixed time prior to, after, or at movement initiation itself (Elliott, Carson, Goodman, & Chua, 1991; Pratt & Abrams, 1996; Meyer et al., 1988). The use of spatial criteria is associated with the limb reaching a specified location on its way to the target.

Researchers have used temporal occlusion because of the mechanical simplicity of the manipulation. However, a major theoretical problem with employing temporal occlusion is that it can occur at proportionally different places in the trajectory, depending on the overall movement time. Although the occlusion can occur prior to the use of on-line visual information, it can also occur following the initiation of visual feedback processes. In extreme cases, the participant can finish their movement prior to the occlusion intended to interrupt the corrective modifications in the proximity of the target. Similarly, a problem with spatial occlusion is that it places different constraints on the task, other than those of the typical aiming task. For example, the control of the movement may differ if the participant knows that the occlusion will occur at the halfway point of the movement (Chua & Elliott, 1993). If the occlusion occurs early or late, the participant may choose to plan a longer, or shorter initial impulse, and spend a longer, or shorter time using online control. In either case, the behaviour differs from normal in order to optimize the use of the limited vision available in that condition.

Undisputedly, the visual occlusion forces the sensory-motor system to adjust to the unexpected requirements of the task. Thus, the no-vision versus full vision paradigm eliminates the regular interaction of the sensory and motor systems, inducing a

substitution of process, or a dependence on open-loop processes. Essentially, the reliance on the primary sensory modality has changed because of the elimination of vision, and therefore the nature of the task itself has changed.

Instead of occluding vision, other researchers have introduced some form of perturbation during movement execution so that the planned movement is no longer viable to achieve the movement goal. In the absence of visual occlusion, the positive feed-forward contribution of vision to limb control achieved through manipulation of the target size, or the target distance during the movement creates a dependence on the use of visual online control processes and therefore an examination of the corrective processes (e.g., Heath, Hodges, Chua, & Elliott, 1998). The target, the ambient environment, and the effector each represent vital information towards the creation of an efficient visual representation of the environment for planning and control of manual aiming movements.

Heath et al., (1998) manipulated the target size, and target location at movement initiation. Participants executed aiming movements to a target on a digitizing tablet. In an initial experiment, the size of the target was manipulated to increase in size on 13 % of the trials, and decrease in size on 13 % of the trials. For the remaining trials, the target remained the same size. The intention was to manipulate the on-line control portion of the movement. By manipulating the size of the target following movement initiation, the intention was to see if participants prepared and executed similar initial movements, and then executed secondary movements based on the new task constraints. Heath and colleagues (1998) found that the on-line control portion (the time after peak velocity) of the movement mimicked that of the new task constraints, in comparison to non-perturbed

trials where movements were subject to the original constraints. Specifically, participants executed faster movements to the larger target, and slower movements to the smaller target in comparison to the non-perturbed trials. In a second experiment, the amplitude of the movement was changed at movement initiation. The results indicated significantly increased times following peak velocity, indicative of an increase in corrective modifications to the movements, or an increase in the on-line control of the movements.

Similar to Heath and colleagues (1998), Paulignan, MacKenzie, Marteniuk, and Jeannerod (1991) manipulated the target location at movement initiation. Paulignan and colleagues (1991) had participants complete prehension movements to a dowel that was perturbed to the right or left on a percentage of the trials. They found that, although the perturbed trials were longer in duration than unperturbed trials, the participants were able to adjust the trajectory of their hand within 100 ms of the perturbation. The results affirm the short duration of the visuomotor system to influence movement regulation.

Proteau and Masson (1997) examined the contribution of the ambient environment as a source of relevant information during manual aiming. Proteau and Masson (1997) had participants apply pressure to a handle that moved a cursor across a computer screen to a target at the edge of the screen. In an initial experiment, the background moved in the opposite direction to the cursor, creating the visual impression that the cursor was moving faster than it was. In a second experiment, Proteau and Masson (1997) had the background to move in the same direction as the cursor, creating the visual impression that the cursor was moving slower than it was. In the first experiment, the participants undershot the target area, and in the second experiment, the

participants overshot the target indicating that the ambient environment affects the perceived velocity of the limb and thus endpoint accuracy.

The methodology selected for this study was a monocular presentation of a Fresnel prism (base left and base right) to displace the movement environment in the horizontal plane in order to induce a general incompatibility between the perception of the environment and the execution of movement within the workspace. Because of this incompatibility, prisms have been used to examine human adaptive processes, and to prevent ceiling effects on improvement during manual aiming (Elliott & Allard, 1985; Elliott & Jaeger, 1988; Hay, 1979).

Most models of manual aiming have assumed that the same sensory-motor processes apply to all individuals. However, there is at least some evidence for individual differences in the relative importance of open-loop and closed-loop processes. For example, eighty years after the studies of Woodworth (1899), Hay (1979) studied the manual aiming behaviour of children to examine the development of upper limb control. Hay's (1979) first experiment was a simple aiming movement without vision of the hand, and the second experiment attempted to determine the extent to which children use visual guidance during prehension. After the examination of the behaviour of the various age groups. Hay (1979) concluded that the control of manual aiming developed in three main phases. With age, the control of manual aiming developed from a totally ballistic movement, to a combination of a ballistic and a smooth movement. Finally, older children displayed a combination of an initial ballistic and a secondary homing-in phase in their movements. Generally, individuals exhibited changes in the control and guidance

of movements with chronological age. More importantly, the two-component process, as described by Woodworth (1899), held for individuals over the age of nine. Additionally, the findings of Hay (1979) support the hypothesis that, with practice, individuals can improve both their pre-planning, and their use of response-produced feedback (Khan & Franks, in press).

Although relatively rare, gender differences in the performance of manual tasks have been found to be associated with the environmental context (Laszlo, Bairstow, Ward, & Bancroft, 1980). The task employed by Laszlo and colleagues (1980) was to roll a ball to intercept a stationary, and a dynamic target. The background was manipulated to be blank, or contain task irrelevant wavy lines. The performance of males was landmark independent, while the females were negatively affected by the irrelevant landmarks (Laszlo et al., 1980). This finding led Laszlo and colleagues (1980) to conclude that females need to reduce salience towards irrelevant cues in the environment in order to improve performance. In other words, female participants are influenced by irrelevant information, and therefore they need to focus only on relevant cues, or ignore the irrelevant in order to improve performance. As a follow-up, Laszlo and colleagues (1980) had males and females perform a sound-tracking task with and without background noise. Similarly, females performed worse with the presence of background noise, while for males the noise had no effect on their performance. For females, it would seem that the dependence on external cues and on-line control is detrimental in some cases, but could be beneficial in other situations. In terms of this research, this

dependence on the external cues, or the context of the task, may cause more movement error when vision is displaced.

EXPERIMENT 1

In this experiment, we decided to examine both the eve and hand asymmetries in aiming. This was because the method selected to present the prism to the participants was a monocular switch of vision during the movement. Provided with evidence of a binocular vision advantage during three-dimensional manual aiming (Coull, Weir, Tremblay, Weeks, & Elliott, 2000), the concern was that the participants may not use optimal regulation strategies in response to the monocular stimuli because the perturbation was not binocular. However, Jones and Lee (1981) observed participants complete a bead-threading task, an object tracking task, and a water-pouring task under monocular and binocular visual conditions, and concluded that the binocular advantage was due to ocular concordance, and not the disparity between the two eyes. In other words, the advantage of the binocular vision exists when the sensory information from the binocular zone is similar, and not because both eyes maintained differing views of the same object. Thus, the location of the target in the common binocular zone should not invoke error in the trajectory of the limb. In support of this, Ogle (1963) found that a monocular exposure of 18 ms created a lasting monocular impression of 96 milliseconds. In this case, subsequent single non-overlapping monocular exposures can create a binocular memory representation of the aiming environment. While a binocular visual representation may remain following a monocular switch, a pre-existing bias towards the

information provided by the dominant eye may also exist, causing biased movement variability and terminal error.

With respect to the manual asymmetry, the hands should display differing performances in relation to the accuracy and speed of response. Todor and Doane (1978) demonstrated differences between the hands for movement preparation, and movement execution. Todor and Doane (1978) employed a simple Fitts' tapping task with varying indices of difficulty, and had participants perform the tasks with their left and their right hands. Todor and Doane (1978) demonstrated that the left hand (right cerebral hemisphere), had an advantage in the preplanning stages as reflected by lower reaction times, while the right hand (left cerebral hemisphere), demonstrated an advantage in the concurrent control phase of the movement as reflected by movement time. Similar effects have also been observed in discrete aiming tasks. Elliott, Lyons, Chua, Goodman, and Carson (1995) perturbed the location of the target during discrete manual aiming movements. Elliott and colleagues (1995) found that when the target was relocated at movement initiation, the right hand acquired the new target location faster than the left hand. Interestingly, both hands performed better when the target was perturbed to the left.

Roy and Elliott (1986, 1989) have attributed the accuracy and speed advantages demonstrated by the right hand to either superior force modulation of the right hand or an attentional bias towards the right hand. In support of the latter idea, Honda (1982, 1984) reported the preferential monitoring of the location of the right hand during manual aiming (Honda, 1982), even when hand was unseen (Honda, 1984). Preferential

monitoring is reflected by an increase in the time that the eyes monitor the dominant hand resulting in an accuracy advantage for that hand.

The procedure selected for the initial experiment was switching monocular vision without visual displacement at movement initiation, 150 ms, and 300 ms into the movement. It was expected that the right hand would out perform the left hand, particularly under monocular conditions involving the right eye. However, the timing of the monocular switch was not expected to affect the accuracy or the movement time of the aiming movements.

METHOD

Participants

The participants were 20 adult volunteers (10 female, 10 male), ranging in age from 19 to 30 yrs. All subjects were right handed and right eye dominant. Handedness and eye dominance was determined through the use of an oral questionnaire. Participants were asked three questions to determine handedness, and three to determine eye dominance. The participants were asked: Which hand do you use to write? Which hand do you use to throw a ball? With which hand do you use a knife? Which eye do you use to look into a microscope? Which eye would you use to look through a keyhole? Which eye would you use in order to line up crosshairs of a gun with a target? Only participants who indicated a right hand and right eye preference for all tasks were included in the study. Each of the participants had normal or corrected to normal vision. All participants were naïve to the purposes of the experiment. The research was conducted according to the guidelines of the McMaster Research Ethics Board.

