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# Visuomotor Adaptation with Augmented Feedback

Andrew D. LeBlanc

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Visuomotor Adaptation with Augmented Feedback

by


Andrew D. LeBlanc

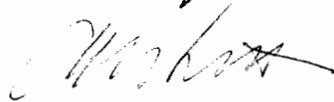
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Master of Science in Experimental Psychology with a concentration in Behavioral  
Neuroscience

Department of Psychology  
Seton Hall University

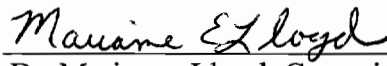
June, 2008

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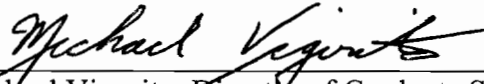
  
\_\_\_\_\_  
Dr. Kelly Goedert, Mentor



\_\_\_\_\_  
Dr. Anna Barrett, Committee Member



\_\_\_\_\_  
Dr. Marianne Lloyd, Committee Member



\_\_\_\_\_  
Dr. Michael Vigorito, Director of Graduate Studies

Dedication

I would like to dedicate this thesis to my parents, David and Anne LeBlanc for their continued love, support, and encouragement throughout my academic pursuits and career. I would also like to dedicate this thesis to my sister Karen for her love and support of my studies and ambitions...and to Nana.

Acknowledgments

I would like to express my sincere appreciation and gratitude to Dr. Kelly Goedert for her constant guidance and support throughout this project and my graduate career at Seton Hall University. As my mentor, the time and effort she gave to advising me was invaluable. I am extremely grateful for her encouragement in helping me to discover my skills and potential. For all this, I offer my sincerest gratitude. I would also like to thank the other essential members of my thesis committee, Dr. Anna Barrett for her direction and training throughout this project; and Dr. Marianne Lloyd for her guidance and interest in my work which always brought about creative and interesting ideas.

Appreciation and thanks goes to Dr. Gregory Burton for agreeing to be apart of my thesis project as a reader, his wisdom and insight was warmly welcomed. Throughout my studies and career at Seton Hall, I have always felt supported by the faculty members of the Psychology Department and would like to express my thanks. Also, I would like to acknowledge the work of my lab assistant Amanda Ferriola for her valuable work in the running of my experiment, as well as Karen Bocian and Marley Kass for their help in proofreading my work. Finally a special thank you and acknowledgment goes to Dr. Amy Silvestri, who has encouraged and inspired me throughout graduate school. Her genuine support of me and my pursuits has been unwavering and will always be treasured.

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### Abstract

Prism displacement for visuomotor adaptation has been used as a tool to investigate how healthy individuals use their sensory and motor systems to attend to the space around them. Visuomotor adaptation through prism training uses prism lenses to laterally displace a participant's vision to the left or right forcing participants to learn a new set of visuomotor coordinates to maintain functional coordination between the perception and action systems. After learning these new coordinates, when the individual takes the prism goggles off, she experiences aftereffects in which she will make errors in the opposite direction of the prism shift. This experiment investigated the differences in direction of prism displacement, and possible asymmetries in the prism adaptation paradigm, through the line bisection task. This experiment also examined the role of external feedback in the line bisection task as compared to the form of intrinsic feedback in a dot pointing task in order to see if adaptation was dependent on a form of feedback. It was found that adaptation to right-shifting prisms induced longer lasting aftereffects than adaptation to left-shifting prisms across. These results are in direct opposition to the results of previous studies which have stated that left-shifting prisms induce longer lasting aftereffects. It was also found that line bisection with external feedback had no effect on facilitating adaptation or creating longer lasting aftereffects as compared to intrinsic feedback tasks. These results suggest that precise external feedback is not necessary for successful prism adaptation.

## Introduction

Visuomotor adaptation has been used to investigate visually guided action in normal individuals (Bedford, 1993a) and is a possible rehabilitation treatment for spatial attentional deficits resulting from right hemisphere brain damage (Berberovic, Pisella, Morris & Mattingley, 2004). Recently, several investigators have also used visuomotor adaptation in attempts to produce a spatial bias in normal individuals, with the intent of modeling the pathological syndrome observed after right hemisphere damage (Berberovic & Mattingley, 2003; Colent, Pisella, Bernieri, Rode, & Rossetti, 2000; Michel, Pisella et al., 2003). In this paper I argue that visuomotor adaptation in healthy individuals does not model the pathological attentional deficits observed after right hemisphere brain damage. In particular, I will review existing visuomotor adaptation research inconsistent with such a model and argue that experimental findings supporting this model are contaminated by failures of generalization and by baseline attentional biases. Finally, I will present an experiment controlling for these contaminating factors that yields results inconsistent with the notion that visuomotor adaptation may be used to induce a pathological spatial bias in normal individuals.

### *Characteristics of prism adaptation in healthy individuals*

Visuomotor adaptation through prism training uses prism lenses to laterally displace a participant's vision to the left or right by 10 to 14 degrees (e.g., Colent et al., 2000; Hamilton & Bossom, 1964; Rossetti et al., 1998). While wearing these prisms, participants must learn a new set of visuomotor coordinates to maintain functional coordination between the perception and action systems. In this paradigm, if a participant's vision is shifted to the right, she will err towards the right and must adapt

her movements leftward in order to reach the intended visual target. Through this adaptation the perceptual-motor translation process is adjusted to once again make fluid movements, thus showing evidence of visuomotor learning. After learning these new coordinates, when the individual takes the prism goggles off, she experiences aftereffects in which she will make errors in the direction opposite the prism shift, thus showing evidence of a new perceptual-motor adaptation (Hamilton & Bossom, 1964; Redding & Wallace, 2006). For example, if the participant wears left shifting goggles, when she removes the goggles she will make errors to the right.

In prism adaptation, participants are often tested on the effects of the prism displacement on their visual shift and proprioceptive shift. These different shifts are determined by the changes in the various components of the perceptual-motor system. The visual shift consists of the sensory-motor relationship between the eye-to-head, or how prism adaptation induces a change in the vision pathways. These shifts are generally measured on a completely visual task with no movements. The proprioceptive shift consists of the relationship between the hand-to-head, or how the prism induces a change in the person's sense of body movement (Redding and Wallace, 1990).

One important determinant of visuomotor adaptation is active training rather than just passive exposure to the visual displacement. The differences between the two were investigated by Michel, Pisella, et al. (2003), who studied whether simply being exposed to or wearing the prism goggles could produce the same effects as prism adaptation or active training with the prism goggles. In this study the participant both bisected a line with a pencil (i.e., manual line bisection), and also judged whether an already bisected line was inaccurately bisected to the left or right of center (i.e., perceptual line bisection).

Two groups of normal, healthy participants either actively trained with the prism goggles, or were simply exposed to the goggles. In these conditions, respectively, the participants would complete a dot pointing task while wearing the prism goggles, or would wear the goggles but make no active hand movements. In this study, aftereffects were contingent upon active training with the prism goggles (Michel, Pisella, et al). These findings imply that active training is essential to inducing changes in the perceptual-action systems. Moreover, passive interactions with the goggles are not sufficient for eliciting these changes.

Individuals learn to adapt to the prism displacement through the errors they make (Redding & Wallace, 2006). Therefore feedback regarding performance accuracy is extremely important to prism adaptation training. Individuals can receive this information in two forms of feedback, intrinsic and augmented. The former consists of sensory information from the performance, while the latter consists of any external information given about the performance (Magill, 2001, p.236). Traditionally prism adaptation paradigms have used a target pointing task which relies on intrinsic feedback. In a target pointing task (e.g. dot pointing), a person immediately receives sensory visual information regarding the outcome of her performance. This immediate feedback lets her know whether she has located the target or not. For example, if a participant is wearing goggles shifting her vision to the right, her first few trials she will most likely err to the right. The sight of her finger pointing to the right of the target will provide her with visual feedback that she is erring rightward and subsequent movements will then be made more leftward in order to overcome the prism displacement. All of the feedback being given in this task is through sensory information (i.e., vision) thus making it entirely task

intrinsic (Magill, 2001, p.236). However, because this information is being given through the sensory systems, the sensory feedback may be biased.

A task which has less intrinsic feedback than target pointing because more than one possible outcome could be interpreted as correct is the line bisection task. In this task an individual is presented with a horizontal line on which she is instructed to mark the center with a perpendicular line. While she may know whether she has made a large error to the left or right of center, some responses could be perceived as the actual center while in reality they are errors to the right or left of actual center. Thus, a correct answer is relative to the performer's perception. There is no absolute sensory information being given back to the participant to indicate an exact correct performance, potentially limiting the ability to adapt to the prism displacement. In fact, normal individuals often have a leftward bias in the line bisection task, by which they err slightly to the left of center under normal conditions (e.g. Porac, Searleman, & Karagiannakis, 2006; for a comprehensive review, see Jewell & McCourt, 2000).

