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Can Virtual Reality Mimic Prism Adaptation?

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Abstract

Prism adaptation therapy is a commonly-used treatment for the neurological disorder, spatial neglect, in which patients are unable to attend to or interact with one side of their visual field. Prism adaptation induces a sensory mismatch between patients' motor movements and visual input through the use of prisms which shift the visual field either to the left or right. Patients have to adjust their motor movements to align with their shifted visual input. This process results in aftereffects that alleviate the symptoms of neglect. The goal of this research is to determine whether a virtual reality version of prism adaptation can alter the spatial attention of healthy, undergraduate students in a way similar to traditional prism adaptation methods. The present study replicated a physical prism adaptation study performed by Goedert, LeBlanc, Tsai & Barrett (2010), but using virtual reality induced visual-motor mismatch. Twenty-four participants performed line bisection and straight-ahead pointing tasks both before and after spending 15 minutes in a virtual reality game in which they poked the noses of cartoon circus animals. The virtual reality environment induced a mismatch between the visual location of the hand and the actual physical location of the hand either in the leftward or rightward direction. Results for the straight-ahead pointing task replicated those of Goedert et al. (2010). Among individuals with a leftward baseline bias of spatial attention the magnitude of the aftereffects was greater for a leftward versus a rightward shift in the virtual reality environment. Performance on the line bisection task, however, was unaffected by the virtual reality manipulation Despite this, this work has implications for the extent to which the vision and action systems respond to virtually reality in a way similar to actual physical reality.

1. Introduction

After learning how to perform motor movements to interact with our environment when we are infants, doing so in daily life seems to come naturally. While reaching out an arm and grasping for a cup can be done with ease, the cognitive processes behind this action are far more complex than one may think. Appropriately acting upon the environment requires the precise coordination between multiple processing systems within the brain.

The main systems that are involved in the production of motor movements are the visual-motor system and the proprioceptive-motor system (Redding & Wallace, 2001). The visual-motor system allows people to use visual input to appropriately initiate motor movements, as well as correct any errors that may occur during the movements. This system works by comparing the visually perceived location of the target object with the visually perceived location of the effector (e.g., the arm) in reference to the visual field. For example, if someone were to reach for a pencil off a desk, this system would help them figure out if they should move their arm more to the left or right based on where they see the object within that space. On the other hand, the proprioceptive-motor system allows people to use proprioceptive input to appropriately initiate motor movements, as well as correct any errors that may occur during the movements. This system works by comparing the visually perceived location of the target object with the proprioceptively perceived location of the effector in reference to the trunk of the body. An example of this would be someone reaching for a doorknob without looking. Most doorknobs land at the same location on a person's body. Because of this, the proprioceptive input of the arm being bent so that the hand is at about waist height allows the person to be able to easily grab the knob.

The everyday, simple actions that we perform actually require a lot of cognitive processing in order to ensure that all systems are functioning properly. The proprioceptive- and visual-motor systems must work together to ensure correct movements. Being that simple motor movements involve multiple systems working together, there is room for dysfunction to occur if one or more of these systems are not working properly.

One way in which these systems can become dysfunctional is by way of a stroke. A possible consequence of having a stroke is a neurological impairment known as unilateral neglect (De Luca et al., 2017). Patients with unilateral neglect are unable to attend to or interact with stimuli on one half of their visual field. Typically, an impairment can be found in the right hemisphere of the patient's brain. This means that the left side of their visual field is impacted as the affected side of space is contralateral to where the brain damage is found. It is also possible for the left hemisphere and the brain and therefore the right side of space to be affected. However, left unilateral neglect is far more common (Ringman et al., 2004). Patients with unilateral neglect often have difficulty caring for themselves as a result of the perceptive and behavioral deficits caused by the neglect. For example, a person with unilateral neglect may not eat enough. They might eat the food on the right side of their plate and think that they had eaten everything. However, because they do not acknowledge the food on the left side, the patient is only eating half of their food and is unaware of this.