Apparatus

Participants sat in front of a single target array situated at a desk 80 cm in height. The home position was a black circle 0.5 cm in diameter. drawn on the back of frosted plastic used as the aiming surface. When pressure was applied to the surface at the home position it would trigger a micro-switch that when released, recorded movement initiation. The target was a 0.5 cm black square located 40 cm away from the home position, at the midline of the participant. The index of difficulty for the movement was 7 bits.

An infrared emitting diode (IRED) was attached to the dorsal side of the distal phalange of the right and left index finger. An OptotrakTM 3020 (Northern Digital) sampling at 200 Hz was used to determine the location of the IRED. The OptotrakTM sampling was triggered by custom software.

Liquid crystal goggles (Translucent Technologies) were set for monocular vision and triggered externally at movement initiation (0 ms). 150 ms, and 300 ms following movement initiation. The final condition was a no switch condition (X) in which the goggles did not change. The switches were triggered by custom made E-prime software to change from monocular vision in the left eye, to monocular vision in the right eye on some trials and from right to left on other trials.

Procedure

The participants were asked to perform 160 rapid and accurate movements from the home position to the target. One block of 80 trials was performed with each hand with hand order counter balanced across participant. Within an 80 trial block, the

participants performed 10 trials in each of the 8 switch conditions, presented in a pseudorandom order (2 starting eye: left, right x 4 switch times: no switch, 0 ms, 150 ms, 300ms), subject to the limitation that trials from a single visual state could not be presented on three consecutive trials.

Each trial commenced with the participants receiving a verbal warning (i.e., "ready?"), then the participants were required to execute the movement as quickly and as accurately as possible upon detection of an 800 Hz auditory tone. For the facilitation of the data reduction, the participants were instructed to remain at the location at which they terminated the movement until they heard a 200 Hz auditory tone that informed them to return to the home position.

Dependent Variables

All dependent variables were determined using custom-made software. The dependent measures were based on the average of the 10 trials in each of the 16 switch conditions. Displacement data were filtered at 10 Hz using a dual pass Butterworth filter, and differentiated to obtain velocity. Movement start and end were defined from the collection frame where the velocity fell above or below 30 mm/s for a minimum duration of 72 milliseconds. Velocity was differentiated again to obtain acceleration.

Constant error and variable error were determined for both the primary and secondary axis of movement. A positive constant error score in the primary axis of movement indicates a movement endpoint beyond the target, and a negative score indicates an undershot. A positive constant error score in the secondary axis of

movement indicates a movement endpoint to the right of the target, and a negative score indicates an endpoint to the left of the target.

Reaction time (RT) and movement time (MT) were also calculated. The following kinematic markers were identified for the movement: peak acceleration (PA); peak velocity (PV); peak deceleration (PD); and the movement endpoint (END).

In order to examine the possibility of extraneous movement in the secondary axis of motion caused by the monocular vision switch, the time spent moving in the secondary axis was calculated. The Deviation time (DT) was defined as the time between when the velocity in the secondary axis fell above and then below 30 mm/s for a minimum duration of 72 milliseconds.

Over 10 trials for each of the 16 visual conditions, the standard deviations of the spatial location of the fingertip in the primary axis of movement were determined at PA, PV, PD, and at the termination of the movement. The analysis of the standard deviation of the finger's spatial position at these kinematic markers provided us with an indication of the variability associated with the programming and on-line control of the movement as it progressed (Khan, Elliott, Coull, Chua, & Lyons, 2002).

Analysis

A separate 2 gender by 2-hand by 2-initial eye by 4-switch time mixed analyses of variance, with repeated measures on the last three factors was conducted for each dependent variable. In order to further examine the corrective processes a 2-gender by 4-switch time by 2-hand by 2-eye multivariate analysis was conducted on type of modification to the movement. All significant main effects and interactions involving

more than two means were examined using Tukey's Honestly Significant Difference Test with α level set at 0.05.

RESULTS

Timing

Because the information processing demands of each trial were identical up to the point of movement initiation, it was expected that trial type would have no effect on reaction time, and the results reflect that expectation, p > 0.05. More importantly, the type of trial also had no effect on movement time in the primary axis of movement. Movement times were similar regardless of the eye with vision at movement initiation, or the time vision was switched. Although, movement times for the left and right hand did not differ, the analysis of the deviation time in the secondary axis revealed a main effect for hand, F(1,18) = 6.81, p < 0.018. The left hand spent longer moving in the secondary axis (349 ms) than the right hand (319 ms). The movement in the secondary axis for the left and right hand movement time in the primary axis of movement time in the primary axis were 446 ms and 460 ms respectively.

Analysis of the proportional time after peak velocity was conducted to examine the length of time the participants were spending in the portion of the movement associated with on-line correction. The analysis revealed a three-way interaction between gender, hand, and eye, F(1,18) = 7.30, p < 0.015. Females spent a significantly longer time after peak velocity, than males. When vision started in the right eye, males spent significantly longer time after peak velocity when using the left hand than when they

used the right hand (see Figure 1). The analysis also revealed a significant three-way interaction between gender, hand, and switch, F(3,54) = 3.22, p < 0.03. Males spent significantly less time after peak velocity compared to females in the movement initiation and no-switch conditions, regardless of hand used. In the 150 ms and 300 ms conditions, the male and female left hand performances were similar. However, males spent a significantly longer time after peak velocity in the 300 ms condition when using the left hand in comparison to when they used their right hand (see Figure 2).

Accuracy

The variable and constant error of the aiming movements was measured in both the primary and secondary axis of movement. The analysis of the constant error in the primary axis of movement indicated a main effect for switch condition, F(3,54) = 5.43, p < 0.003. Participants overshot the target more in the 300 ms and control condition than in the movement initiation condition (see Figure 3).

The analysis of constant error in the secondary axis indicated a main effect for hand, F(1,18) = 9.58, p < 0.007. The left hand landed to the right of the target (3.29 mm) and significantly to the right of where the right hand landed, which was left of the target (-2.93 mm).

Analysis of the variable error within the primary axis of movement revealed a main effect for hand, F(1,18) = 19.54, p < 0.001 and an interaction between hand and gender, F(1,18) = 6.79, p < 0.018. The left hand (7.25 mm) had a higher variable error than the right hand (6.09 mm). The performance of males was similar for both hands while female left hand performance was significantly more variable than right hand

performance (see Figure 4). Analysis of the variable error in the secondary axis of movement revealed no significant main effect or interactions. The resulting effects are consistent with other studies reporting manual asymmetries (e.g. Elliott & Chua, 1996; Elliott, Chua, & Pollock, 1994; Elliott et al., 1995; Roy & Elliott, 1986; 1989). However, these previous studies failed to examine gender as a factor in their analysis.

In the examination of the variability of the finger's location during the movement, the results were instructive. A main effect for kinematic marker location, F(3,54) = 23.87, p < 0.001, indicated that the variability of the location of the finger increased from peak velocity to peak deceleration, and then the variability decreased significantly between peak deceleration and the movement endpoint (see Figure 5). Also, a main effect for initial eye, F(1,18) = 6.27, p < 0.023, indicated that participants were more variable in their movements when vision was initially provided to the left eye (32.01 mm), than when it was initially in the right eye (29.68 mm).

In order to examine the effects of the monocular switch on the error reduction of the movement, an analysis of the time to the primary sub-movement endpoint, and an analysis of the average number of modifications per trial were conducted. Surprisingly, no effects were found for the average time to modification, indicating that the timing of the error reduction and online control was independent of the monocular vision switch. The analysis of the number of modifications revealed a main effect for hand, $\Lambda(5,14) = 0.30$, p < .002. Follow up t tests indicated that the right hand made significantly more significant deviations prior to peak velocity, t(18) = 2.32, p < 0.03, and the left hand made significantly more reversals, t(18) = 5.26, p < 0.001 (see Table 1).

DISCUSSION

The purpose of this experiment was to examine the effects of switching vision from one eye to the other during manual aiming. It was hypothesized that switching monocular vision would not affect movement planning or the online control of the aiming movements as the target was within the common binocular zone. However, manual asymmetries were expected. The results indicate that participants used different online control strategies depending on the effector used, and the initial eye provided with vision.

Specifically, while constant errors for the left and right hands were similar, the left hand had a significantly larger variable error in the primary and secondary axes of movement. The advantage of the right hand was expected (Elliott & Chua, 1996; Westwood. Roy. & Heath, 2003). In this study, and similar to Roy and Elliott (1986), the right hand advantage for spatial accuracy did not depend on the availability of visual feedback. The study by Roy and Elliott (1986) employed a binocular lights on/ lights off paradigm and not a monocular vision switch, but it demonstrates that the advantage held by the right hand over the left is independent of the afferent visual information. In our study, the left and right hands also displayed different error reducing strategies during their movements. Specifically, the left hand made more reversals, and the right hand completed more significant deviations prior to peak velocity.

Differences in the type of modification could reflect a superiority of the right hand at producing the minute corrective changes required to reduce movement error (Elliott et al., 1995). The significantly increased number of deviations prior to peak velocity provides evidence for the superiority of the right hand to produce optimal

corrective sub-movements without causing increases in movement time relative to a trial that required no correction. A number of reversals by the left hand are potentially caused by the dependence of the left hand on non-visual closed-loop regulation (Carson, Goodman, Chua, & Elliott, 1993), and are associated with increased movement times and energy expenditures (Elliott, Hansen, Mendoza, & Tremblay, in press).

The effects of gender were limited to the proportional time after peak velocity. The results indicated that the female participants spent significantly more time in the phase of the movement most often associated with on-line correction. In contrast, the male participants spent significantly more time in the phase of the movement associated with prior planning. The indication is that the genders employed different strategies resulting in similar performances, except in the case of variable error in the primary axis of movement.

The intention of this experiment was to determine the effects of the monocular switch of vision in order to validate the methodology to displace vision in future experiments. It is evident that, regardless of gender, the participants demonstrated different kinematic profiles depending on the initial eye, and exhibited significantly higher variable error when using the left hand. In the absence of significant interactions between switch time, hand, and eye performance effects, the results indicate that it would be appropriate to use a monocular switch procedure to introduce a displacement perturbation during an aiming movement.