Intrinsic feedback is extremely important in visuomotor adaptation paradigms, as it is involved with the mechanisms for adaptation to the prism displacement. A study by Redding and Wallace (1990) investigated intrinsic feedback by manipulating the amount of hand movement in a participant's view. Using increments of 5 cm the researchers tested the effects of decreasing the amount of pointing movements that were visible, and the effects of increasing the amount of pointing movements that were occluded on a rightward prism displacement. The former ranged from the sight of her fingertip when the movement was terminated to the sight of the entire hand movement. The latter ranged from viewing all but the last 5cm of a hand movement to only viewing the first

5cm of a hand movement. The researchers found that in the decreasing view condition, the more of the limb that was visible, the visual shift increased and the proprioceptive shift decreased. For the occluding condition, as the amount of visible limb decreased, proprioceptive shift increased and visual shift decreased. The less they could see their arm, the less visual shift they had. These results support the idea that an early view of the limb that is performing the action is essential for proprioceptive adaptation: the less of the hand movement blocked at the beginning of the action, the more the participant will proprioceptively adapt and the less she will visually adapt (Redding & Wallace, 1990). Both visual adaptation and proprioceptive adaptation are important for visuomotor adaptation.

These researchers also investigated the timing of augmented feedback, or externally presented performance information which can be given both during (concurrently) or at the conclusion of (terminally) a performance (Magill, 2001, p.236). Redding and Wallace (1992) studied the differences between concurrent and terminal feedback using a visual test, a proprioceptive test, and a total adaptation test after manipulating the participant's pointing rate (e.g., a slower pointing rate or a faster pointing rate). The participant was given augmented visual feedback either concurrently or terminally. The study found that the proprioceptive shift was greater than the visual shift for concurrent feedback with the faster pointing rate, but the visual shift was greater for terminal feedback and the slower pointing rate. The implication of these results is that the visual system seems to be limited by the speed with which it can track a proprioceptively-based image of a moving limb (Redding & Wallace).

In visuomotor adaptation, the use of a cognitive strategy will hinder the participant's ability to visually or proprioceptively adapt to the prism displacement (Mazzoni & Krakauer, 2006). In this scenario, she will not learn a new set of visuomotor coordinates; and would not yield aftereffects because she is using top-down processing instead of adapting to the prism displacement. Prism adaptation is thought to involve bottom-up processes. These processes have been associated with the cerebellum (Jeannerod & Rossetti, 1993; Rossetti, Jacquin-Courtis, Rode, Ota, Michel & Boisson, 2004), a brain structure which may be involved in the realignment of visuo-motor coordinates, and the posterior parietal cortex contralateral to the acting hand, might be activated during adaptation to a prism-induced shift of the visual field (Tham, Ginsburg, Fisher, Tegner, 2001). The use of strategy is thought to evoke top-down processes in which an individual attempts to overcome her perceptual and behavioral biases through higher cognitive processes (Luate, Halligan, Rode, Jacquin-Courtois, & Boisson, 2006).

In healthy individuals, the use of a strategy during adaptation may prevent the formation of aftereffects, but aftereffects may also be prevented by lack of transfer to tasks different from those engaged in during prism adaptation (Kitazawa, Kimura, & Uka, 1997; Martin, Keating, Goodkin, Bastian, & Thach, 1996). Aftereffects in these paradigms often do not generalize outside of the characteristics of the movement used during the training (Martin, et al.). For example, the velocity of the hand movement during training was found not to generalize to other velocities in aftereffects testing (Kitazawa, et al.s).

*Use of prism adaptation to treat spatial neglect and characteristic findings*

Right shifting prisms have been introduced as a potential treatment for spatial neglect syndrome, which is the failure to report, respond or orient to the side of space opposite a brain lesion (Heilman, 1979) causing functional disability (Barrett & Burkholder, 2006). Neglect of the left side of space due to right hemisphere brain damage is more common, and often more severe, than neglect of the right side of space due to left hemisphere brain damage (Ringman, Saver, Woolson, Clarke, & Adams, 2004). This finding suggests that the right hemisphere has a special role in attention and the representation of space (Heilman & Van den Abell, 1979; Heilman, Watson, & Valenstein, 2003). The failure to attend to the left side of space can be detected in many functional tasks such as dialing a telephone or reading a menu (Frassinetti, Angeli, Meneghello, Avanzi, & Ladavas, 2002). For a review of the syndrome of spatial neglect see Vallar (1998).

It is thought that if neglect patients wear goggles that shift their vision in the opposite direction of the neglect, then the aftereffects they experience will force them to attend to the neglected side (Berbovic et al., 2004). In a group of right-hemisphere stroke patients suffering from left spatial neglect, Rossetti and colleagues (1998) used the traditional prism adaptation paradigm as described earlier for the healthy controls in which the participants wore either leftward or rightward shifting prism goggles while they made pointing movements to targets. In the experiment, the researchers replicated the typical symmetrical adaptation and post-adaptation shift in perceived body center in their group of normal controls. However, the results from the patient group were different from those typically seen in normals: the neglect patients failed to adapt to the left-



shifting prisms. After removing the left-shifting prisms, the patients did not improve their error over time, nor did they demonstrate aftereffects. On the other hand, while training with the right-shifting prisms, the pointing performance exhibited by the neglect patients improved over trials. In addition, the neglect patients demonstrated a significant aftereffect in the leftward direction and this aftereffect transferred to tasks used for detecting the presence of neglect (e.g., the copy a scene task). Taken together this initial study demonstrated prism adaptation with neglect patients results in asymmetrical adaptation and aftereffects. Moreover, in these neglect patients the aftereffects generalized to tasks beyond those used during prism training. Both of these findings are inconsistent with previous results of prism adaptation studies with normal individuals (e.g., Ktazawa et al., 1997; Martin et al, 1996)

Contemporary research using right-shift prisms as a treatment have shown improvement on several standard tests for spatial neglect such as line bisection and cancellation tasks (Dijkerman et al., 2003; Frassinetti et al., 2002). Several studies have also been able to demonstrate that a single prism adaptation session can have long lasting effects which can be generalized to tests measuring wheelchair navigation (Jacquin-Courtis, Rode, Boisson & Rossetti, 2006), reading (Farne, Rossetti, Toniolo, & Ladavas, 2002), and spatial dysgraphia (Rode, Pisella, Marsal, Mercier, Rossetti, & Boisson, 2006). Prism adaptation has also been found to have beneficial effects in a dichotic listening test, where improvements of auditory extinction were displayed (Luque et al., 2006). Findings such as this highlight that the beneficial effects of prism adaptation are not limited to visuomotor tasks, and can affect perception of other non visual areas. This

also illustrates how prism adaptation with neglect patients generalizes to other tasks, which is not really seen in healthy controls.

Neglect patients often are unaware of or fail to consciously acknowledge their deficits (for a review of this symptom of neglect see Vallar and Ronchi, 2006). This failure to acknowledge their performance deficits suggests that it is unlikely they are using a cognitive strategy while training with the displacing goggles. Prism adaptation has led to improvements in numerous neglect related manifestations such as visual exploration toward the left hemispace (Ferber, Danckert, Joanisse, Goltz & Goodale, 2001), balance of posture (Tilikete, Rode, Rossetti, Pichon, Li & Boisson, 2001), contralesional somatosensory perception (McIntosh, Rossetti, & Milner, 2002), temporal order judgment (Berbrovic, Pisella, Morris, & Mattingley, 2004), mental representation of maps (Rode, Rossetti, Li, Boisson, 1998), as well as improvement in functional tasks such as picture scanning, object naming, word reading, and non-word reading in which the patient had to read word strings that were orthographically plausible but were not words (Farne et al.). These improvements suggest that prism adaptation is a low-level sensorimotor intervention which acts on cortical areas in a bottom-up fashion (Rode, Pisella, Rossetti, Farne, & Boisson, 2003). Therefore it is unlikely that patients use strategies since they are more characteristic of top-down cognitive higher order process.

### *Induction of Neglect in Healthy Controls*

Once visuomotor adaptation has been introduced as a potential treatment for spatial neglect, it is of importance to understand the mechanisms of the adapting to prism displacement, which can be investigated in healthy controls. The asymmetrical adaptation to prism displacement exhibited by neglect patients is of great interest.

Therefore, if this finding could be replicated in non-brain damaged participants, healthy individuals could serve as a model for spatial neglect. There have been several studies recently that have reported the ability to induce left neglect in healthy controls (Berberovic & Mattingley, 2003; Colent, Pisella, Bernieri, Rode, & Rossetti, 2000; Michel, Pisella et al., 2003).