Unilateral neglect is a complex neurological impairment that involves many processing systems (De Luca et al., 2017). Because of this, identifying a universally effective treatment is also a complex task. Although much has yet to be discovered in regard to what the exact mechanisms behind this unilateral neglect are, as well as what is the best way to treat it, a promising treatment that has been developed is prism adaptation therapy (Rossetti et al., 1998). In addition to being used as a treatment for spatial neglect, prism adaptation has also been used to alter the spatial attention of neurologically healthy individuals. Although, prism adaptation has less of an effect on the spatial attention of healthy individuals than it does on neurologically impaired individuals. The effects of adaptation are stronger and last longer in impaired populations (Michel et al., 2007). This increased effect is beneficial in the treatment of unilateral neglect.

Prism adaptation therapy involves patients wearing goggles fitted with prisms. The prisms cause the visual field of the patient to be laterally shifted either to the left or right depending on what hemisphere is impaired. The patient is then asked to interact with their environment, usually by pointing at targets or marking the subjective midline of objects or lines appearing in their visual field (Jewell & McCourt, 2000). This shift causes a sensory mismatch between the proprioceptive-motor and visual-motor systems discussed previously. A patient with left neglect would be treated with right shifting prisms. While wearing the goggles, the patient will visually perceive the target object as being to the right of where the object is physically located due to the shift of the prisms. The visual-motor system will direct the patient's hand to point to the right as that is where the object is seen. However, the patient will be alerted that this is the incorrect response because when they complete the action, they will see that they are not touching the object. Their proprioceptive-motor system will then have to adjust to the shifted visual input. In order to touch the object that appears in the right of their visual field, the patient will actually have to point more leftward, in the direction opposite of the shift, because that is where the object is in physical space. With repeated pointing trials during prism exposure, people will begin to make less errors as their proprioceptive-motor and visual-motor systems adapt to the mismatched inputs.

The adjusted motor movements produced during prism adaptation remain for a period of time even after patients and neurologically unimpaired individuals stop wearing the prisms. These shifted motor movements following the removal of the prisms are known as aftereffects. These aftereffects are what make prism adaptation therapy an effective treatment for unilateral neglect. One way in which aftereffects are measured is by asking patients to perform a proprioceptive straight-ahead pointing task. During this task, individuals are asked to close their eyes and point to the position they believe is directly in front of the midline of their bodies. When completing this task prior to prism exposure, impaired individuals will point to the left or right of their midline while healthy individuals will accurately point at their midline, or slightly off to the left. Unlike during exposure, here making errors in pointing is the desired behavior for unimpaired individuals. Following exposure to right shifting prisms, pointing to the left of the midline indicates that adaptation was achieved. Although for healthy participants aftereffects are represented as errors in straight-ahead pointing, for neurologically impaired individuals, aftereffects would take the form of a more accurate performance. This increased accuracy in pointing at their midline translates to more accurate interactions with the environment for impaired individuals. In both instances, the farther a person errs from their baseline performance, in the direction opposite of the prismatic shift, demonstrates a stronger adaptation.

As with any other treatment, prism adaptation has its pros and cons and the resulting motor shift or aftereffect can be affected in different ways by various manipulations. Among the pros is the idea that the simple pointing tasks completed during prism exposure generalizes their adjusted motor response to other, more involved tasks (Fortis et al., 2010; Rossetti et al., 1998). Fortis et al. (2010) demonstrated this by comparing the aftereffects of two different groups of patients. One group completed straight-ahead pointing trials prior to, during, and after adaptation to a 10° optical shift to the right. The other group completed pointing trials only during adaptation and completed visuomotor tasks, such as collecting coins off a table, prior to and after adaptation to the same degree shift. The results of this study show that there was no significant difference between the aftereffects seen in both groups. Additionally, Rossetti et al. (1998) showed patients who completed pointing trials during prism adaptation therapy with a 10° optical shift to the right were more likely to successfully complete a battery of neurological tests, such as copying a simple drawing, than were their counterparts in the control condition. These findings for the generalization of aftereffects demonstrate how prism adaptation therapy can have an impact on the motor movements and visual field representations of unilateral neglect patients that far exceeds the simple motor movement of pointing.