EXPERIMENT 2

The purpose of the second experiment was to examine the visually guided corrective processes associated with the presentation of displaced visual information. The models of manual control that emphasize the importance of vision at the termination of the movement (e.g. Woodworth 1899) predict that the manipulation will have the most influence when presented near the end of the movement. In contrast, models that emphasize the importance of vision during the initial portions of the movement (Beggs & Howarth, 1972; Crossman & Goodeve, 1983; Meyer et al., 1988) predict that the early presentation of the visual displacement will have the most influence on terminal accuracy, and less influence when presented later in the movement. As the differences between the left and right hands were not the focus of this series of experiments, the participants completed the movements using only their right hands.

Although typical prism adaptation experiments (e.g., Redding & Wallace, 2001, 2003; Welch. 1978) involve a pre-exposure phase, an exposure phase, and a post-exposure phase, the methodology was to present the prism for a short-term, and in a randomized base left or base right orientation, thus preventing adaptation (Elliott & Allard, 1985). In spite of the randomization, the prism adaptation processes are relevant to our examination of limb control. Major processes in the adaptation to visually displaced information are the calibration to the new task constraints, and the alignment response to the displacement (Redding & Wallace, 2001). The alignment process occurs offline and is a permanent adjustment to prism exposure. In contrast, calibration results

from the perceptual incompatibility of the visual and motor systems, and is reflected by the immediate change in the behaviour of the participant.

A process known as first-trial adaptation best reflects the calibration process (Redding & Wallace, 2003). In this context, Redding and Wallace (2003) had participants execute repetitive aiming movements at a target under visual displacement. On the first trial, participants terminated their movements significantly closer to the target than the perceived location of the target would dictate. In other words, if the prism displaced the target from the midline to 10° from the right of the midline, the participants managed to terminate their movements only 5° from the actual target position, this indicates that some sort of on-line calibration process occurred during the movement to adjust for the sensory incompatibility (Redding & Wallace, 2003). In contrast to the calibration process, the alignment of the sensory-motor system is a more permanent adjustment in the spatial mapping and control of the sensory-motor system in response to a continuous and predictable perturbation. Thus, the calibration process may have a feedforward contribution to the alignment of the sensory-motor system.

The expectation of gender differences in the calibration processes, and ultimately, the accuracy of the aiming movements was anticipated based on the findings of Experiment 1. Specifically, females took more time following peak velocity to complete their movements, demonstrating an increased length of time attending to the contextual information of the movement. In contrast, the males spent a significantly shorter time after peak velocity, indicating less of a dependence on the contextual information received during the movement for terminal accuracy.

Some gender differences involving prism adaptation have been observed in past research. Specifically, Elliott (1982) employed a left-handed force production task, irrelevant to the primary task of manual aiming with the right hand, and found that the secondary task significantly degraded adaptation in female, but not male participants. Perhaps the secondary task interfered with the feedforward, or feedback aspect of the calibration processes, and thus decreased the alignment of the female sensory-motor systems. Elliott (1982) suggested that: "The gender differences should disappear in less feedback dependent tasks such as ballistic pointing." Based on the proportional time after peak velocity results from the initial experiment, the female participants should be more influenced by the visual displacement, as they depend more on visual feedback processes. In contrast, males should not be as influenced by the visual displacement as they are use the visual information presented prior to movement initiation.

METHOD

Participants

The participants were 20 adult volunteers (10 female and 10 male), ranging in age from 21 to 29 yrs. All subjects were right handed, were right eye dominant, and had normal or corrected-to-undisplaced vision. Handedness and eye dominance were determined using the same oral questionnaire employed in Experiment 1. All participants were naïve to the purposes of the experiment. The research was conducted according to the guidelines of the McMaster Research Ethics Board.

Apparatus

The apparatus, and the target array were identical to those used in Experiment 1. The OptotrakTM sampled at 200 Hz, and was triggered by custom software. The liquid crystal goggles were set for monocular vision and triggered in the same manner as in Experiment 1.

An apparatus created to hold a 25-diopter Fresnel prism lens (corresponding to a visual displacement of 14.25°) could be placed over the right or the left lens of the liquid crystal goggles. The experimenter could rotate the lens 180° and remove the prism from the lens, so that the visual field could be normal or displaced left, or displaced right.

Procedure

The participants were asked to complete 240 rapid and accurate movements from the home position to the target. Monocular vision was initially present in either the left or the right eye. For each trial, a single monocular switch occurred at movement initiation (0 ms), 150 ms, 300 ms, or it did not occur (X). There were 3 visual conditions for the second eye when it received vision. The vision in the second eye could be displaced left, displaced right, or not displaced. A total of 24 conditions existed, corresponding to 2 starting eyes (left, right), 4 switch times (0, 150, 300, X) and 3 vision states (left, right, normal).¹

A total of 240 trials were conducted. The trial order was pseudo-randomly selected based on the limitation that trials from a single visual state could not be presented on three consecutive trials. Participants were given breaks every 60 trials and were additionally instructed to ask for breaks when they desired one.

Each trial commenced with the participants receiving a verbal warning (i.e., "ready?") followed by an auditory signal (800 Hz) before they were required to execute the movement as quickly and as accurately as possible at the auditory tone. For the facilitation of data reduction, participants were asked to remain at the movement termination location until they heard a 200 Hz tone indicating a return movement to the home position was required. All movements were completed with the right hand.

Dependent Variables

All dependent variables were determined using custom-made software. The dependent measures were based on the average of the 10 trials in each of the 24 conditions. The dependent measures were determined in the same manner as in Experiment 1. The following measures were calculated: reaction time (RT), movement time (MT), and deviation time (DT). Constant error and variable error were defined as in Experiment 1. The following kinematic markers were identified for the movement: peak acceleration (PA); peak velocity (PV); and peak deceleration (PD), and the termination of the movement (END). The standard deviations of the spatial location of the fingertip in the primary axis of movement were determined at PA, PV, PD, and at the termination of the movement (END).

Analysis

The dependent measures were subjected to separate 2-gender (male, female) by 3prism (left, nil, right) by 2-eye (left, right) by 4-switch times (0, 150, 300, X) mixed analysis of variance. The standard deviation of the kinematic markers was examined using a 5 factor (2-gender x 4-kinematic markers x 3-prism x 2-eye x 4-switch) mixed analyses of variance. In order to further examine the corrective processes a 2-gender by 3-prism by 2-eye by 4-switch time multivariate analysis was conducted on type of modification to the movements. Also, in order to examine the timing of the corrective modifications, a 2-gender by 3-prism by 2-eye by 4-switch analysis of variance was conducted on the time to the primary sub-movement endpoint. All main effects and significant interactions involving more than two means were analyzed using Tukey's Honestly Significant Difference Test with α set at 0.05.

RESULTS

Timing

The analysis of reaction time indicated no significant main effects or significant interactions. The analysis of the movement time in the primary axis indicated a significant gender by prism interaction, F(2,36) = 5.41, p < 0.009. The interaction revealed that when presented with visual displacement, females spent a significantly longer time moving in the primary axis of movement than males. In contrast, males performed significantly faster than females with displaced visual information (see Figure 6).

A significant three-way interaction of gender by prism by switch interaction, F(6.108) = 3.62, p < 0.003, indicated that the influence of gender on the movement time was only present in the movement initiation condition with left and right visual displacement, and under right visual displacement in the 150 ms condition (see Figure 7).

The analysis of the deviation time revealed a main effect for prism, F(2.36) = 5.67, p < 0.008. The deviation time was significantly longer under left visual displacement (288 ms) than under normal (274 ms) or rightward (276 ms) displacement. A gender by prism interaction, F(2,36) = 3.85, p < 0.031, indicated that males performed similarly under each of the three visual conditions, whereas females spent significantly longer in the leftward visually displaced condition (see Figure 8). A significant prism by switch condition interaction, F(6,108) = 2.83, p < 0.013, indicated a significant increase in deviation time occurred when the left prism was presented at movement initiation (see Figure 9).

The analysis of time to peak acceleration revealed a main effect for gender, F(1.18) = 8.09, p < 0.011. Females (80 ms) reached peak acceleration sooner than males (113 ms). The difference in time to peak acceleration could indicate that females are selecting a strategy to maximize their time using on-line feedback processes, and less time executing the pre-planned portion of their movements. This shorter time to peak acceleration is indicative of smaller initial impulses, and therefore a longer time in a secondary feedback dependent corrective phase. In support of this, the analysis of peak acceleration showed a main effect for gender F(1,18) = 5.02, p < 0.036. The female participants produced movements with lower peak accelerations (1.90 m/s²) than the male participants (3.10 m/s²).

The analysis of the proportional time after peak velocity revealed a significant three-way interaction between gender, prism, and switch, F(6,108) = 2.34, p < 0.032.

Females spent significantly longer than males after peak velocity in the movement initiation condition, but only under leftward displacement conditions (see Figure 10).

Accuracy

The analysis of the constant error in the primary axis revealed a main effect for prism, F(2,36) = 8.95, p < 0.001. The participants undershot the target in each of the three visual conditions. Participants were closer to the target in the rightward condition (-0.93 mm) than in the normal (-2.53 mm) and leftward (-2.54 mm) visually displaced conditions, which were statistically similar. A significant prism by switch interaction, F(6.108) = 3.00, p < 0.009, indicated that participants undershot the target significantly more under the left displacement, than under rightward displacement in the 150 ms switch condition (see Figure 11).

The analysis of constant error in the secondary axis indicated a main effect for prism. F(2,36) = 4.70, p < 0.016. Participants terminated their movements to the left of the target under left displaced information (-0.03 mm), and to the right of the target under normal (0.55 mm) and rightward (4.11 mm) displaced visual conditions. Participants landed significantly more to the right in the rightward visually displaced condition than in the leftward condition, and the normal condition was intermediate. A main effect for eye, F(1.18) = 9.92, p < 0.006, indicated that participants terminated their movements farther towards the right of the target when vision switched to the left eye (2.54 mm), than when it switched to the right eye (0.55 mm).