Colent, Pisella, Bernieri, Rode, and Rossetti, (2000) looked at both manual and perceptual line bisection measuring induced neglect. After training by target pointing with left- and right-shifting prisms, participants did not have a significant bias in either direction for the manual line bisection task. However, for the perceptual task in which the participants were asked to indicate whether line was pre-bisected to the right or left of center, they exhibited significant aftereffects from the left-shifting prisms, erring right of center. The researchers claim that their results show an asymmetrical bias induced by prism adaptation in normal individuals, and that only the leftward-shifting prisms were able to induce this perceptual bias. They further concluded that this asymmetry reflected an “induced” spatial neglect.

Other researchers have also investigated these claims for asymmetries in prism adaptation and found results suggesting an asymmetrical bias. Berberovic and Mattingley (2003) used left and right prism adaptation in the immediate reaching space with a pointing task. Participants were then tested for aftereffects from this adaptation in both their immediate reaching space, and in the area beyond the participants’ immediate reaching space. Participants were tested on accuracy in manual pointing to targets while wearing prism goggles, and in pointing accuracy for straight ahead pointing trials with visual feedback blocked in order to assess any shift in perceived proprioceptive straight

ahead. The results showed a symmetrical adaptation to the prism displacement within approximately 15 trials, and maintained that adaptation for the remainder of the prism training session (Berberovic & Mattingley, 2003). While a shift in perceived proprioceptive straight ahead also occurred after adaptation to either the left or right-shifting prisms, post adaptation performance on a perceptual line bisection task was altered only by adaptation to left-shifting prisms. In this task, the researchers found an asymmetrical perceptual bias, where 10 out of the 16 participants' had a shift to the right in subjective judgment after training with the leftward-displacing prisms. There was no significant effect on the participants after training with the rightward-displacing prisms. These results appear to affirm the previous results by Colent et al., (2000), that in immediate reaching space, normal individuals have an asymmetrical perceptual bias for prism adaptation and that only leftward-shifting prisms can induce this bias.

The results of Michel, Pisella, et al. (2003) also appear to support the results of Colent et al. (2000) that leftward-shifting prisms induce an asymmetrical perceptual bias in healthy individuals by testing the results of both manual and perceptual line bisection tasks in three locations directly in front of a participant (left, right and center of the participant's midline) after training with left-shifting prism goggles. The researchers found that there was a significant rightward shift for both the manual and perceptual bisection tasks, but not for lines on the right side of space. Michel, Pisella et al. claimed that perhaps in healthy individuals, the right hemisphere is differentially sensitive to prism adaptation.

This asymmetrical bias has also been found outside of the visual perception of body space in postural control (Michel, Rossetti, Rode, & Tilikete, 2003). The

investigators studied postural control before and after completing fast pointing movements for 20 minutes while wearing prism goggles that shifted in both directions. They tested the participants by having them stand evenly in a central location where the participants were measured on whether they were putting more pressure to the right or left side, forward or backward, and the distribution area of the center of pressure. These tests were completed twice, once with the eyes open, and once closed (Michel, Rossetti et al., 2003).

The researchers found that for postural shifts, leftward prism training produced a significant shift to the right in the open eye condition, inducing an asymmetrical postural position. This suggests a visual change rather than a proprioceptive change as our bodies adjust posture based upon visual input. There was, however, a symmetrical increase in surface area for the closed eye condition. These results support their assertion that prism adaptation with healthy participants will only be effective with a leftward deviating prism; more importantly, these results show that prism adaptation does not exclusively induce visual sensory changes (Michel, Rossetti et al. 2003).

### *Problems with conclusion of “induced neglect”*

There are several issues with researchers’ claims that they are “inducing” neglect in normal individuals. First, participants are also adapting to right-shifting prisms. Second, conclusions of inducing neglect may be premature, as it may be possible that there were contaminations in the researchers’ findings from lack of generalization to testing tasks from the prism training procedure. Finally there may be contaminations in the findings from healthy individual’s leftward bias.

Despite some of the current studies' claims, the prism adaptation paradigm has existed for quite some time and other research studies have found adaptation and aftereffects to rightward prism displacements (Redding & Wallace, 1990; Hamilton & Bossom, 1954). In many studies with unimpaired individuals, the aftereffects are symmetrical (e.g., Harris, 1963; Prablanc, Tzavaras, & Jeannerod, 1975). Also in all the "induced" neglect studies that used both right and left shift prisms, there was symmetrical adaptation to the prism displacement.

The "induced neglect" studies may have also been contaminated by failures of generalization from training to testing conditions. Colent, et al., (2000) looked at both manual and perceptual line bisection and found for the perceptual task significant aftereffects from the left-shifting prisms, erring right of center, but not significant leftward aftereffects from right-shifting prisms. Because Colent et al.'s (2000) experiment used a pointing and not a line bisection task for prism training, it is possible that for the manual task, the aftereffects did not transfer or generalize from the training to the testing task. Since visuomotor adaptation for healthy individuals has difficulties in generalization of aftereffects, the failure to generalize outside of the manual training task could be the reason for the perceptual aftereffects results.

Colent et al. (2000) claimed that prism adaptation to a rightward displacement does not induce any cognitive effects in normal individuals. This claim, however, is based on the results of a perceptual task after training on a different manual task. Prism adaptation has both visual and motor components (Girardi et al., 2004; Michel, 2006). If a person trains on the pointing task (which is a manual task), as participants did in Colent et al.'s study, then she may be more likely to show the aftereffects on a manual task than

on the perceptual task. This is because generalization works on a gradient in which the amount of generalization is dependent on the strength of the relationship between the training and the testing conditions (Bedford, 1993). The further removed the testing conditions are from the training conditions, the less the effects will transfer from one task to another. If there are differences in learning between directions of prism displacement, then these differences would be more likely shown in a testing task that is more like the training task. For example, in Colent et al.'s study the manual line bisection task should show the effects of asymmetrical adaptation rather than the perceptual line bisection task. Based on this gradient, the question that should be asked is why are there only perceptual effects and no effects for the manual task, since this task is more like the training task? Since prism adaptation requires an active motor behavior, one would expect to see a motor effect from the prism adaptation, (Michel, 2006). The claim from these results suggests that more research should be done for the types of training for prism adaptation.

Berberovic and Mattingley's (2003) experiment also used a manual pointing task for the prism adaptation and found perceptual asymmetrical aftereffects. Michel, Pisella, et al. (2003), and Michel, Rossetti et al., (2003) also used pointing tasks and tested on tasks outside of the manual tasks they tested on. If there had been asymmetries in learning from the prism adaptation, they should have appeared in the manual tasks as well. Michel, Pisella et al. claimed that perhaps in healthy individuals, the right hemisphere is differentially sensitive to prism adaptation.

Another issue with these "induced neglect" studies is when using the line bisection task as a testing task, normal individuals, as previously mentioned, traditionally err leftward of center (Jewel & McCourt, 2000). This tendency to err leftward could

contaminate the detection of leftward error on the task, when compared to rightward error. The effect of a baseline leftward bias on the line bisection task could lead to the conclusion that participants have a significant rightward shift in line bisection performance after training with left-shifting prisms, but no leftward shift in line bisection performance after training with right-shifting prisms.

### *Overview of current study*

The current experiment was designed to investigate the effects on training and aftereffects from differences in training tasks based on the availability of feedback and direction of prism displacement. The experiment compared using the line bisection task with and without feedback and the dot pointing task for its effects on prism adaptation training and aftereffects. Also, this experiment examined the differences between training with left- and right-shifting prisms.

This experiment was designed to investigate in a prism adaptation paradigm the differences in using the same task during both training and testing and in using different tasks during training and testing. This design also assessed the issues with generalization in prism adaptation training such as the use of dot-pointing versus line-bisection. One potential problem with using line bisection as a prism adaptation training technique is that this technique differs in the type of feedback available to the participant. As discussed earlier the line bisection task has limited intrinsic feedback thus potentially limiting the amount of visuomotor adaptation that could occur. The purpose of this experiment was to see if the addition of augmented feedback could help facilitate adaptation with the line bisection task to produce results similar to training with a dot pointing task. Participants who received augmented feedback while training on the line



bisection task were visually presented with a vertical line at the center of the stimulus which they were asked to bisect

This experiment examined the effects of feedback on adaptation training and aftereffects during. The independent variables were the methods of prism adaptation training (line bisection with augmented feedback, line bisection without augmented feedback, and dot pointing). These variables were measured in training errors, and aftereffects errors. The aftereffects errors were tested as line bisection errors and straight ahead pointing errors.