Although prism adaptation therapy seems to be a highly effective treatment for unilateral neglect, studies done show that there are numerous factors that can influence the aftereffects of the patients. One factor that can affect the aftereffects seen from prism adaptation is whether or not people are aware of the visual shift that is being induced. Research indicates that a displacement of up to 2° lies below people's perceptible threshold, meaning they are unaware of this degree of shift (Hatada et al., 2006). As mentioned previously, the degree of lateral shift that is typically induced is 10° which leads to healthy individuals being able to easily detect the shift being induced. These conditions may have served to weaken the produced aftereffects as it has been demonstrated that being unaware of the shift produces larger aftereffects (Hatada et al., 2006; Michel et al., 2007). Michel et al. (2007) conducted an experiment in which two groups of neurologically unimpaired individuals underwent prism adaptation. However, for one group the visual shift increased gradually, with a minimum shift of 2° and a maximum shift of 10° achieved by increasing increments of 2°. The other group experienced the 10° visual shift immediately . The results showed that, although the participants experiencing the immediate 10° shift completed more adaptation trials with the maximum degree of shift, the aftereffects of this group were weaker than that of the group which had their shift gradually increased. This experiment indicates the importance of awareness on the strength of aftereffects.

In an attempt to uncover what impact awareness has on the time course of prism exposure and its aftereffects, Hatada et al. (2006) included a gradual shift as a factor they believed would be critical in producing prolonged aftereffects. The study consisted of having participants point at two targets in fixed positions while wearing prisms. Similar to the procedure of Michel et al. (2007), the optical shift was gradually induced. The minimum shift was 2° and the maximum was 15° which was achieved through increasing increments of 2° and a 3° increase for the final step. The results indicated that the gradual increase of the lateral shift served to produce aftereffects that last longer than those of conventional prism adaptation therapy. Aftereffects here were measured immediately following exposure, 2, 4, and 6 hours after as well as 1, 2, 3, and 7 days after. Aftereffects were strongest immediately following exposure and showed a gradual decrease for all subsequent measures up to 6 hours after. However, after the sixth hour, the aftereffects began to increase and on the seventh day returned to levels comparable to those achieved immediately after prism exposure. These studies indicate that awareness is an important factor that, if minimized, could produce larger, more long-lasting aftereffects.

Another factor that impacts the aftereffects is the degree of lateral shift that is induced (Gammeri et al., 2018). While 10° is a frequent optical deviation used, greater shifts may produce greater aftereffects (Gammeri et al., 2018). Gammeri et al. (2018) compared the aftereffects of groups exposed to varying rightward lateral shifts. This experiment did not use conventional prism adaptation, however. Instead, a virtual reality version of prism adaptation was employed. The same sensory mismatch between the visual-motor and proprioceptive-motor systems, which is crucial to prism adaptation therapy, was attained, this was just done in a virtual environment. There was a control group which had no lateral shift, a group that had a 10° shift to the right, a group that had a 20° shift to the right, and a group that had a 30° shift to the right. All groups were meant to be unaware of these shifts, so they were increased gradually throughout the trials. Gammeri et al. (2018) found that the aftereffects of the group exposed to the 30° were stronger than those of any other group. This study serves to demonstrate that achieving greater extents of optical shifts may also be a crucial factor to promote increased aftereffects. Additionally, it is interesting to note that typically healthy individuals do not demonstrate strong aftereffects following adaptation to rightward shifting prisms. The fact that aftereffects were seen only in the 30° group despite this trend further highlights the importance of the extent of shift induced on aftereffects.

One other notable point is that pre-existing spatial biases, known as pseudoneglect, may also impact the aftereffects produced (Goedert et al., 2010). Young individuals largely present with a left-ward spatial bias that is thought to negatively impact the aftereffects produced by prism exposure (Goedert et al., 2010). This information is the reason the aftereffects seen in Gammeri et al. (2018) were so surprising. In order to examine this interaction further, Goedert et al. (2010) ran two experiments. The procedures of the two experiments were similar, but the subject pools looked at differed between them. The general procedure required participants to be exposed to both left and right shifting prisms on two separate days. On each of the sessions, participants completed a line bisection task with no visual shift, which was meant to measure if a pre-existing spatial bias was present. Following this they completed pointing tasks while wearing prisms that had a 12.4° shift. After the adaptation trials, participants completed more line bisection tasks, again without a visual shift which was meant to measure the aftereffects achieved. In the first experiment the performance between young and aged individuals was compared because aged individuals are thought to lack pre-existing spatial biases (Goedert et al., 2010). In the second experiment, only young individuals were included, but a larger portion of these participants were right-biased at baseline when compared to the young participants in Experiment 1. This was done to ensure that spatial biases were likely the reason for the findings rather than age. Goedert et al. (2010) demonstrated that healthy, young individuals tend to have pre-existing spatial biases that are to the left of true center and that these biases do, in fact, potentially cause the aftereffects produced by rightward-shifting prisms to be weakened. This bit of information is interesting especially when compared to the results found by Gammeri et al. (2018). Gammeri found significant adaptation to rightward shifting prisms despite this trend of pseudoneglect. This then begs the question what is different about his work and why?