A gender by prism interaction, F(2.36) = 6.69, p < 0.004, indicated that the performance of males was similar under each vision state. When performing under

rightward displacement conditions, females (9.05 mm) erred significantly more to the right than males (1.54 mm), and significantly more to the right in comparison to their own performance with leftward (-1.73 mm) or normal (2.41 mm) visually displaced information (see Figure 12).

A prism by switch interaction, F(6,108) = 4.41, p < 0.001, indicated that when vision switched at movement initiation, the participants erred much more to the right with rightward visual displacement than when their vision was displaced to the left. The switch at movement initiation when undisplaced vision was available was intermediate (see Figure 13). It is important to note that the visual displacement did not affect movement accuracy in the secondary axis of movement beyond 150 ms into the movement.

The variability of the endpoint locations in the primary axis of movement indicated a gender by eye interaction, F(1,18) = 4.84, p < 0.041. Females demonstrated higher variable error (13.19 mm) than males (8.99 mm) only when vision was initially in the left eye. The variable error with the right eye was similar for males (10.08 mm) and females (10.48 mm).

The analysis of the variability of the movement endpoint in the direction of the visual manipulation indicated a main effect for prism, F(2,36) = 19.25, p < 0.001. The variable error in the left (14.22 mm) and right (15.53 mm) visually displaced conditions was statistically similar and significantly higher than under undisplaced vision (12.03 mm). A main effect for eye, F(1,18) = 5.79, p < 0.027, indicated that the variable error was significantly higher when participants started with vision in their left eye (14.34

mm), in comparison to when they started with vision in their right eye (13.51 mm). A main effect for switch, F(3,54) = 18.48, p < 0.001, indicated that the variable error was significantly decreased from the movement initiation condition (17.19 mm), to the 150 ms condition (14.26 mm), and then the variable error significantly decreased again to the no-switch condition (11.77 mm). The variable error of the 300 ms condition (12.48 mm) was intermediate to the 150 ms and no-switch conditions.

An interaction of the prism and switch, F(6,108) = 7.92, p < 0.001, indicated that without visual displacement, the variability in the movement endpoint remained low. However, the variable error under the rightward visually displaced state was significantly higher than under the left displaced state. Both displacement conditions were significantly higher in variability than in the non-displaced condition when vision switched at movement initiation (see Figure 14). The variability of the endpoint was similar at the other switch times.

The analysis of the standard deviation of the finger's location in the primary axis of movement indicated only a main effect for location, F(3.54) = 6.30, p < 0.001. Posthoc analysis indicated that spatial position was more variable at peak acceleration, peak velocity, and peak deceleration than at the movement endpoint (see Figure 15).

In order to examine the effect of the prism on the corrective modifications and the error reduction of the movement, an analysis of the time to the primary sub-movement endpoint, and an analysis of the average number of modifications per condition were conducted. Surprisingly, no effects were found for the timing of the modifications,
indicating that the timing of the error reduction and subsequent online control were independent of the prisms and the time of the monocular switch.

The analysis of the number of modifications revealed a main effect for prism $\Lambda(10.9) = 0.15$, p < 0.011. Follow up calculations indicated that more significant deviations in the acceleration profile prior to deceleration of the movement, occurred when the left prism was present (0.26) than when no prism was present (0.20), and the right prism was intermediate (0.24) F(2,36) = 3.46, p < 0.043. Fewer reversals in the finger's direction occurred when the left prism was present (0.20) than when no prism was present (0.20).

DISCUSSION

The purpose of this experiment was to examine the visual regulation of discrete manual aiming, and the associated corrective responses to the presentation of visually displaced information. The visual displacement was presented at different times during the movements. As a whole, the participants were most affected by the visual displacement at the time of movement initiation. As expected, the variable error decreased with more time spent prior to the switch. The increased variability was also primarily due to the prisms when presented early. Overall, the results support models of manual control that posit that the visual information received during the initial portion of the movement is most important for movement accuracy (Beggs & Howarth, 1972; Crossman & Goodeve, 1983; Meyer et al., 1988).

In addition to the evidence that the participants used early visual information for movement accuracy, the results suggest that the participants engaged in different gender

specific psychomotor strategies, or different corrective processes in response to the visual displacement. Specifically, female participants were slower at completing their movements, especially when prismatic displacement was presented early. In addition, the female participants spent more time deviating in the horizontal direction under left visual displacement, especially when the prism was presented at movement initiation. Females also spent significantly more time after peak velocity under left displacement when the switch occurred at movement initiation. The increased time corresponds to decreases in the constant error in comparison to the levels achieved by the male participants. However, under right visually displaced information, females spent an equivalent amount of time in motion to the male participants resulting in a significantly higher constant error in comparison to male performances. The results indicate that the female participants are using the contextual information more than males for the attainment of movement accuracy.

In the absence of the evidence implicating hardwire differences between genders, a potential exists for participants to engage in different strategies based on their gender. Drinkwater (1968) used a pilot's altitude reporting task to examine the decision making of male and female civilian pilots. The participants were shown 30 transparencies consisting of the images of three flight instruments, and were asked to decide if the instruments did or did not match. Drinkwater (1968) found that females initially responded slowly, but correctly, and then sped up their responses with practice. In contrast, males responded rapidly, but incorrectly, then became more accurate with practice. Initially, the response strategies differed between genders, and then following

practice the performance outcomes were similar. Because daily tasks are repeated multiple times prior to testing in the laboratory, the strategy differences between genders found by Drinkwater (1968) may not be evident unless the task employed is novel. The current task was presumably novel, as most of the participants did not have previous experience with prism goggles.

EXPERIMENT 3

The purpose of the third experiment was to examine the visually guided corrective processes associated with the removal of displaced visual information. The prism perturbation was reversed in order to observe if the removal of the prism would have the opposite effect on the dependent measures from the presentation of the prism. Provided with the results of the second experiment, the early removal of the visual displacement was posited to have beneficial influence on the terminal accuracy of the movements. As ocular asymmetries were not the main focus of this experiment, the monocular switch was limited to the right-eye to left-eye switch.

With respect to gender, if males complete their movements based primarily on the visual information received prior to their movements, then under visual displacement they should err significantly away from the target regardless of switch time. In comparison, if females complete their movements dependent on the visual context during the movement and the early visual information is most important for terminal accuracy, then the early removal of the displaced visual information should allow the female participants to reduce their terminal error.

METHOD

Participants

The participants were 20 adult volunteers (10 female and 10 male), ranging in age from 20 to 33 yrs. All subjects were right handed, were right eye dominant, and had normal or corrected-to-undisplaced vision. Handedness and eye dominance was determined using the same oral questionnaire employed in Experiments 1, and 2. All participants were naïve to the purposes of the experiment. The research was conducted according to the McMaster Research Ethics Board.

Apparatus

The apparatus, and the target array were identical to those used in Experiments 1 and 2. The OptotrakTM sampled at 200 Hz, and was triggered by custom software. The liquid crystal goggles were set for monocular vision and triggered in the same manner as in Experiments 1 and 2. The apparatus to hold the Fresnel prism was identical to that used in Experiment 2.

Procedure

The participants were asked to complete 120 rapid and accurate movements from the home position to the target. For each trial, a single monocular exchange from the right eye to the left eye occurred at movement initiation (0 ms), 150 ms, 300 ms, or it did not occur (X). The vision in the right eye was displaced left, right, or not displaced with the use of a prism lens. Therefore, a total of 12 visual conditions existed, corresponding to 4 switch times (0, 150, 300, X), and 3 vision states (left, right, normal). The trial order was pseudo-randomly selected based on the limitation that trials from a single visual condition could not be presented on three consecutive trials. Participants were instructed to ask for breaks whenever they desired one, and they were thus given time to rest.

Prior to each trial, non-displaced monocular vision was present for the left eye. The prism in the base left or right position, or a blank lens was affixed to the translucent right lens of the liquid crystal goggles. Participants received a verbal warning (i.e., "ready?") followed by the experimenter depressing a button to engage the custom software to switch the monocular vision from the left to the right eye. The participants were exposed to the vision of the right eye for a fixed 2 s period prior to an auditory signal (800 Hz). The participants were required to execute their movements as quickly and as accurately as possible at the 800 Hz auditory signal. A monocular switch from right eye to left eye occurred during the movement (or did not occur in the case of condition X). Again, to facilitate data reduction, participants were asked to remain at the movement termination location until they heard a 200 Hz tone indicating a return movement to the home position was required. Similar to Experiment 2, all movements were completed with the right hand.

Dependent Variables

All dependent variables were determined using custom-made software. The dependent measures were based on the average of the 10 trials in each of the 12 visual conditions. The dependent measures were determined in the same manner used in Experiments 1 and 2. The following measures were calculated: reaction time (RT),

movement time (MT), and deviation time (DT). The constant error and variable error were defined in the same way as in Experiments 1 and 2. The following peak kinematic markers were identified for the movement: peak acceleration (PA); peak velocity (PV); and peak deceleration (PD), and the location of the movement endpoint (END). The standard deviations of the spatial location of the fingertip in the primary axis of movement were determined at PA, PV, PD, and at END.

Analysis

A separate 2-gender by 3-prism by 4-switch time mixed analysis of variance was conducted on each of the dependent measures. A four factor 2-gender by 4-kinematic marker by 3-prism by 4-switch mixed analysis of variance was conducted to examine the variability in the trajectory of the finger throughout the movement. In order to further examine the corrective processes a 2-gender by 3-prism by 4-switch time multivariate analysis was conducted on type of modification to the movements. The timing of the corrective modifications was analyzed using a 2-gender by 3-prism by 4-switch analysis of variance was conducted on the time to the primary sub-movement endpoint. All significant effects and interactions involving more than two means were examined using Tukey's Honestly Significant Difference with alpha set at 0.05.

RESULTS

Timing

In this study, longer reaction times were expected in the prism conditions due to the time required to calibrate the visual system to the displaced information (Redding & Wallace, 2003). Surprisingly, the analysis of reaction time revealed no significant effects.

The analysis of movement time in the primary axis of movement indicated a main effect for prism, F(2,36) = 3.61, p < 0.037. Movements were significantly longer in the primary axis of movement under right displaced information (404 ms) in comparison to the undisplaced vision condition (393 ms). The movement time under leftward displacement was intermediate (397 ms) and not significantly different from the other two conditions.