It was predicted that by providing augmented feedback to the line bisection task, that this training group would yield similar training results to the dot pointing training group. It was also predicted that the line bisection with feedback group would yield the most line bisection aftereffects because it was the same training task as the testing task for aftereffects, but the participant had received more exact feedback during training and would adapt more to the prism displacement. It was also predicted that the dot pointing group would show a more accurate performance on the training trials than the line bisection without feedback since this group had more intrinsic feedback. It was expected, however that the line bisection without feedback group would yield more aftereffects than the dot pointing group because the line bisection without feedback would be tested on a task that was more similar to the one they trained on than the dot-pointing group. Finally, it was predicted that the straight ahead pointing task would yield similar results of aftereffects opposite the prism displacement from both the line bisection with feedback and dot pointing groups; and that both of these groups would be significantly different than the results from the group that trained on the line bisection without feedback.

This experiment also examined the differences in the direction of prism displacement, in order to attempt to replicate the previous results which indicate an asymmetrical bias with left-shifting prism goggles. Because of the potential contaminations of the results of the “induced neglect” studies, we attempted to take into account the issues of generalization and natural biases when investigating any differences between the directions of displacement by subtracting out participants’ baseline bisection error from the dependent measure of their aftereffect error. I predicted that there would be a symmetrical adaptation for both left and right shifting prisms in the training trials. I also predicted there would be symmetrical and equal aftereffects with both left- and right-shifting prisms for both the line bisection task and the straight ahead pointing task.

## Methods

*Participants*

Seventy-two healthy right-handed individuals between the ages of 18 and 25 ( $M = 19.07$   $SD = 1.25$ ) from the psychology participant pool participated in fulfillment of a course requirement. All participants gave informed consent. Twelve individuals participated in each of the six between-groups conditions described below.

*Design*

The primary variables of interest were manipulated using a 3x2 between-groups factorial design with type of training (line bisection with feedback, line bisection without feedback, target pointing) and prism displacement (left, right) as factors. There were three dependent measures of interest: training error, aftereffects error, and proprioceptive straight ahead pointing error. All error was measured as horizontal distance from the target location in cm.

*Apparati*

Participants sat in front of and made all responses on a touch-screen monitor. Stimuli were delivered and response information collected using *E-prime 2.0*. The participant interacted with the computer screen with her finger. The computer program would record the initial and end coordinates of the participant's responses in pixels. These pixel coordinates were then converted to error scores (see results section for conversion equation). To occlude participants' initial view of their hand a 6 inch piece of wood was attached to free standing wooden poles located on either side of the seated participant. Two clamps made the shelf level adjustable to the person's height. During training, participants wore Deluxe Prism Training Glasses from the Bernell Optical

Company fitted with wedge prisms that produced a 12.4 degree visual shift to either the left or right. These plastic eye frames contained a strap that the participant adjusted for comfortable wear. During the baseline and aftereffects trials, participants wore placebo goggles that consisted of frames that were exactly the same as the prism goggles; however, the lenses were flat, non-prescription lenses, producing no optical shift.

### *Procedure*

All Participants tested individually. See Figure 1 for a graphical depiction of the procedure and the Appendix for the experimental protocol. Participants first tested in a proprioceptive straight ahead pointing task to assess their baseline perception of the center of their own body. During this task, the participant was seated centered in front of the touch screen computer and asked to close her eyes and hold her hand directly in front of her chest. With eyes closed, she reached her arm out straight ahead and pointed to the screen. The location on the screen was recorded in pixels by the computer as a baseline coordinate for proprioception.

The participants next completed three baseline line bisection trials while wearing the placebo goggles. A horizontal line 13.5cm long appeared on the screen in front of them at eye level with a visual angle subtending of  $23.12^\circ$ . They were instructed to make a rapid ballistic movement bringing their hand from in front of their chest underneath the plank of wood and mark the screen with their finger as if drawing a perpendicular line through the center of the line presented on the screen. After every response a line representing the participant's response would remain for 1 second. Then the participants pulled their hand back to in front of their chest. The line disappeared and a visual mask appeared for 1 second. A new line was then presented and this procedure was repeated

for a total of 3 baseline trials. The computer program recorded the beginning and end coordinates of the participants' responses. These points were later used in an equation to determine the error in the participant's response from where it intercepted the center of the given line.

During training the participants were randomly assigned to wear either the left or right prism goggles. All participants completed 60 training trials in one of three training groups while wearing the prism goggles. The three training groups were: line bisection with feedback, line bisection without feedback, and dot pointing. Each training group was divided between those who trained with right-shift prisms, and those who trained with left-shift prisms.

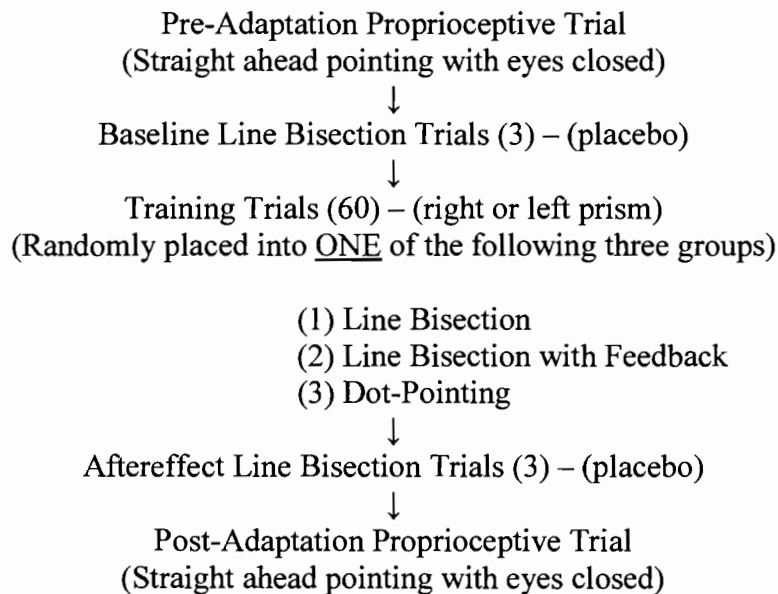


Figure 1. Flow-chart depiction of the experimental procedure.

The line bisection without feedback group completed the same line bisection task as described for the baseline, but for a total of 60 trials. The line bisection with feedback group completed the same procedure with the addition of external feedback at the conclusion of every trial. Following the participant's response, a small black line, would

appear perpendicular to and at the exact center of the horizontal line for 500 ms. After the 500 ms, the given stimulus and the feedback line would disappear and be replaced by the visual mask, followed by a new line to be bisected, just as with the baseline procedure. The computer recorded the beginning and end coordinates of the participant's response just as with the baseline procedure.

The third group of participants completed a pointing task in which a black dot appeared at a random location on the screen and the participant made a quick ballistic movement in the exact same fashion from in front of their chest underneath the plank of wood, to the screen and touched the dot. There were 60 trials. The computer recorded the coordinates of the response in pixels, which was later converted to error in cm from the location of the center of the given dot.

All participants then completed three aftereffects trials on the computer screen with the line bisection task exactly as they had in the baseline trials. Following this, the participants were again measured in the proprioceptive straight head pointing task.

At the conclusion of the experiment, all participants were asked to complete a brief survey that assessed whether they were using a strategy during the prism adaptation training. For example, after noticing that she was making errors in the rightward direction, the participant may have attempted to aim at a new spatial target to the left of the original target. The survey consisted of two yes-or-no questions:

“Did you use a strategy to overcome the prism displacement?”

“After noticing you made an error, did you aim your pointing movements in the opposite direction?”

## Visuomotor Adaptation

If the participant responded “yes” to a question, she was asked to provide detail regarding the strategy she used.

## Results

The computer recorded the responses of the participants in pixels, with the top left corner of the screen as the origin (0,0), and the bottom right corner of the screen as (640, 480). For the purpose of creating the error dependent measures, the center of the screen was converted to an origin using traditional algebraic X,Y coordinates: (320, 240) = (0,0). The scores recorded in pixels were then converted to traditional algebraic X,Y coordinates by subtracting 320 from all X values and subtracting the Y values from 240. After converting to this coordinate system, errors were calculated by using equations for proprioception, line bisection and dot pointing. These error scores were converted from pixels to cm by dividing the value by 96 and multiplying that value by 2.54. All significant effects are at the  $p \leq 0.05$  unless otherwise specified.