Recently, researchers have been looking into ways in which to recreate prism adaptation therapy that would help to address these factors, and, much like in the case of Gammeri et al. (2018), possibly remove the negative impacts of these factors all together. Transforming conventional prism adaptation into a virtual reality format may provide an answer. Work done by Ramos, Horning, & Wilms (2019) provides additional evidence to what was found by Gammeri et al. (2018) in support of this claim. Ramos et al. (2019) conducted research that directly compared the effects of conventional prism adaptation with two different virtual reality forms. In this study, participants were exposed to all three forms of prism adaptation, each of which induced a rightward lateral shift. The conventional prisms induced a 8.7 degree shift and the virtual reality conditions induced a 10 degree shift. Prior to, during, and following each adaptation condition, participants were asked to point at the center of target lines that appeared in the left, center, and right spaces of a computer screen or a simulated virtual screen. The results indicated that adaptation for both virtual reality conditions was stronger than the adaptation produced by the conventional method. Although these results may be attributed to the differing degrees of shift, as it is known greater shifts produce greater aftereffects (Gammeri et al., 2018), the implications of this research are still important to note. It may not be the case that virtual reality adaptation produces greater aftereffects, but at the very least this research indicates that virtual reality prism adaptation is just as impactful as conventional methods and may afford researchers and clinicians with more control.

It is already evident that virtual reality adaptation therapy can address the important interacting factors of awareness of lateral shift, pre-existing spatial biases, as well as the extent of the shift induced. When it comes to gradually inducing the visual shift to decrease awareness, although it is possible with conventional prism goggles, it is accomplished much easier in virtual reality. With conventional prisms, a gradual increase in the prismatic shift is often achieved by having patients wear numerous goggles with varying shifts, causing them to take breaks in order to replace the weaker prisms with incrementally stronger ones (Michel et al., 2007). This method requires a lot of time and attention on the side of the researcher and participant as well. With virtual reality however, the increase can be accomplished by simply programming the virtual environment to do so. In addition, the shift achieved by conventional goggles can only go so far before adverse side effects start to emerge (Gammeri et al., 2018). Virtual reality allows for a greater shift to be reached without producing these side effects. It is likely that the gradual increase of the shift paired with the greater extent of the shift achieved through virtual reality adaptation were enough to negate the effects of pre-existing biases of the participants. Research looking into how effective virtual reality adaptation therapy is relatively scarce as this is a new area of interest. However, it is easy to see that the results that have been yielded so far warrant the continuation of such research.

In the present study, I attempted to combine the methods and procedures seen in both Gammeri et al. (2018) as well as Goedert et al. (2010) to add to this growing body of research. The present research most closely resembled that of experiment 2 completed by Goedert et al. (2010), but it employed a virtual reality adaptation program as was the case in Gammeri et al. (2018). Being that it has been shown that pre-existing spatial biases can affect the aftereffects produced by adaptation in the sense that people demonstrate stronger aftereffects following adaptation to shifts in the same direction as their biases, I attempted to see if I can recreate this pattern. Based on the results of Gammeri et al. (2018) and Ramos et al. (2019), it can be assumed that virtual reality adaptation therapy may behave in the same way as traditional prism adaptation therapy. That being said, it was expected that replicating the results found by Goedert et al. (2010) would be possible in a virtual reality format. If this is pattern is found, it could imply that something about the study done by Gammeri et al. (2018) was amiss, or if this pattern is not found, it could imply that something about virtual reality adaptation, perhaps the ability to induce a greater shift, makes the effects of pre-existing biases less evident.