The analysis of the deviation time indicated a main effects of prism, F(2,36) = 15.06, p < 0.001. The deviation time with non-displaced visual information (213 ms) was significantly shorter than under rightward (291 ms), and leftward (273 ms) displacement. The deviation time was similar in the two displacement conditions. A main effect for switch. F(3.54) = 4.17, p < 0.010, indicated that the deviation time was significantly shorter when vision switched at movement initiation (243 ms), than when it switched 150 ms (263 ms), or 300 ms (268 ms) into the movement. The no-switch condition (260 ms) was intermediate.

The analysis of the proportional time after peak velocity revealed a main effect for prism, F(2,36) = 3.37, p < 0.046. The participants spent a significantly longer time after peak velocity in the right displaced vision condition (0.48), than in the left displaced vision condition (0.44). The proportional time after peak velocity in the undisplaced vision condition (0.47) was intermediate.

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Accuracy

The analysis of the constant error in the primary axis of movement indicated a main effect for prism. F(2,36) = 5.67, p < 0.007. Participants significantly undershot the target when leftward visual information was presented (-2.88 mm), in comparison to rightward (-0.35 mm) and normal visual information (-0.39 mm), which were statistically similar.

The analysis of constant error in the secondary axis of movement indicated a main effect for prism, F(2.36) = 45.69, p < 0.001. Participants landed significantly to the left of the normal-vision endpoints when leftward visual displacement was presented, and significantly to the right of the normal-vision endpoints when rightward visual information was presented (see Figure 16). A prism by switch interaction, F(6,108) =11.75, p < 0.001, indicated that, compared to the no-prism condition, the effect of the prism was consistent across the 150 ms, 300 ms, and X switch times. The terminal endpoint under left visual displacement was significantly to the left of the non-displaced. and visually displaced rightward conditions. The terminal endpoints under rightward visual displacement were significantly to the right of the non-displaced conditions. However, at the switch of movement initiation, the endpoints under leftward visual displacement were similar to those under undisplaced vision, and the endpoints of the rightward condition remained significantly to the right of the other two visual states (see Figure 17).

A gender by prism by switch interaction, F(6,108) = 3.19, p < 0.006. indicated that females terminated their movements significantly to the left of undisplaced vision endpoints when left displaced vision was present, and significantly to the right of undisplaced vision endpoints with right displaced vision except when vision switched to normal at movement initiation. The constant error was statistically lower for females for the switch at movement initiation. In addition, the error was similar to the undisplaced vision endpoint error. Males exhibited the same pattern, except that when rightward visual information was presented, males erred to the right of their undisplaced vision performances, and significantly more so than females in the movement initiation switch condition (see Figure 18).

The variability of the movement endpoint in the primary axis of movement was statistically similar under all conditions. However, the analysis of the variability in the endpoint location within the secondary axis of movement indicated a main effect for gender. F(1.18) = 6.04, p < 0.024. The responses of males (19.0 mm) were significantly more variable than females (14.8 mm) in the secondary axis of motion. A main effect for prism, F(2.36) = 47.46, p < 0.001, indicated that the variability in the endpoint location was significantly lower under undisplaced vision (8.60 mm) than when rightward (21.7 mm), or leftward (20.6 mm) visual displacement occurred. The variability of the visually displaced conditions was statistically similar.

A gender by prism interaction, F(2,36) = 5.14, p < 0.011, indicated that male variable error under the two displaced visual states was similar, and statistically higher than under undisplaced vision. For females, the variable error under leftward visual

displacement was significantly higher than under undisplaced vision, and the rightward displacement condition was intermediate. Under rightward displacement, males were significantly more variable than females in their endpoint locations (see Figure 19).

The analysis of the standard deviation of the movement in the primary axis of movement indicated a main effect for location, F(3,54) = 10.48, p < 0.001. The variability in the location of the finger throughout the movement was significantly lower at the movement termination, than at peak acceleration, peak velocity, or peak deceleration, which were statistically similar (see Figure 20).

A significant three-way interaction of gender, location, and prism, F(6,108) = 2.34, p < 0.037, indicated that the standard deviation of the finger's location was similar at each of the kinematic locations for males and females under right visual displacement. Under undisplaced vision, males had a higher variability at peak deceleration. Under left displaced vision, males again had higher variability than females at peak deceleration, while females had a higher variability at peak acceleration (see Figure 21). The analysis of the timing, the locations, and the types of modifications during the movement revealed no significant main effects or interactions.

DISCUSSION

The purpose of this experiment was to examine the visual regulation during discrete manual aiming, and the associated corrective responses to the removal of displaced visual information. The displaced visual information was removed at different times during the movements. Regardless of gender, the removal of the prism at movement initiation led to a shorter movement time, and a smaller deviation time. Under

visual displacement, a higher constant error in the secondary axis of movement was accompanied by higher variable error. In addition, the early removal of the visual displacement was most effective for the reduction of constant error in the secondary axis of movement. With increased exposure to the visual displacement, the participants were unable to correct for the errors in the trajectory of their limb. With respect to the use of early visual information, the results of this study are similar to those of Experiment 2. Thus, the current data are consistent with models that posit that the use of early visual information is necessary for optimal movement outcome (Beggs & Howarth. 1972; Crossman & Goodeve, 1983; Meyer et al., 1988). That is, in order to complete fluid movements with minimal discontinuities, the participants use the visual information received during the initial impulse to correct for errors in the movement trajectory.

Although early removal of the displaced visual information was the most important factor in the achievement of movement accuracy, the results again indicate that males and females differ in the way they use visual feedback. The female participants were able to reduce their error to levels similar to those under undisplaced vision when the prism was removed at movement initiation. It appears that female participants benefited from a return to undisplaced vision at movement initiation and rapidly recalibrated their sensory-motor system. In contrast, males were significantly influenced by their exposure to the visual displacement, even when the visual displacement was removed at movement initiation. Thus, accuracy for females seemed to be dependent on the visual context during the movement (see also Laszlo et al., 1980), while male accuracy was more dependent on the visual information received prior to movement

initiation, leading to an accuracy advantage for females when the displaced vision was removed at movement initiation.

The rightward visual displacement had the most effect on the variability of male responses in the secondary axis. The trial-to-trial location of the finger during the trajectory of the movement for male participants was more variable later in their movements. The higher variability late in the movement is indicative of a movement that is highly pre-planned, while a reduction in variability at the end of the movement is evidence that corrective modifications are occurring based on the early visual information. In contrast to the male performance, females were more variable during the initial portions of their movements. The female performance indicates that they sacrificed a rapid and pre-planned initial impulse in favour of greater time for visual feedback utilization. This strategy allows for an increased amount of time to take advantage of the potentially non-displaced information, provided the prism is removed early.

GENERAL DISCUSSION

The purpose of this study was to examine the visual regulation of rapid limb movements. A secondary purpose was to examine gender differences in the control of limb movements in response to displaced visual information. The results of the first experiment indicated that the switch of monocular vision was an appropriate method of presenting the visual perturbation. The presentation of the displaced visual information significantly influenced movement accuracy, but only when presented at movement initiation. When the displaced visual information was removed, participants produced

more rapid and accurate movements, but only when the displacement was removed at movement initiation. Overall, the results of these experiments support models of manual control positing that visual information early in the movement is the most influential for movement accuracy (e.g. Beggs & Howarth, 1972; Crossman & Goodeve, 1983; Meyer et al., 1988). Common to each of these models is the idea that the visual information received prior to movement initiation, and during the initial impulse is employed to maximize movement outcome. The manipulation early in the movement accentuated this point by causing movement error in the case of the presentation of the displacement, and reducing movement error with the removal of the visual displacement.

The results of the current study contrast with occlusion studies that found that visual information received near the target area is the most important for movement accuracy (Carlton 1981; Chua & Elliott, 1993). Chua and Elliott (1993) occluded vision of the cursor during the initial half and subsequently the last half of the movement (i.e., 50% of the movement amplitude). In addition to the partial vision trials, the participants also performed trials under full vision and no-vision at movement initiation (for the entire length) conditions. Participants made more accurate movements when vision was available, but vision was most useful for regulation and initiating efficient modifications when it was available in the last half of the movement.

In another experiment, Carlton (1981) used a spatial occlusion to investigate the timing of visual regulation. Carlton (1981) had participants aim to targets with a shield covering none of the movement, the initial 25 %, 50 %, 75 %, or 93 % of the movement. Carlton (1981) found a significant increase in the movement time between the 50 %, and

the 75 % condition. In addition, the rate of errors also increased significantly between the 50 %, and the 75 % no-vision conditions. Film analysis of the movements indicated that the time between the visual acquisition of the stylus from behind the occlusion shield and the movement endpoint was approximately 135 milliseconds. Based on these results, Carlton (1981) estimated the visual processing time to be approximately 135 milliseconds. However, guiding or correcting the trajectory of the limb following the sudden appearance of the stylus, is not similar to the continuous visual guidance of the limb throughout the movement, regardless of the movement duration.

Elsewhere, Khan and Franks (2003) examined the contribution of vision to the corrective portion of the movement by limiting vision to the initial portions of the movements. Based on the premise that visual information is most important in the initial portion of the movement. Khan and Franks (2003) had participants aim to a target under no-vision, 50 percent first half vision, 75 percent first portion vision, and full vision conditions. Consistent with the results of this study, the participants were found to be more accurate and more efficient in correcting their movements with increasing amounts of vision of the initial portion of the movement (Khan & Franks, 2003). The results again demonstrate the robust effect the presence of vision has on the terminal accuracy of manual aiming.

A major limitation of the spatial occlusion paradigm is that it places different constraints on the task, other than those of the typical aiming task. In other words, the control of the movement may differ if the participant knows that the occlusion will occur halfway. If the occlusion occurs early or late, the participant may choose to plan a

longer/shorter initial movement, and spend a longer/shorter time using online control. In either case, the behaviour would differ from the normal in order to optimize the use of the limited vision.

Clearly, the visual occlusion forces the sensory system to adjust to the unexpected requirements of the task. Thus, the no-vision versus full vision paradigm eliminates the regular interaction of the sensory system, inducing a substitution of processes, or a dependence on open-loop processes. Essentially, the dependence on the primary sensory modality has changed because of the elimination of vision, and therefore the nature of the task itself has changed.