*Baseline*

*Proprioceptive Straight-Ahead.* The baseline for proprioception was established by transforming the computer coordinates to the algebraic coordinates and converting the score from pixels to cm. The distance from zero on the horizontal axis in cm was analyzed using an ANOVA with prism displacement (left and right) and training group (line bisection with feedback, line bisection without feedback and dot pointing) as between-groups factors. The analysis revealed a significant main effect of training group,  $F(2,71) = 4.03$ ,  $\eta^2 = 11.59$ , and no other effects  $F_s < 0.6$ . Tukey's HSD post-hoc tests revealed that the feedback group erred more leftward ( $M = -0.01$ ,  $SE = 0.25$ ) than the no feedback ( $M = -0.03$ ,  $SE = 0.21$ ) and dot pointing groups ( $M = -0.07$ ,  $SE = 0.0.27$ ), which did not differ significantly from each other. There were no significant differences



between the no feedback and dot pointing groups. This baseline difference in proprioceptive straight-ahead performance was unexpected given that all groups had been treated similarly at this point of the experiment. However, as expected, there were no differences between straight ahead pointing baseline performances for the left and right training groups.

*Line Bisection.* The baseline results were produced by using the beginning and end point of the participant's performance on the line bisection task. The recorded coordinates were converted to the standard algebraic coordinate system. These two new sets of coordinates were submitted to the following equation: (the end X coordinate minus the beginning X coordinate) divided by (the end Y coordinate minus the beginning Y coordinate). This gave us the slope of the line of the participant. The slope was then multiplied by the beginning Y coordinate and subtracted from the beginning X coordinate. This gave us the location in pixels of where the participant intercepted the line on the screen. This coordinate was measured in its distance from zero as left being negative and right being positive. Finally this error was converted from pixels to cm the same as proprioception had been.

The results were analyzed using a mixed multivariate analysis of variance (MANOVA) with trials (one-three) as the within groups factor and direction of prism displacement (left and right) and training groups (line bisection with feedback, line bisection without feedback, and dot pointing) as the between groups factors. Participants' average error in each condition is depicted in Table 1. The analysis revealed an effect of trial,  $F(2,65) = 3.703$ ,  $\eta^2 = 0.102$ , and no other effects,  $F_s < 1.50$ . As can be seen in Figure 2, participants progressively erred more leftward across the three baseline

trials. A one-sample t-test revealed that, on average, participants erred significantly left of center,  $t(71) = -2.302$ , a bias consistent with the findings that normal healthy individuals err leftward on the line bisection task (e.g., Porac, Searleman, & Karagiannakis, 2006). As with the proprioceptive straight ahead pointing there were no differences in baseline line bisection performance between left and right prism training groups.

Table 1. Average baseline error across trials, training condition and prism displacement.

Baseline Trial	Prism Shift	Training Condition		
		Feed	None	Dot
1	left	0.08 (.3)	-0.02 (.36)	-0.01 (.32)
	right	-0.04 (.32)	-0.07 (.23)	0.29 (.78)
2	left	-0.09 (.18)	-0.11 (.27)	-0.07 (.39)
	right	-0.13 (.27)	-0.08 (.13)	-0.01 (.28)
3	left	-0.18 (.17)	0.03 (.92)	-0.27 (.32)
	right	-0.15 (.27)	-0.15 (.15)	-0.16 (.20)

Note: Numbers in parentheses indicate standard deviations.

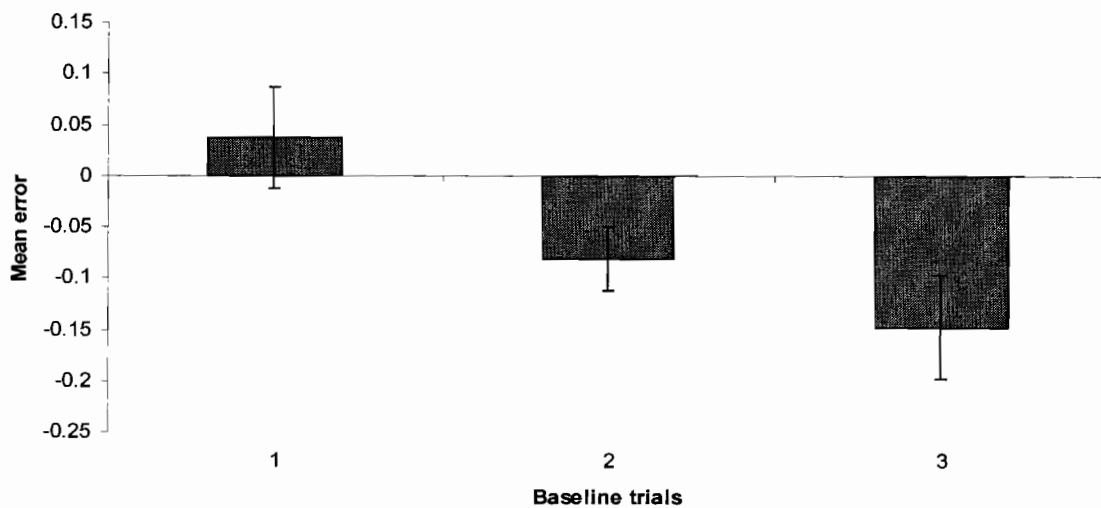


Figure 2. Average error in cm across baseline trials. Negative values indicate error left of center and positive values indicate error right of center. Error bars are +/- 1 SE

*Training*

Errors in cm for the training data for the line bisection task and the line bisection with feedback groups were calculated the exact same way they were calculated for the baseline trials. Dot pointing error was determined using the X coordinates from the stimulus dot and using the X coordinates for the performance dot and converting them to the algebraic system. After obtaining these new X coordinates, we then subtracted the difference between the two and then converted this value from pixels to cm the same way all other data has been.

To account for a priori line bisection biases, the three baseline trials were averaged and these scores were subtracted from the training trials of the line bisection and line bisection with feedback groups. Also, the 60 training trials were divided into 10 blocks of 6 trials each. The results of those who trained on left-shifting prisms were analyzed by reversing the sign of the responses in order to combine the data with that from the right-shifting prisms (Welch et al., 1993). We ran a MANOVA with prism displacement (left vs. right) and training type (line bisection, line bisection with feedback, and pointing task) as between-groups variables and block (one – ten) as within-groups variables.

Table 2. Average training error across training blocks by, training condition and prism displacement

Training Block	Prism Shift	Training Condition		
		Feed	None	Center
T1	Left	0.69 (0.59)	1.05 (0.64)	0.70 (0.43)
	Right	0.74 (0.37)	1.29 (1.64)	0.75 (0.88)
T2	Left	0.11 (0.22)	0.43 (0.35)	0.16 (0.17)
	Right	0.23 (0.17)	0.59 (1.59)	0.35 (0.37)
T3	Left	0.11 (0.28)	0.32 (0.32)	0.04 (0.15)
	Right	0.16 (0.20)	0.30 (1.20)	0.26 (0.24)
T4	Left	0.02 (0.24)	0.34 (0.32)	0.10 (0.12)
	Right	0.19 (0.28)	0.13 (0.80)	0.24 (0.32)
T5	Left	0.00 (0.19)	-0.10 (1.21)	0.04 (-0.14)
	Right	0.12 (0.20)	-0.14 (0.45)	0.19 (0.23)
T6	Left	-0.01 (0.17)	0.24 (0.26)	0.02 (0.11)
	Right	0.16 (0.27)	-0.22 (0.40)	0.13 (0.28)
T7	Left	-0.03 (0.16)	0.13 (0.28)	-0.02 (0.14)
	Right	0.10 (0.15)	-0.27 (0.38)	0.10 (0.25)
T8	Left	-0.02 (0.25)	0.12 (0.33)	-0.02 (0.29)
	Right	0.07 (0.20)	-0.33 (0.39)	0.03 (0.14)
T9	Left	-0.05 (0.18)	0.14 (0.40)	-0.05 (0.14)
	Right	0.02 (0.20)	-0.25 (0.44)	0.08 (0.27)
T10	Left	-0.08 (0.24)	0.02 (0.34)	-0.04 (0.08)
	Right	0.03 (0.24)	-0.33 (0.38)	0.07 (0.31)

Note: Numbers in parentheses indicate standard deviations

It was hypothesized that the participants' errors would decrease across blocks of training and that the dot-pointing and line bisection with feedback groups would demonstrate similar performance which would be greater than that of the line bisection without feedback group. As hypothesized, the analysis revealed a main effect of block in which the participants' errors decreased across blocks of training,  $F(9, 58) = 11.54$ ,  $\eta^2 = 0.64$  (see Figure 3; see table 2). Contrary to the hypothesis that the line bisection with feedback and the dot-pointing groups would have superior performance to the line bisection without feedback group, there were no significant effects of training group,  $F < 1.32$ ,  $p = 0.88$ . As hypothesized, there was also no difference in training based on direction of prism displacement,  $p = 0.89$ .