2. Methods

2.1 Participants

An a priori power analysis (G*Power 3.1) indicated that in order to achieve a power of 0.85 for detecting the between-within interaction, using an alpha of 0.05, and assuming a small to medium effect size, 122 participants would be necessary. However, due to the closure of campus caused by the COVID-19 pandemic, only 24 undergraduate students participated in the study. The participants were at least 18 years of age and volunteered to participate for course credit. The participants all had normal or corrected-to-normal vision and unrestricted use of both of their arms and hands.

2.2 Design

The experiment had a 2 (visual shift: left, right) X 2 (assessment time: pre, post) X 2 (pre-existing bias: left, right) mixed design, with pre-existing bias a between-groups variable while visual shift and assessment time were within-groups variables. The dependent variables were the performance of participants on proprioceptive pointing and line bisections tasks completed before (pre) and after (post) virtual reality adaptation exposure.

2.3 Procedure

Participants underwent adaptation to both left- and right- shifts in the virtual environment. They completed the adaptation trials on two separate days separated by at least 48 hours. They were exposed to either the left or right shift on the first day, and the opposite on the second. The shift they were exposed to on their first visit was randomly selected. On the first day, participants were seated in front of a computer and were asked to read and sign an informed consent form. Following this, participants completed a baseline proprioceptive pointing task in physical space, as well as a pen-and-paper, baseline line bisection task, again in physical space. These tasks were in place to assess pre-existing spatial biases. For the proprioceptive pointing task, participants sat across from the researcher with about three feet of space between them. They were separated by a 12" high 24" wide Plexiglas panel which had a ruler on the side of the researcher. Participants were asked to close their eyes and use their dominant hand point to where they believed was directly in front of their midline. The researcher used the ruler to measure their deviation from true center. For the line bisection task, participants were presented with six sheets of paper, one at a time, in the left, middle, and right spaces of a desk. The lines presented in middle space were placed approximately 59.1 cm straight ahead of the midline of each participant. The lines presented in left and right spaces were 29.8 cm to the left or right of the midline. Each sheet of paper had a horizontal line on it. Participants were asked to mark the center of each line with a pen. Their deviation from the true center was recorded.

Following this, participants were fitted with an HTC Vive virtual reality headset. The headset had a leap motion system attached to it. This allowed participants to interact with the environment with their hands rather than a controller. The virtual reality program that participants were exposed to was a custom proprietary program that was developed for the Kessler Foundation Research Center. The program first had each participant complete a calibration task to ensured that their hand was accurately represented in the virtual environment. Once the system was calibrated, participants underwent the virtual reality adaptation task. This task was set in a virtual circus and consisted of having participants poke the noses of cartoon circus animals that ran into the center of the circus ring and jumped onto a platform. The shift for this task was gradually induced over 100 straight-ahead pointing trials. In order to assess the effects of the adaptation, the participants completed a post-adaptation proprioceptive pointing task as well as a line bisection task. The procedures for the post-adaptation trials was the same as that of the baseline trials.

The procedures for the second day were largely the same as the first with a few exceptions. Participants did not need to fill out another informed consent form as they did so on the first day. Additionally, participants were asked to complete an awareness survey as well as the Edinburgh Handedness Survey at the completion of the second day. These measures were included to ensure participants were not aware of the shift being induced, in addition to seeing if handedness did in fact interact with pre-existing biases and therefore the aftereffects produced. The last thing that was done was the debriefing of the participants.

3. Results

Although the target sample size was 120 participants, due to the COVID-19 outbreak, data collection was suspended. This suspension resulted in a small sample size overall ($N = 24$) as well as an even smaller number of participants who were able to return for their second session ($N = 9$). For this reason, given the data collected, it was decided to perform the analyses looking at the independent variables as between subjects rather than within, so only data from the first sessions were analyzed. An additional consequence of the suspension of data collection was that only a small number of participants ($N = 2$) presented with a rightward spatial bias at baseline. This is an expected trend as most healthy young individuals tend to have a leftward bias at baseline (Jewell & McCourt, 2000). Due to the small number of rightward biased individuals, I analyzed only the leftward biased individuals ($N = 22$).