Although Experiments 2 and 3 had opposing results with respect to movement outcome, the observed gender results remained similar with respect to feedforward versus on-line control. Specifically, male participants completed their movements based on the visual information presented to them prior to the movement. In contrast, the female participants were more dependent on the visual information presented to them during the movement for terminal accuracy. The dependence of females on the information received on-line, and an increased time following the initial impulse of the movement, is suggestive of differing calibration processes than males in response to the displaced visual information (Redding & Wallace, 2003).

Without further empirical investigations of manual control with gender as an independent variable, the interpretations of the results are currently speculative. Despite an abundance of literature focused on gender, the reasons behind the dissimilarities between genders in manual control are relatively unknown. However, evidence of

manual control differences in a multitude of experimental situations indicates the differences in the neurological development of that control (Hay, 1979; Von Hofston & Rösblad, 1988). The findings of our study, specifically of Experiment 1, are interesting in that under non-displaced environmental circumstances, the different control strategies allow for similar terminal accuracy.

The question remains however, as to whether these control differences arise primarily due to differences in higher order cognitive processes or to lower neural mechanisms. Software differences include possibilities such as dissimilarity in the development of limb control processes (Hay, 1979; von Hofsten & Rösblad, 1988), salience to environmental context (Laszlo et al., 1980), and cognitive strategies (Drinkwater, 1968).

In terms of the development of control strategies and schema, von Hofsten and Rösblad (1988) examined differences in the control strategies and changes in the mode of manual control with age. Von Hofsten and Rösblad (1988) examined the performance of 270 children, from nine age groups. The participants aimed to a single target in four different feedback conditions. Participants aimed under full vision, and no-vision conditions, but in a third and fourth condition the children placed their left hand under the aiming board at the target location, then aimed under no-vision and full vision conditions. Von Hofsten and Rösblad (1988) found that while male accuracy with both hands was similar and equal to female right hand performance, female left hand accuracy was significantly worse. These differences in performance disappeared by age 11. However,

as the results of Experiment 1 indicate, the same performance can be achieved in a different way.

The observations of Laszlo and colleagues (1980) suggest that the differences in the performances between the genders might be caused by the stimulus configuration in the experimental situation, or the motor programming demands of the task. In other words, the genders interpret the information differently employ different strategies based on the same information. Some studies have reported evidence of differences in cognitive strategies between the genders. For example, Drinkwater (1968) found that females responded slowly, but accurately, on the altitude report task. In contrast, the male participants responded quickly, but inaccurately. Initially, the response strategies differed between genders, and then following practice the performance outcomes were similar. The results of Drinkwater (1968) indicate that different strategies can end in the same outcome. In this context, the observation of strategy and differences between males and females may not be a true reflection of the neural lateralisation of the male and female brains.

Beyond the possibility of strategy differences there is the strong potential for a neural-physiological cause of the laterality and control differences. Potential hardware differences include differences in the specialization of the neural areas responsible for neural-spatial function (Inglis & Lawson, 1982), and differences in cerebral blood flow (Gur et al., 1982).

Given an enormous body of literature examining the effect of brain lesions on human performances, Inglis and Lawson (1982) completed a meta-analysis of unilateral

brain damage studies and re-examined the effect of gender on verbal and performance intelligence tests. Inglis and Lawson (1982) examined the results of 16 experiments that used the Wechsler Scales of Intelligence to score verbal and visuo-spatial performance of the participants. The results indicated that unilateral brain damage affected both the verbal and visuo-spatial performance of females equally regardless of the lesioned hemisphere. The results also indicated that male verbal performance was significantly decreased following lesions to the left hemisphere, and significant decreases in the visuospatial performances following lesions to the right cerebral hemisphere. The latter results are consistent with the notion that males are more functionally lateralized, and females are more bilaterally organized. The differences in functional lateralisation may be related to differences in structural organization in turn leading to the motor control strategy, and motor performance differences.

In search of a neuro-physiological reason behind the evidence of laterality dissimilarities between gender and handedness groups, Gur and colleagues (1982) examined the regional cerebral blood flow (rCBF) of participants at rest, during a verbal analogy task, and during a spatial line-orienting task. Gur and colleagues (1982) found that cognitive activity significantly increased the rCBF. Interestingly, Gur and colleagues (1982) found that for the female participants, the rate of rCBF, and the percentage of tissue with a higher rate of perfusion were significantly higher. The right-handed females had higher rCBF in the left hemisphere during the verbal task, and higher rCBF in the right hemisphere during the spatial task. In contrast, the right-handed males only had a higher rCBF in the left hemisphere during the verbal task. The gender differences in

rCBF could account for the evidence of differing control strategies, and the spatial and verbal laterality differences.

The previous literature suggests that females would be disadvantaged during Experiments 2 and 3 (realizing the inference of equivalence between the visual-spatial tasks and the current displacement during goal directed aiming task). However, the results of the study indicate that the male and female participants engaged in different control strategies leading to similar results in Experiment 1, and opposing results in Experiments 2 and 3. Perhaps the differences in the control are reflective of the female participant's ability to rapidly re-calibrate their visual-motor system in response to the visual perturbations. The re-calibration of the female systems in turn could therefore be an adaptive behaviour to the inherent disadvantage during visual-spatial task.

The results of this study are an addition to the body of evidence indicating that the visual information received during the initial impulse of the movement is most useful for the terminal accuracy of rapid manual aiming movements. The evidence of dissimilarity in the control of manual aiming between genders indicates neuro-physiological laterality differences and/or differences in strategic behaviour.

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FOOTNOTES

¹The participants received undisplaced vision throughout the no-switch condition regardless of the prism present in the second eye. However, the means were analyzed separately as a method of testing the reliability of the manipulation.

Table 1

Average Number of Modifications For Every Ten Trials

	Hand	
Modification	Left	Right
SD_PV	0.31*	0.43*
PV_SD	0.13	0.14
PreZC	0.46	0.37
PstZC	1.38	1.26
REV	0.48*	0.26*

Note. *p< 0.05

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FIGURE CAPTIONS

Figure 1: experiment 1: The proportional time after peak velocity (PTAPV) in the primary axis of movement as a function of gender, hand, and the initial eye. Figure 2: experiment 1: The proportional time after peak velocity (PTAPV) in the primary axis of movement as a function of gender, hand, and the switch condition. Figure 3: experiment 1: Constant Error (mm) in the primary axis of movement as a function of switch condition.

Figure 4: experiment 1: Variable Error (mm) in the secondary axis of movement as a function of gender and hand.

<u>Figure 5:</u> experiment 1: The between trial standard deviation of the location of the finger (mm) at various kinematic markers (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, END = endpoint location).

Figure 6; experiment 2: Movement Time (ms) in the primary axis of movement as a function of gender, and prism.

Figure 7: experiment 2: Movement Time (ms) in the primary axis of movement as a function of gender, prism, and switch condition.

Figure 8; experiment 2: Deviation Time (ms) in the secondary axis of movement as a function of gender, and prism.

Figure 9; experiment 2: Deviation Time (ms) in the secondary axis of movement as a function of prism, and switch.

Figure 10; experiment 2: The proportional time after peak velocity (PTAPV) as a function of gender, prism, and switch condition.

Figure 11: experiment 2: Constant Error (mm) in the primary axis of movement as a function of prism, and switch condition.

Figure 12; experiment 2: Constant Error (mm) in the secondary axis of movement as a function of gender, and prism.

Figure 13: experiment 2: Constant Error (mm) in the secondary axis of movement as a function of prism, and switch condition.

Figure 14; experiment 2: Variable Error (mm) in the secondary axis of movement as a function of prism, and switch condition.

Figure 15; experiment 2: The between trial standard deviation (mm) of the location of the finger at various kinematic markers in the primary axis of movement (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, END = endpoint location). Figure 16; experiment 3: Constant Error (mm) in the secondary axis of movement as a function of prism.

Figure 17; experiment 3: Constant Error (mm) in the secondary axis of movement as a function of prism, and switch condition.

Figure 18; experiment 3: Constant Error (mm) in the secondary axis of movement as a function of gender, prism, and switch condition.

Figure 19; experiment 3: Variable Error (mm) in the secondary axis of movement as a function of gender, and prism.

Figure 20; experiment 3: The between trial standard deviation (mm) of the location of the finger at various kinematic markers in the primary axis of movement (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, END = endpoint location).

Figure 21; experiment 3: The between trial standard deviation (mm) of the location of the finger at various kinematic markers in the primary axis of movement as a function of gender, and prism (KIN = Kinematic Marker, PA = peak acceleration, PV = peak velocity, PD = peak deceleration, END = endpoint location).

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STUDY TWO

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A Real Time Manipulation of Visual Displacement

During Manual Aiming

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ABSTRACT

This study examined the contribution of the visual system to the control of the upper limb, and the spatial and temporal limitations of the corrective process. A real time calculation of optoelectronic data was used to trigger visual displacement of the movement environment during manual aiming. Using an OptotrakTM ODAU unit, and a custom made C-language program, the perturbation was triggered at the peak acceleration, the peak velocity, and the expected time of peak deceleration of manual aiming movements. The movement outcome of the participants was significantly influenced when the displaced information was presented at peak acceleration. The results support models of visual control that posit vision during the initial portion of the movement is used to initiate corrective modifications. This work represents a new methodology for studying the on-line control of goal directed movement. A Real Time Manipulation of Visual Displacement During Manual Aiming

The timing of the visual regulation of goal-directed movement is continually disputed in the motor behaviour community. The visual system provides the information to pre-plan movement towards a target, and feedback about the position of the limb relative to the target during the movement (Elliott, Helsen, & Chua, 2001). Traditional two-component models of goal directed aiming (e.g. Woodworth, 1899) emphasize the importance of vision at the end of the movements for on-line control. Such models suggest that, following an initial ballistic movement that takes the limb to the target area; the visual information received near the target area provides information to guide the limb towards its goal. In contrast, the single correction (Beggs & Howarth, 1972), and the optimized sub-movement models (Meyer, Abrams, Kornblum, Wright, & Smith, 1988) posit that the visual information received in the initial portions of the movement is most beneficial for terminal accuracy. Presumably, the early use of visual information allows the participant to detect movement error, and then plan and initiate subsequent discrete corrections during the initially pre-planned phase of the movement.