Although across the blocks of trials the average scores did not produce any significant differences between groups, there appeared to be more variability in the responses for the line bisection without feedback group. The standard deviations for each of the groups in trials one and ten appear in Table 3. To assess whether the variability differed among the groups we used a Levine's Test for Equality of Variances, which revealed that the group that received no feedback in the line bisection task varied more in training errors in the first block of trials than both the line bisection with feedback,  $t(46) = -2.54$ , and dot pointing groups,  $t(46) = -0.57$ . This effect was also present in the last block of training trials as well: the line bisection without feedback group had more variability than the line bisection with feedback,  $t(46) = -1.989$ , and dot pointing groups,  $t(46) = 2.393$ . These results show that the line bisection without feedback group in the first block of trials were less consistent in their responses than in the line bisection without feedback and dot pointing. This is an expected result because in motor skill learning feedback, whether intrinsic or augmented, aids performance; thus, when there is some deficit of feedback, the performance will be more variable than with it (Bernier, Chua, Franks, & Khan, 2006).

Table 3. Average standard deviations of training blocks 1 and 10 for each training task group

	Training Condition		
	Feed	None	Dot
TB1	0.48	1.22	0.68
TB2	0.24	0.4	0.23

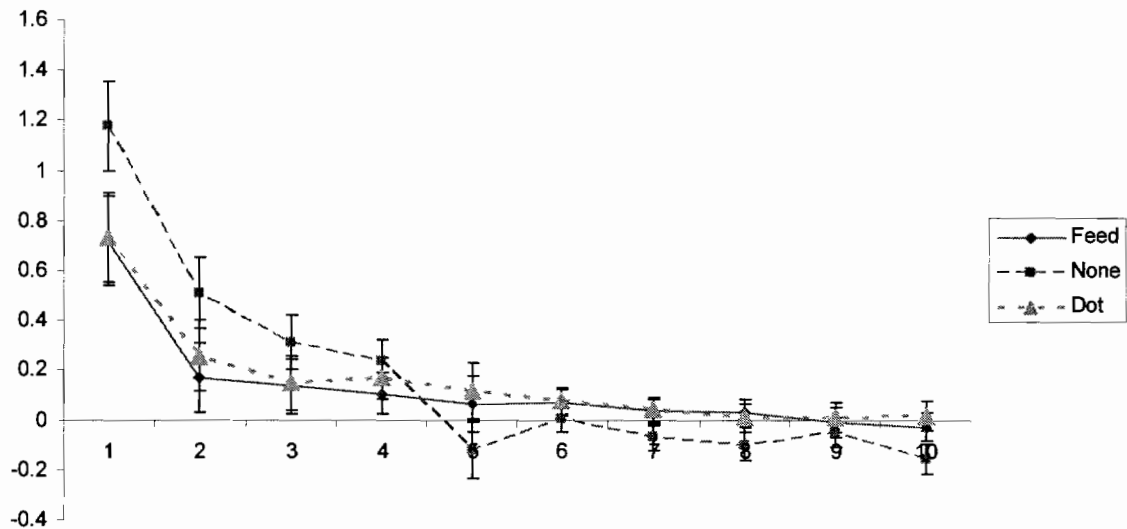


Figure 3. Average error for participants across blocks of training trials by training groups. Positive values are in the direction of the prism displacement, while negative values are in the direction opposite the prism displacement. Error bars are  $\pm 1$  S.E.

### *Aftereffects*

*Proprioception Straight Ahead.* The aftereffects for the proprioceptive pointing task were calculated exactly the same as for the baseline performance. It was expected that all participants would have aftereffects in the direction opposite the prism displacement when compared to their baseline performance and that there would be no differences between groups in the amount of shift from the baseline performance. A MANOVA was used with proprioception trial (baseline and aftereffects) as the within groups factor, and training groups (line bisection with feedback, line bisection without feedback and dot pointing) and prism displacement (left and right) as between-groups factors. The MANOVA revealed an interaction between the proprioceptive trial and training groups,  $F(2,66) = 3.71$   $\eta^2 = 0.10$  (see figure 5). This analysis was followed up by simple main effects tests for each training group, which revealed significant differences between the baseline and aftereffects trials for both the no feedback group

and the dot pointing group,  $F(1,23) = 26.72$ ,  $\eta^2 = 0.54$  and  $F(1,23) = 7.05$ ,  $\eta^2 = 0.23$  respectively. There were however, no significant differences between baseline and aftereffects performances for the feedback group  $F < 0.13$ . This is most likely due to the baseline leftward bias observed in this group (see figure 4). There was no effect of which prism direction the participants trained with  $F < 0.64$ .

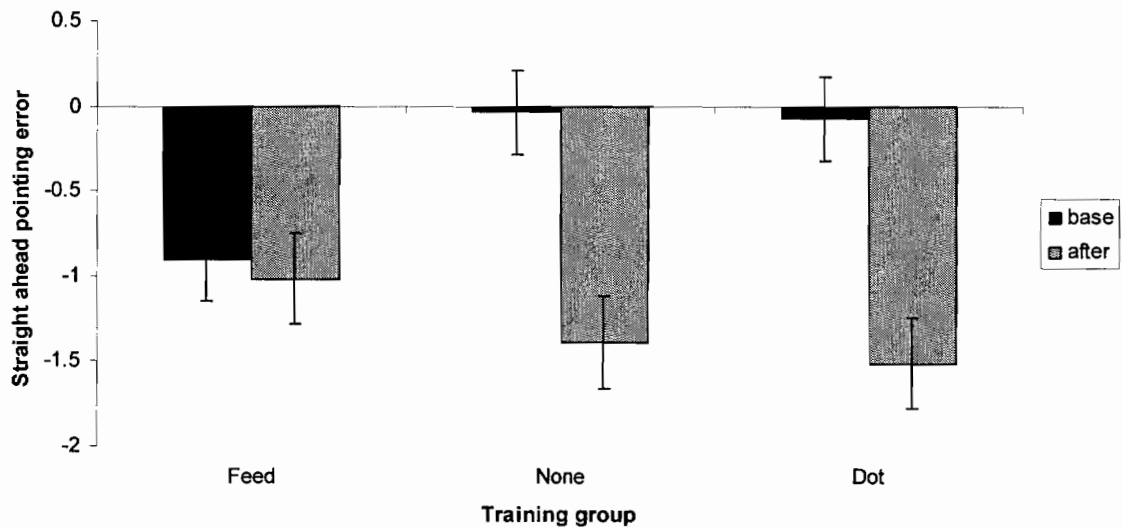


Figure 4. Straight ahead proprioception pointing. The more negative value means that the participant erred more left of center. Error bars are  $\pm 1 SE$

*Line Bisection.* Aftereffects scores were created the same way line bisection scores for the baseline trials were made. After computing individual aftereffects scores in cm we subtracted the average of the baseline performance from the individual aftereffects performances, yielding 3 aftereffects scores per participant. This was done for all participants regardless of training group. Leftward-shifting prisms were analyzed by reversing the sign of the responses in order to combine the data (Welch et al., 1993). Note that unlike the training error, greater aftereffects error indicates greater learning of the new visuomotor adaptation. In this paradigm we expected that line bisection with feedback would produce the most aftereffects and line bisection without feedback would

produce fewer aftereffects. The dot pointing task would produce the least aftereffects because it was the most dissimilar training task compared to the line bisection testing task. We also predicted there would be equal aftereffects for both left and right shifting prisms. We expected that line bisection with feedback would have the most aftereffects and that there would be no differences between prism directions in aftereffects. We ran a MANOVA with prism displacement (left vs. right) and prism training task (line bisection, line bisection with feedback, and pointing task) as between-subjects variables and trials (one – three) as within-subjects variables. Table 4 depicts the aftereffects error in line bisection across all treatment conditions.

Table 4. Mean line bisection aftereffects scores by training group and prism displacement

Aftereffects Trial	Prism Shift	Training Condition		
		Feed	None	Dot
1	left	-0.59 (0.29)	-0.71 (0.71)	-0.59 (0.65)
	right	-0.55 (0.56)	-0.74 (0.54)	-0.42 (0.47)
2	left	-0.19 (0.41)	-0.20 (0.41)	-0.19 (0.41)
	right	-0.56 (0.67)	-0.62 (0.40)	-0.44 (0.40)
3	left	-0.32 (0.22)	-0.08 (0.41)	-0.15 (0.36)
	right	-0.21 (0.47)	-0.48 (0.49)	-0.35 (0.40)

The analysis revealed a main effect of trial in which the participants' errors post training decreased,  $F(2,132) = 19.522$ ,  $\eta^2 = 0.34$ ; and, contrary to both my hypotheses and previous results, the analysis revealed an interaction between prism direction and aftereffects trials,  $F(2,65) = 5.69$ ,  $\eta^2 = 0.15$  (see Figure 5), and no other effects. This interaction was followed up with simple main effects tests, which revealed that in trial 2, there was a significant difference between those who trained on the left-shifting prisms,



versus those who trained on the right-shifting prisms,  $F(1,71) = 10.06$ ,  $\eta^2 = 0.64$ , where those who trained with the right-shifting prism had a larger error in the direction opposite the prism displacement. Trials 1 and 3 did not yield any significant difference between groups,  $F(1,71) = 2.86$ , respectively. Both right- and left-shifting prisms had aftereffects in the direction opposite prism displacement (see table 4). Right-shifting prisms maintained longer aftereffects over more trials than left-shifting prisms.