3.1 Baseline Biases

Baseline biases were determined by looking at the average performance of participants over 6 trials of the line bisection task completed prior to the virtual reality adaptation exposure. For the line bisection task, negative measures indicated a leftward deviation from center, and positive measures indicated a rightward deviation from center. This means that a participant with a leftward baseline bias would have a negative average across the 6 trials of the line bisection task.

3.2 Aftereffects

Proprioceptive Pointing Task

Participants' baseline and post-exposure performance on the proprioceptive pointing task were compared in order to analyze the magnitude of the aftereffects produced. Additionally, data were also compared based on the shift the participants were exposed to (left, right). Figure 1 shows the average proprioceptive pointing error for left bias participants as a function of shift exposure and assessment time. This graph indicates that left biased individuals exhibited greater aftereffects following exposure to a left shift than they did following exposure to a right shift. An ANOVA revealed a main effect of shift as well as a shift by assessment time (pre, post) interaction [$F(1,38) = 5.71, p < 0.05$, and $F(1,38) = 13.16, p < 0.001$, respectively]. These findings indicate that the aftereffects produced depended on the shift left biased participants were exposed to. This is consistent with the results found by Goedert et al. (2010) that were meant to be replicated in the present study.

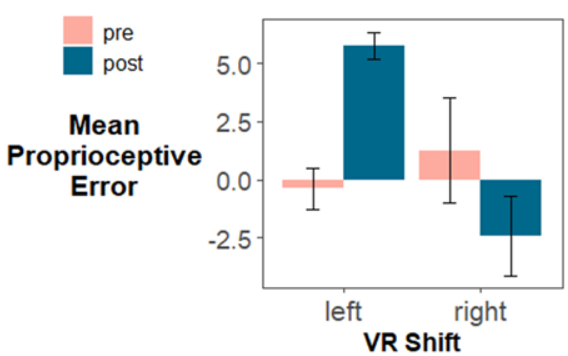

Figure 1. Average proprioceptive pointing error for left biased participants prior to and following virtual reality adaptation exposure as a function of shift exposure.

Line Bisection Task

Like the proprioceptive pointing task, analyses for the line bisection task, looked at the factors of assessment time and shift exposure. However, unlike the proprioceptive pointing task, the factor of line placement (left, center, right) was also included. Figure 2 shows the average line bisection error made by participants prior to and following virtual reality adaptation for each line placement for both shift conditions. An ANOVA revealed a main effect of line placement as well as a line placement by shift interaction [$F(2,126) = 5.38, p < 0.01$, and $F(2,126) = 3.12, p < 0.05$, respectively]. These results indicate that where the line was placed did have an impact on participants' performance. However, because there was no main effect for shift found, these results are not consistent with what was expected based on Goedert et al. (2010). Participants performance on their baseline line bisection task and their post-exposure line bisection task was similar across the two shift exposure conditions. It was expected that the difference between participants pre- and post-exposure performance would have been greater for the left shift condition. Additionally, there doesn't seem to be an effect of shift at all for the line bisection task. Not only was the pre- and post-exposure performance similar between the two groups, but the pre- and post-exposure performance was similar within each group as well. Although there was an interaction found between line placement and shift, it is likely that this was due to some outliers in the data that were a result of issues with random assignment.

4. Discussion

Given the known information about prism adaptation in both traditional and virtual reality forms, this study set out to find evidence to support that virtual reality forms are in fact comparable to traditional methods. To do this the work of Goedert et al. (2010) was replicated using a

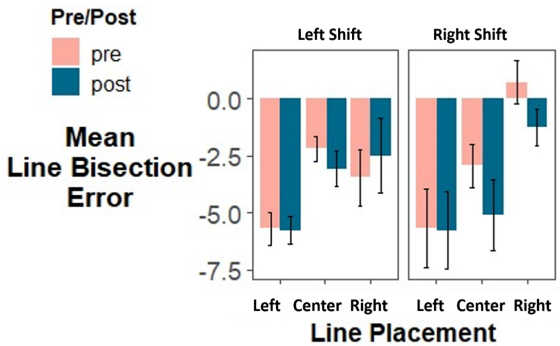

Figure 2. Average line bisection error for pre- and post-exposure as a function of line placement and shift.