The traditional method to study the timing of the visual regulation of manual aiming, or more specifically the contribution of the visual closed-loop control, has been to eliminate the visual information at some point during the planning or the execution of the movement and then examine the resulting behaviour. The timing of the occlusion becomes important if an investigator wants to test the various two-component models of manual control. In different experiments, investigators have either adopted a temporal or a spatial criterion for occluding vision. Temporal occlusion studies typically compare full vision trials with trials where vision is removed at movement initiation (Elliott, Carson. Goodman, & Chua, 1991; Meyer et al., 1988; Pratt & Abrams, 1996). Movement initiation is selected as an optimal temporal location to perturb the aiming movement because it is the physical separation between the visual information received during the pre-planning stage of the movement, and the visual information received during the movement. The occlusion of the movement environment can also occur prior to the movement, so that the contribution of pre-movement visual information can be examined (Elliott & Madalena, 1987). Upon occlusion, the opportunity to make corrections during the movement based on visual feedback is eliminated.

A major theoretical problem with employing temporal occlusion during the movement is that the occlusion can occur at proportionally different times for each of the participants. Although the occlusion can occur prior to the use of on-line visual information, it can also occur following the initiation of visual feedback processes. In extreme cases, the participant can finish their movement prior to the occlusion intended to interrupt the corrective modifications in the proximity of the target.

Spatial position occlusion studies, on the other hand, compare full vision trials with trials where portions of the movement distance are occluded (Carlton, 1981; Chua & Elliott, 1993; Khan & Franks, 2003; Whiting & Sharpe, 1974). The reasoning behind using spatial occlusion as a method of occlusion is to attempt to examine the importance of vision at the start and end of the movement, and thus contrast the predictions of the various models of manual control.

On problem with the spatial occlusion protocol, however, is that it imposes different constraints on the task, other than those of typical aiming. Specifically, the control of the movement may differ if the participant knows that the occlusion will occur part way through the movement. If the occlusion occurs early or late, the participant may choose to plan a longer/shorter initial movement, and spend a longer/shorter time using online control. In either case, the behaviour differs from the typical observed behaviour in order for the participant to optimize the use of the limited vision.

Unequivocally, visual occlusion forces the sensory system to adjust to the unexpected requirements of the task. However, the no-vision versus full vision paradigm eliminates the regular interaction of the sensory system, inducing a substitution of processes, or a dependence on open-loop processes. Essentially, the dependence on the primary sensory modality changes because of the elimination of vision, and therefore the nature of the task itself has changed.

Recent studies have examined the kinematic profiles of manual aiming using three dimensional movement techniques to investigate the pre-planning and on-line control phases of manual aiming under different feedback schedules (Khan, Chua, Elliott, Lyons, & Coull, 2002; Khan & Franks, 2003; Khan, Franks, & Goodman, 1998; Khan et al., 2003). These investigations have aided in defining where the preplanning ends, and online control begins.

The argument presented by Khan and colleagues (1998) is that when pointing at a target with a finger, the variability of the location of the finger begins low and will become increasingly more variable as the movement progresses in the absence of

modification because of the inherently "noisy" neural-motor system. Consequently, corrective modifications are characterized by a decrease in the variability in the location of the finger. Therefore, decreases in the variability of the location of the finger at peak deceleration, and significant decreases in the variability between the peak deceleration and the movement endpoint indicate the presence of the corrective modifications late in the movement.

Following the rationale of the two-component models of limb control (Elliott et al., 2001; Woodworth, 1899), if offline processes are reflected in the movement trajectory up to peak velocity (Elliott, Binsted, & Heath, 1999), then online processes should be reflected in the movement trajectory beyond peak velocity. Although triggering the perturbation at movement initiation theoretically separates the off-line and on-line visual information. triggering the perturbation at peak velocity will physically separate the visual information received prior to the end of the pre-planned phase from the visual information received during the online control portion of the movement.

Based on the limitations of visual occlusion, the perturbation selected for this study was a monocular presentation of a Fresnel prism (base left and base right) to displace the movement environment in the horizontal plane. The advantage of prismatic displacement over visual occlusion is that prisms allow the displacement of the entire visual field including the target, the effector, and the home position (Elliott & Allard, 1985; Elliott & Jaeger, 1988). Thus, prisms perturb the typical interaction between the participant and the environment. Specifically, the presence of a prism induces a general incompatibility between the perception of the environment and the execution of

movement within the workspace. Because of this incompatibility, prisms have been used to examine human adaptive processes, and to prevent ceiling effects on improvement during manual aiming (Elliott & Allard, 1985; Elliott & Jaeger, 1988; Hay, 1979).

The purpose of the current research was to examine visual regulation following visual displacement at different kinematic markers. The presentation of the erroneous information prior to the planning and initiation of corrective sub-movements, should lead to increased terminal error, while presenting it after the initiation of the correction should not have a detrimental effect. Specifically, the perturbation of visual information prior to peak velocity, or the switch at peak acceleration, should have the most impact on the movement accuracy.

METHOD

Participants

The participants were 10 adult volunteers (5 female and 5 male) from the University of Houston, ranging in age from 20 to 30 yrs. All subjects were right handed, were right eye dominant, and had normal or corrected-to-undisplaced vision. The research was conducted following the guidelines of the McMaster Research Ethics Board, and the University of Houston Research Ethics Board.

Apparatus

Participants sat in front of a single target array situated on a desk 100 cm in height. The target array was placed on top of electrical boxes 15 cm in height. The home position was a 1.5 cm yellow lighted micro-switch situated directly underneath a sheet of white Plexiglas. The target was a 0.5 cm black square drawn on the back of the same sheet of plastic. The target was located 40 cm away from the home position, in participant's midline. The index of difficulty for the movement was 7 bits.

An infrared emitting diode (IRED) was attached to the dorsal side of the distal phalange of the right index finger. An OptotrakTM sampling at 400 Hz was used to determine the location of the IRED. The OptotrakTM sampling was triggered by custom made E-prime software.

A pair of liquid crystal goggles (Translucent Technologies) were set for monocular vision and triggered externally by a custom made e-prime software program to change from monocular vision in the left eye, to monocular vision in the right eye on some trials and right to left eye on others. An apparatus created to hold the 25-diopter Fresnel prism lens (corresponding to a visual displacement of 14.25°) could be placed over the right or the left lens of the liquid crystal goggles. The experimenter could rotate the lens 180° and remove the prism form the front of the lens, so that the visual field could be undisplaced or displaced to the left or right.

Procedure

The participants were asked to perform 240 rapid and accurate movements from the home position to the target. Monocular vision was initially present in either the left or the right eye. For each trial, a single monocular switch occurred at either: peak acceleration (PA), peak velocity (PV), or the estimated time of peak deceleration (PD). In a fourth condition (X), the perturbation did not occur.

The C-language program used a five point floating average of the resultant displacement in order to calculate velocity. The instantaneous acceleration was determined using two consecutive velocity samples. The peak acceleration was defined as the frame where the acceleration fell for two consecutive frames in a row. Following the detection of peak acceleration, the program waited 8 frames, or 20 ms before searching for the peak velocity of the movement. The peak velocity was defined as the frame where the velocity fell for two consecutive frames in a row, with a minimum criterion reduction of 10 mm/s. For simplicity, the movement was assumed to have a symmetric acceleration profile, and therefore, the estimated time of peak deceleration was defined as the sum of the time to peak velocity, plus the time between peak acceleration and peak velocity. When the criterion kinematic marker was reached, the Clanguage program triggered the ODAU unit to change voltage. A concurrently running E-prime software program waited for the change in voltage through the parallel port of the host computer, and then triggered the liquid crystal goggles to change state through the same parallel port.

The monocular switch was associated with three perturbation conditions. The vision in the second eye could be displaced left, to the right, or not displaced. Therefore, a total of 24 conditions existed, corresponding to 2 starting eyes (left, right), 4 switch times (PA, PV, PD, X), and 3 vision states (left, right, normal).

Each participant performed a total of 10 trials for each condition, or 240 trials. The trial order was pseudo-randomly selected using the custom made E-prime software,

and was based on the limitation that trials from a single visual condition could not be presented on three consecutive trials.

Each trial commenced with the participants receiving a verbal warning (i.e. "ready?") followed by an auditory signal (800 Hz, 100 ms in duration) before they were required to execute the movement as quickly and as accurately as possible at the auditory tone. For the facilitation of data reduction, participants were asked to remain at the movement termination location until they heard a 200 Hz tone indicating a return movement to the home position was required. All movements were performed with the right hand.

Dependent Variables

All dependent variables were determined following data collection using custommade software. The dependent measures were based on the average of the 10 trials in each of the 24 visual conditions. Displacement data were filtered at 10 Hz using a dual pass Butter-worth filter. The displacement data were differentiated to obtain velocity. Velocity was differentiated again to obtain acceleration. Movement start and end were defined from the collection frame where the velocity fell above or below 30 mm/s.

The following measures were calculated in the primary axis of movement: reaction time (RT) and movement time (MT). Kinematic markers were identified for the movement: peak acceleration (PA); peak velocity (PV); and peak deceleration (PD). The time-to and time-after peak acceleration, peak velocity, and peak deceleration were also determined. Over 10 trials for each of the 12 conditions, the standard deviations of the

spatial location of the fingertip in the primary axis of movement were determined at PA, PV, PD, and at the termination of the movement (END).

In order to examine the possibility of extraneous movement in the secondary axis of motion caused by the displacement of vision, the time spent moving in the secondary axis was calculated. The Deviation time (DT) was defined as the time between when the velocity in the secondary axis fell above and then below 30 mm/s.

Analysis

The dependent measures were subjected to separate 3-prism (left, nil, right) by 2eye (left, right) by 4-switch times (PA, PV, PD, X) repeated measures analysis of variance. The standard deviation of the finger location at the four kinematic markers was examined using a 4 factor (4-kinematic marker x 3-prism x 2-eye x 4-switch) ANOVA. All main effects and significant interactions involving more than two means were analyzed using Tukey's Honestly Significant Difference Test with α set at 0.05.