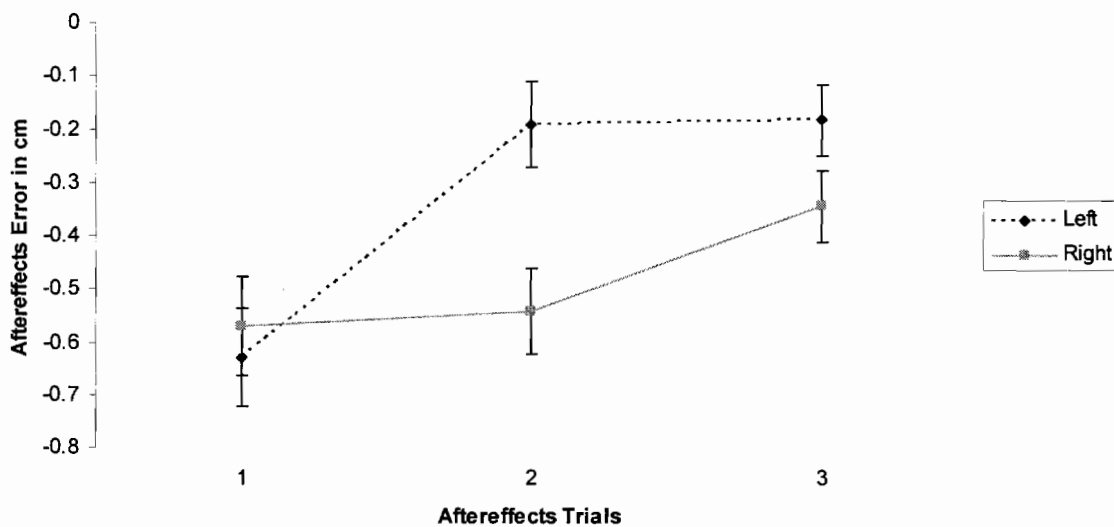


Figure 5. Average error in cm by prism displacement across aftereffects trials. The greater the negative error, the more aftereffects. Error bars are +/- 1 SE

### Post-Experimental Survey

The post-experimental survey used two yes-or-no questions in order to determine whether participants were using a strategy during the experiment. The first yes-or-no question asked if the participant used a strategy to overcome the prism displacement: 29 of the 72 participants reported an answer of yes. The second yes-or-no question asked: “After noticing you made an error, did you aim your pointing movements in the opposite direction?” Forty-three of the 72 participants reported yes to this question. The number

of participants who responded “yes” to each question was broken down by training group (see Table 5).

Table 5. Number of participants who responded “yes” to each post-experimental survey question by training condition

		Training		
		Feed	None	Dot
Question 1	Left	6	4	3
	Right	7	6	3
Question 2	Left	7	8	6
	Right	9	7	6

Following each question, if a participant answered yes, he or she was asked to describe their answer. While the surveys were given to the participants in order to determine whether or not they used a strategy during the prism adaptation training, there was no consistent definition used for “strategy.” For example, one participant reported yes that he or she was using a strategy but explained this strategy as, “I tried to mark the center of the line every time, and when I missed, I just tried again on the next one.” While this was taken by the participant as a strategy, the experimenter would merely classify this as performing the task as requested. This made the analysis of the results based on the use of strategy not possible. Also, a few participants self-corrected during the experiment, changing the trajectory of their hands at the last possible second just before making contact with the screen. While they reported that they understood the directions of the experiment, they attempted to be as accurate as possible on every trial and sacrificed making a ballistic movement in exchange for being correct.

## Discussion

The goal of this investigation was to determine the viability of using prism adaptation to induce neglect while controlling for potential confounds associated with previous reports (Colent et al., 2000; Berberovic & Mattingley, 2003; Michel Pisella et al., 2003; Michel, Rossetti, 2003). In this experiment participants trained on either left-shifting or right-shifting prism goggles. I hypothesized there would be a symmetrical bias and equal aftereffects for both directions of prism shifts. The results showed symmetrical adaptation to the prism training; however, the right shifting prisms induced longer lasting aftereffects than left shifting prisms. The results are opposite the findings of previous studies which reported perceptual aftereffects only for left-shifting prisms (Berberovic & Mattingley, 2003; Colent, et al., 2000; Michel, Pisella et a., 2003). I also hypothesized that the line bisection with augmented feedback would facilitate prism adaptation and induce longer lasting aftereffects than prism adaptation training with line bisection without feedback. I found that there were no differences in the aftereffects of the different training groups.

This experiment essentially examined whether the type of prism adaptation training (i.e. dot pointing versus line bisection) or the availability of feedback (intrinsic or augmented) was more important. As healthy controls have difficulty with generalization in prism adaptation, then it could be that having training tasks and testing tasks being similar is more important. However, if aftereffects to the prism displacement are determined by the accuracy of performance in the training task, then it is more important to have the most accurate information being presented to the performer. The results showed that the availability of feedback did not impact the performance of the

participants for the aftereffects. Based on the current results, aftereffects may be more dependent on training with a task that is similar to the testing task for healthy individuals.

Participants' training with right-shifting prisms maintained longer lasting aftereffects than those with left-shifting prisms across the aftereffects trials. The performance of both groups were comparable in training since there was a decrease in error across training trials, implying that visuomotor learning occurs in both directions of prism displacement. These findings are contrary to previous studies in which only leftward shifting prisms produce generalizable aftereffects (Colent et al., 2000; Berberovic & Mattingley, 2003, Michel, Pisella, et al. 2003). The inconsistency with previous literature shows that stating left shifting prisms can be used to model spatial neglect may be premature as a claim. It may also be premature to claim that right shifting prisms cannot produce generalizable aftereffects. Since in this study left-shifting prisms did not produce as long lasting aftereffects, more research is required to investigate these claims.

The reason for left-shifting prisms produced less rightward aftereffects may be that since healthy individuals have a natural leftward bias (Jewel & McCourt, 2000), then shifting their vision to the left may not lead to as much of an adaptation than shifting to the right. When attempting to compensate for a leftward displacement, they may not be changing their movements as much to the right as they would for a rightward displacement, since they have a tendency to err both visually and proprioceptively to the left of center anyway. While this tendency to err leftward was accounted for by subtracting out their baseline performance, this a priori bias could lead to less visuomotor learning than if participants were to fully overcome the prism displacement and mark the

line in the exact center. If there were less visuomotor learning from left shifting prisms, then there would be fewer aftereffects.

In this experiment it was expected that the participants in the line bisection task with feedback group would make fewer errors in the direction of the prism displacement in the training phase, and have the most aftereffects when compared to the group training without feedback. There were no differences in training or aftereffects independent of the task that was used to adapt the participants to the prism displacement. All training groups produced similar aftereffects showing no differences in visuomotor learning. This indicates that having external feedback may not facilitate adaptation any more than without it; also, the fact that there is less intrinsic feedback in the line bisection task may have no impact on performance in visuomotor learning. There may, however, be other factors involved in this issue.

The lack of difference in aftereffects could also mean that participants were using a strategy and not learning the new set of visuomotor coordinates. The post-experimental questionnaire attempted to assess whether participants were using a strategy. It was not possible however, to analyze scores based on strategy because each participant when basing their interpretation of their performance appeared to be using a different definition strategy. This resulted in too much variation in answers of their descriptions of strategies used. There were, however, more participants in the feedback group who reported using a strategy. This may indicate that the nature of the line bisection with feedback task is more prone to the use of a strategy since the line was always presented in the same location. Plus, the external feedback allowed for an exact knowledge of the location of the line, which would always be in the same location. However, there were no

differences between groups and since it was not possible to analyze scores based on strategy due to the variability of answers, it is unlikely that strategy had any more of an effect on any particular group

This experiment investigated the role of feedback in prism adaptation training tasks and although the mean differences between training groups indicated no differences in visuomotor learning, there were differences in the variability of the training trials between groups. The line bisection with no feedback group had more variability in responses during the first block and last block of prism training trials when compared to the feedback and dot pointing groups. Both the dot pointing and the feedback groups had comparable variability in training patterns. The differences in the variability between the no feedback and other groups are most likely due to reduced intrinsic feedback in the traditional line bisection task. While this task does have some relative intrinsic feedback, the ability for a person to improve her performance based on errors is decreased when exact error is not known. This is well a known fact in motor skill where intrinsic feedback works best, but performance can still receive some aid from augmented (Bernier, Chua, Franks, & Khan, 2006). While there were no significant differences in aftereffects from training groups, the differences in the variability did demonstrate that training performance was aided with more exact feedback and perhaps this is a direction for future research with different perceptual tests other than the line bisection task.