virtual reality form of prism adaptation. The results yielded from this study do suggest that this may be the case. The present study was able to replicate the proprioceptive pointing performance of left biased individuals that was seen in Goedert et al. (2010) This performance indicated that the shift participants were exposed to did have an impact on the aftereffects produced. However, this same effect was not found for the line bisection task. It is likely that because these data points were distributed across three different spatial locations, rather than concentrated at just one, there was not enough power to reveal an effect. Although, due to data collection being suspended, the analyses run for this study differed from those done in Goedert et al. (2010), these results still provide evidence that suggests additional investigations be done in this area of research. There is something to be said regarding the results found from this study. Even with a small sample size and differing analyses, significant results that, for the most part, supported the initial hypothesis still emerged.

4.1 Limitations

It is important to note again that the results yielded were for left biased individuals only. No conclusive statements can be made about the effect of pre-existing spatial biases on the magnitude of aftereffects overall as the effects of a rightward baseline bias were not analyzed. As touched upon previously, a major limitation of this study was the small sample size due to suspended data collection. It could be the case that if there were a larger sample size, the impacts of a rightward baseline bias could have been analyzed. Additionally, even if the number of right biased individuals remained small in spite of a larger sample size, it may have been beneficial for the analyses performed for the line bisection task if more data points were included. Perhaps the expected trend would have emerged. These statements are obviously just speculation, but the continuation of this research, based on the preliminary results seems warranted.

In some ways the suspension of data collection can be seen as a positive. This unforeseen circumstance allowed for additional time to mull over the results and find possible ways of improving the current study for future research. After some consideration, it was suggested that perhaps the interaction found was a result of tactile feedback rather than of pre-existing spatial biases as was the initial thought. The participants all completed this study with the use of their right hand. It could be the case that, following exposure to a rightward shift, participants were less likely to err more leftward because they were able to feel their arm pushing up against their body. This may have served as a cue for participants that may have impacted their performance. When participants were exposed to a leftward shift, they did not have any feedback when erring more rightward. This may be a possible, alternative explanation for the interaction found. In order to see if this explanation holds any merit, it would be interesting to adapt the procedure so that participants use both hands rather than just their right.

4.2 Implications

After looking at the results of this study, it becomes clear that virtual reality adaptation may pave the way for more effective spatial neglect treatments in the future. Of course, the research done in this area is still relatively sparse, but it has gained some traction in recent years. The research that has been done provides additional evidence in support of this claim. A study done by Ramos et al. (2019) employed two virtual reality forms of prism adaptation that altered the visual field of participants in ways that differed from how it was done in the current study. Despite this, their results still indicated that both forms of virtual reality prism adaptation produced aftereffects in healthy adults that were comparable to that of the traditional method. This highlights a possible benefit of virtual reality prism adaptation. Virtual reality may afford researchers and clinicians with the opportunity to have more control over the specific conditions set for adaptation. Additional support for this claim comes from the work done by Gammeri et al. (2018). This study indicated that a varying degree of shift could be induced within the virtual environment. Although this can also be done for traditional methods as well, it is done with much more ease in a virtual setting. Rather than having to deal with different pairs of prisms that are different weights, this same effect can be produced with a few clicks of a mouse in a virtual environment. It is also easier to induce gradual shifts in a virtual environment than it is with physical prisms.

It is known that there are many factors that impact aftereffects. The magnitude of the shift being induced (Gammeri et al., 2018), and the awareness of the shift (Hatada et al., 2006; Michel et al., 2007) are factors that can negatively impact aftereffects if they are not treated properly. Virtual reality seems to have the potential to aid researchers and clinicians in finding the best ways in which to maximize the aftereffects produced. Because it has been demonstrated that prism adaptation can be simulated in virtual reality in a number of ways, this may mean there are more factors that can be manipulated in virtual reality than there are in physical space. This affords researchers and clinicians additional control which may in turn result in a better treatment for spatial neglect. These potential benefits are just the few that have been discovered and tested so far. Research in this area has a long way to go in order to tap into all of the ways virtual reality could be used to improve the treatment of spatial neglect.

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