RESULTS

Timing

Analysis of reaction time revealed no main effects or significant interactions. The results were expected since the information processing demands associated with each trial were identical prior to movement initiation. The analysis of the movement time in the primary axis of motion indicated no main effects or significant interactions. The grand mean was 398 ms.

The analysis of the proportional time after peak velocity revealed a main effect for switch condition, F(3,27) = 5.00, p < 0.007. The proportional time after peak velocity was significantly shorter in the PV condition than in the PD condition. The PA and X conditions were intermediate (see Figure 22).

An eye by switch condition interaction, F(3,24) = 4.43, p < 0.013, indicated that in the start right eye condition, the proportional time after peak velocity was similar and significantly lower in the PA and PV switch conditions than in the statistically similar PD and X conditions. For the start left eye condition, the proportional time after peak velocity was significantly higher in the PA condition than in the PV condition. The PD and X conditions were intermediate. The proportional time after peak velocity was significantly higher when vision switched from the right eye to the left eye, than when it switched from the left eye to the right eye at peak acceleration (see Figure 23).

The analysis of the deviation time in the secondary axis revealed a main effect for prism, F(2,18) = 4.73, p < 0.023. The deviation time in the secondary axis was significantly higher when leftward visually displaced information (189 ms) was present, than when non-displaced information (173 ms) was presented. Deviation time was intermediate with rightward visually displaced information (183 ms). A main effect for eye, F(1,9) = 11.08, p < 0.009, indicated that deviation time in the secondary axis was significantly longer when vision started in the left eye (189 ms), than when vision started in the right eye (175 ms). Perhaps the dominant eye system monitors the hands more efficiently than the non-dominant eye, as reflected by the decreased deviation time.

Accuracy

Analyses of the constant error and variable error in the primary axis of movement revealed no main effects or interactions. Regardless of the manipulation, participants were able to complete their movements with the correct amplitude. The analysis of the constant error in the secondary axis, or the direction of the manipulation, indicated prism by switch interaction, F(6,54) = 6.14, p < 0.001. The responses of the participants in the PA condition while right displaced visual information was available, were significantly more to the right than under the non-displaced, or the leftward displaced visual conditions. The left and non-displaced conditions were statistically similar (see Figure 24). Participants exhibited intermediate and statistically similar results under all other switch conditions. Because the right hand of the participant is already in the right environmental workspace, displacing vision farther towards the right caused the participants to err more to the right of the target.

The analysis of the variable error in the primary axis of motion revealed no significant main effects or significant interactions. The analysis of the variable error in the secondary axis indicated a main effect for prism, F(2,18) = 10.24, p < 0.001. The variability of the movement endpoint was significantly lower under undisplaced vision (8.24 mm) than under left (10.42 mm), or right (9.62 mm) displacement. The variability in the responses was statistically similar for both the rightward and leftward conditions.

A main effect for switch, F(3,27) = 6.88, p < 0.001, indicated that the variability in the PA condition was significantly higher than the variability in the PD and X conditions. The variability of the PV condition was intermediate (see Figure 25). The responses of the participants were more variable when the erroneous information was presented at an earlier stage of the movement.

An interaction of prism and switch, F(6,54) = 2.42, p < 0.038, indicated that the variability in the movement endpoint was similar in the non-displaced visual condition regardless of switch time. However, the performance of the participants was significantly more variable with left displaced vision than with undisplaced vision in the PA condition. The error with right displaced information was intermediate. The variable error for left displacement significantly decreased from the PA to the PV switch times. Under right visual displacement, the variable error decreased from the PA switch time to the PD switch time (see Figure 26).

A three-way interaction of prism, eye, and switch, F(6,54) = 2.47, p < 0.035, indicated that under left displaced visual information, the variable error was significantly higher than under undisplaced vision at PA, but only when vision switched from the left to the right eye (see Figure 27). Under the three visual conditions, the variable error at the remaining switch times for both eyes was statistically similar.

The analysis of the trial-to-trial variation in the location of the finger at various kinematic markers in the primary axis of movement revealed a main effect for kinematic marker, F(3,27) = 17.19, p < 0.001. Specifically, the variability in the location of the finger increased significantly from peak acceleration to peak velocity, and increased again at peak deceleration. The variability decreased significantly from peak deceleration to the end of the movement. Variability at the end of the movement was similar to variability at peak acceleration (see Figure 28). This decrease, in the variability of the

location of the finger at the end of the movement, is a prime indicator that corrective modifications were employed to decrease the variability, and thus achieve endpoint accuracy.

DISCUSSION

The purpose of this experiment was to examine the visual regulation during discrete manual aiming, and the associated corrective responses to the presentation of visually displaced information. The visual perturbation was presented when the finger reached peak kinematic markers based on real time analysis of the displacement data. The results are supportive of models that emphasize the importance of early visual information for the correction of trajectory errors. Thus displacement of vision, in contrast to the occlusion of vision during the movement, indicates that the visual information from the initial portion of the movement is most influential for the movement outcome.

The introduction of the prism did not affect the movements in the primary axis of movement. However, the prisms did significantly increase the deviation time in the secondary axis of movement. In addition, they caused increased constant error in the secondary axis, and the variability of the responses in the secondary axis. The introduction of the visually displaced information at peak acceleration, and prior to the peak velocity of the movement had the most effect on the responses in the secondary axis. Based on the current study, the visual information received between peak acceleration and peak velocity, is an important variable for the mediation of errors in the trajectory of the finger towards the target.

An argument could be made that the variable and constant error results are simply caused by the length of exposure to the prism (wherein the variability of the responses decreased with decreasing amounts of prismatic exposure). The results still support the importance of early information for corrective modifications in that later displacements did not have the same effect on the constant error in the secondary axis. Perhaps a shorter movement in duration and amplitude is required to more appropriately examine the effects of the length of exposure to the prism.

While the information early in the movements seems most important for movement accuracy, the right eye-right hand system also seems to maintain an advantage for the recognition and reaction to relevant stimuli. The deviation time advantage when vision started in the right eye, and the increased proportional time to peak velocity when switching from the right eye to the left eye support the presence of ocular asymmetries. In addition, the results support the concept of an overall advantage of the right eye - right hand system for right handed and right eye dominant individuals as suggested by the work of Honda (1982).

In temporal perturbation studies, the perturbation can occur prior to the use of online visual information, it can also occur following the initiation of visual feedback processes. In extreme cases, the participant can finish their movement prior to the perturbation intended to interrupt the corrective modifications in the proximity of the target. Similarly, in spatial occlusion studies, the control of the movement may differ if the participant knows that the occlusion will occur part way through the movement. In response to these limitations, the kinematically tied perturbations maintain an advantage

over the spatial and temporal protocols, in that the perturbation cannot be anticipated, and therefore the behaviour of the participants remains unchanged prior to the execution of the movement.

The triggering of perturbations at movement initiation separates the vision received prior to the movement from that received during the execution, triggering the perturbation at peak velocity theoretically separates the visual information received prior to the end of the pre-planned phase from the visual information received during the online control portion of the movement, thus providing another theoretical aspect unavailable in the temporal and spatial perturbation paradigms. In addition, the use of the displacement provides the participants with a continuous use of visual information, and does not eliminate the visual feedback processing as with visual occlusion paradigms.

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AUTHOR NOTE

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FIGURE CAPTIONS

Figure 22: experiment 4: The proportional time after peak velocity (PTAPV) as a function of switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

<u>Figure 23</u>; experiment 4: The proportional time after peak velocity (PTAPV) as a function of initial eye, and switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

Figure 24: experiment 4: Constant Error (mm) in the secondary axis of movement as a function of prism, and switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

<u>Figure 25</u>; experiment 4: Variable Error (mm) in the secondary axis of movement as a function of switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

Figure 26: experiment 4: Variable Error (mm) in the secondary axis of movement as a function of prism, and switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

<u>Figure 27:</u> experiment 4: Variable Error (mm) in the secondary axis of movement as a function of prism, initial eye, and switch condition (PA = peak acceleration, PV = peak velocity, PD = peak deceleration, X = no switch).

Figure 28; experiment 4: The between trial standard deviation (mm) of the location of the finger at various kinematic makers (PA = peak acceleration, PV = peak velocity, PD = peak deceleration. END = endpoint location).











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GENERAL CONCLUSION

The purpose of this thesis was to examine the visual regulation of upper limb control under visually displaced conditions. The results of the initial control experiment validated the use of the monocular switch of vision for the introduction of visual displacement. In the second experiment, the presentation of displaced visual information at movement initiation caused significant terminal error. In the third experiment, the removal of displaced visual information at movement initiation allowed the participant to terminate their movements accurately, while removal later in the movement had detrimental effects on movement accuracy.

The fourth experiment employed a real time procedure to trigger the visual perturbation based on specific kinematic events in the limb's trajectory. The theoretical basis behind triggering the perturbation at peak velocity was to separate the vision received prior to the on-line portion of the movement, from the vision received during that part of the movement shown to be important for on-line control (Elliott et al., 1999). The results indicated that the presentation of displaced visual information at peak acceleration caused significant terminal error, while visual displacement later in the movement had little effect on movement accuracy.

Our results contrast with occlusion studies such as Chua and Elliott (1993), and Carlton (1981) that suggest that vision near the target area is important for optimal accuracy. However, our results are in agreement with the results of Khan and Franks

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(2003) that indicate that vision of the initial portion of the movement is most important for movement accuracy.

A secondary purpose of this thesis was to examine gender differences in upper limb control processes. The current models of upper limb control do not consider gender differences in the control processes. Several experiments focusing on visual regulation have unintentionally biased the participant pool towards one gender. As a result, the means of these experiments may be only representative of a single gender. Even when equal numbers of males and female participants, if gender is not included as an independent variable in the design, the pooled results may not reflect the performance of either gender group. The findings of our study, specifically of the primary experiment, are interesting in that under non-displaced environmental circumstances, the different control strategies allow for similar terminal accuracy.

In conclusion, the results of this thesis add to the body of evidence indicating that the visual information received during the initial impulse of the movement is most useful for the terminal accuracy of rapid manual aiming movements (e.g. Khan & Franks, 2003). This thesis also indicates that males and females may control their upper limb movements in fundamentally different ways. Although I have identified a number of possible strategic and neuro-physiological mechanisms for the observed gender differences, a definitive explanation requires further investigation.

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