This experiment investigated the role of feedback and it was found that there were differences between groups in the proprioception straight ahead pointing baseline trial. The line bisection with feedback pointed more to the left than the no feedback and dot pointing groups. While this baseline difference between groups could indicate an a priori

bias amongst these participants, the effect did not carry over to the line bisection baseline performance. This bias did not seem to have any effect on the prism training or aftereffects either, as there were no differences amongst training groups.

While this experiment revealed several findings for prism adaptation and feedback, the experimental design did have several drawbacks. One of the drawbacks to the design of this study is the possible aforementioned use of strategy in the participants. If participants were adjusting their aim to a different spatial location, then they were not adapting to the prism displacement. Visuomotor learning is based on learning from error, so to use a strategy would hurt aftereffects performance as the participant did not learn anything. The use of strategy would lead to fewer aftereffects, and since aftereffects are the main measure of prism adaptation, this would hinder the results. Young, healthy, non-brain injured individuals are more likely to use a strategy than an older healthy individual and neglect patients (Fernandez-Ruiz, Hall, Vergara, Diaz, 2000). Both the neglect patient and older participant would be much less likely to attempt to use a strategy and more likely to overcome and adapt to the prism displacement. Also, a few participants self-corrected during the experiment, changing the trajectory of their hands at the last possible second just before making contact with the screen. While they reported that they understood the directions of the experiment, they attempted to be as accurate as possible on every trial and sacrificed making a ballistic movement in exchange for being correct. This could be corrected by using a harder paradigm such as eliminating all view of hand movement up until contact with the computer screen, or doing an analysis based on continuous movement.

Since explicit, top-down strategy does not facilitate prism adaptation and aftereffects, this may indicate that top-down feedback may not be effective in training with prism adaptation. There has been evidence that spatial neglect is affected by bottom up feedback (Rode, Klos, Courtois-Jacquin, Rossetti, and Pisella, 2006). The use of more a knowledge based strategy may not be effective in prism adaptation. If this is the case than prism adaptation training is not going to be affected by augmented feedback, and it will induce no more aftereffects than any other form of training for prism adaptation.

The results of this study have shown that future research is needed to investigate both asymmetries of prism adaptation, and the role of feedback. One possible future direction for this study could be to replicate this experiment with using both manual tasks and purely perceptual tasks when testing the aftereffects. This experiment tested for aftereffects on manual line bisection tasks, so it would be interesting to look for these results in both manual and perceptual tasks. Perhaps the external feedback has more of an effect on the perceptual tasks. Also since strategy was one possible hindrance to this experiment, one could attempt to prevent the use of a strategy, by attempting to force the participant to do the task faster. Another possibility to reduce strategy would be to randomize the location on the screen of the lines for the line bisection task during prism training.

In conclusion, I found that right-shifting prisms induced greater and longer lasting aftereffects on a perceptual motor task, which was in contrast to previous literature, which stated that only left shifting prisms induced generalizable aftereffects (Berberovic & Mattingley, 2003; Colent, et al., 2000; Michel, Pisella et al., 2003). These results should prompt further research on the topic of the symmetry of prism adaptation in



healthy individuals. This experiment also found that line bisection with feedback produced similar aftereffects to line bisection without feedback and dot pointing. This result indicates that prism adaptation on the line bisection task may not be facilitated by augmented feedback, and should prompt further research into the role of feedback in prism adaptation.

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Appendix

Visuomotor Adaptation with Augmented Feedback Experimental Protocol

- 1) Participants will sit and be centered in front of a touch screen computer. They will sit a little more than arms reach from the wall.
- 2) Participants will be asked to hold their hand in front of their chest. They will be asked to close their eyes.
- 3) They will then be told to point their hand out directly in front of them and touch the screen.

*["Please hold your hand in front of your chest and close your eyes."]*

Once participant has his or her eyes closed

*["Please point straight ahead and touch the screen."]*

- 4) The error will be marked in terms of coordinates in the computer and be converted so that to the left of zero as negative and to the right of zero as positive.
- 5) The participant will sit with the two free-standing poles to either side of them with the bar resting on the two C-clamps directly in front of their chest. The bar will be adjusted to below their chin, so as to occlude the view of their hand.
- 6) The participant will then put on the placebo goggles
- 7) A single horizontal line measuring 20cm x 0.3cm will appear on the screen in front of them.
- 8) The participant will be instructed to move their hand from directly in front of their chest and make a rapid single movement to reach out to the line and bisect it by drawing a perpendicular line through its center with their finger and bring their hand back to in front of their chest.

*["Please mark the line in the center in a single quick movement in which you draw a line perpendicular to the one presented. Please do this as accurately as you can, but make it a single movement once you have begun the task."]*

- 9) The computer will score the error of the mark made from the actual center of the line in pixel coordinates which will be later converted into mm with left of center being designated as negative and right of center being designated as positive.
- 10) The line will disappear and will be replaced by a new line after 2 seconds.
- 11) This process will be repeated three times, totaling 3 baseline trials.

*[“Please take the goggles off and replace them with these goggles”]*

12) The participant will then put on the prism goggles. These goggles will shift their vision either leftward or rightward by 12.4 degrees.

13) Participants will be split into three training groups counterbalanced between the training tasks.

- a) If participants are in the line bisection training group:
  - i) Participants will repeat the line bisection procedure as above with the computer screen
  - ii) Process will be repeated for a total of 60 trials.
  - iii) At the conclusion of 60 training trials, participants will be asked to remove the prism goggles and put back on the placebo goggles.
  - iv) Participants will repeat the same baseline line bisection procedure for a total of 3 trials.

*[“Please repeat the same procedure as before with marking the center of the line in a single quick movement”*

*“You are now going to take the prism goggles off and place these goggles back on.”*

*“Now you are going to mark the center of the line with the pen just as we did before in a single quick movement.”]*

- b) If participants are in the line bisection with feedback group:
  - i) Participants will repeat the line bisection procedure as above with the computer screen, but at the conclusion of every trial the computer will provide immediate feedback to the actual location of center.
  - ii) Process will be repeated for a total of 60 trials.
  - iii) At the conclusion of 60 training trials, participants will be asked to remove the prism goggles and put back on the placebo goggles.
  - iv) Participants will repeat the same baseline line bisection procedure for a total of 3 trials.

*[“You are going to repeat the same procedure as before, however this time after each time you mark where you think the center of the line is, the computer is going to display the actual center of the line for a half a second.”*

*“You are now going to take the prism goggles off and place these goggles back on.”*

*“Now you are going to mark the center of the line with the pen just as we did before in a single quick movement.”]*

- c) If participants are in the dot pointing training group:
  - i) Participants will be presented with a dot on the computer screen and asked to point at the dot in a single rapid movement with their hands beginning in front of their chest.
  - ii) After touching the screen the dot will be removed and error will be measured by the computer in terms of lateral distance from the target dot measured in

pixels to be later converted into mm, with left of center being considered negative and right of center being considered positive.

- iii) A new dot will appear in another location on the screen for the participant to point to.
- iv) This process will be repeated for a total of 60 trials.
- v) At the conclusion of 60 training trials, participants will be asked to remove the prism goggles and put back on the placebo goggles.
- vi) Participants will repeat the same baseline line bisection procedure for a total of 3 trials.

*["Now the computer is going to display a dot to you. In the same fashion that you were marking the line, as before, you are going to point to the dot displayed. So begin with your hand in front of your chest and in a single quick movement, point to the dot, and then return your hand back to in front of your chest."]*

*"You are now going to take the prism goggles off and place these goggles back on."*

*"Now you are going to mark the center of the line with the pen just as we did before in a single quick movement."]*

- 14) Participants will complete the experiment by copying the procedure for the proprioception task in which they pointed straight ahead with their eyes closed to the computer screen.

*["Please hold your hand in front of your chest and close your eyes."]*

Once participant has his or her eyes closed

*"Please point straight ahead and touch the screen."]*