PRISM ADAPTATION IN THE REHABILITATION OF PATIENTS WITH UNILATERAL SPATIAL INATTENTION

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Abstract

Unilateral spatial inattention (USI), also known as neglect, can occur subsequent to acquired brain injury, including traumatic brain injury or stroke. USI can be present with or without a visual field defect, as determined by standard clinical methods. Patients with USI can show varying degrees of spontaneous recovery within the first three months post-brain injury, but for many patients, USI symptoms remain severe. Yoked prism has long been used in optometric management of visual field defects, including USI. In this regard recent research shows that prism adaptation (PA) to a rightward displacement of the visual field improves USI symptoms. Not only does PA ameliorate neglect on a sensorimotor level, it also influences higher spatial representation and cognition. Its effects continue for up to six months with two weeks of twenty minute per day PA training. Though PA's mechanism is not fully understood, the posterior parietal cortex and cerebellum are implicated in the process. PA has huge implications for USI rehabilitation; its non-invasive nature makes it an effective rehabilitation tool to ameliorate both visuo-motor responses and higher levels of spatial representation and cognition in USI patients.

Key Words

acquired brain injury, cerebral vascular accident, hemi-inattention, neglect, posterior parietal cortex, prism, prism aftereffect, stroke, traumatic brain injury, unilateral spatial inattention, yoked prism

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INTRODUCTION

Unilateral spatial inattention (USI), also known as neglect, can occur subsequent to acquired brain injury, including traumatic brain injury or cerebral vascular accident (CVA).[1,2] USI can occur with or without a visual field defect, as determined by standard clinical methods**,** and most often results from injury to the right posterior parietal cortex.[2] Since the posterior parietal cortex is responsible for the cognitive representation of space, insult to this cortical area can result in a defect on the patient's contralateral side. While USI can occur after damage to either the left or right hemisphere, it is much more common after right brain damage. This is probably because in most people, the right hemisphere is dominant for control of spatial attention.[3] Most of the literature regarding USI limits discussion to USI consequent to right hemispheric damage from a CVA. For that reason, the following discussion focuses on USI that occurs on the patient's left side after damage to the right hemisphere of the brain.

USI can manifest itself in a patient's personal space, peri-personal and extra-personal space as proposed by Stein,[4] and elaborated by Suchoff and Ciuffreda.[2] Table 1 summarizes the behavioral consequences of USI in each of these spaces.

In the majority of patients, the signs and symptoms of neglect disappear spontaneously within six weeks to three months after the CVA. Patients with USI can show varying degrees of spontaneous improvement in the days, weeks, or months after insult to the posterior parietal cortex occurs. However, for many patients, USI symptoms remain severe.[2,5] Persistence of USI symptoms beyond three months has been linked with poor functional and motor prognosis. Over 25% of patients do not experience complete spontaneous recovery beyond this point.[6] Their symptoms of neglect can persist for several years, and their quality of life is greatly diminished.[5,7]

For those who do not experience complete spontaneous resolution of USI symptoms, rehabilitation is prescribed. USI is particularly difficult to rehabilitate due to the fact that the patient is unaware of the problem.[8] Rehabilitation specialists have employed both bottom-up and top-down strategies to increase patients' ability to

Table 1: Spatial areas where USI may occur and behaviors associated with each area.[2,4]

Area of Space	Description	Impairment of	Associated Behaviors
Personal	Poor awareness of body schema	Body awareness	Anosognosia or asomatognosia Extinction, hemianaesthesia, hemiparesis, hemiplegia Body schema unawareness Instability Akinesia, hypokinesia, hypometria, impersistence
Peri-personal	External world *within* arms' reach	Difficulty making purposeful motor actions such as: o Reaching for objects o Manipulating objects	Misses food on one side of plate Fails to comb hair, apply make-up, shave one side of face Unable to copy or spontaneously draw one side of a picture Unaware of objects placed on one side of table When dressing, fails to put limbs into shirt and pants on one side
Extra-personal	External world *further* than arms' reach	Visual and Auditory space Visual motor control Visual localization Visual representation of world	Unresponsive to sounds, objects, people on affected side Collides with objects and people which "pop up" suddenly out of nowhere

function. Procedures based on bottom-up mechanisms like sensory-based (vestibular, optokinetic, transcutaneous, and proprioceptive) stimulation have shown enhanced representation of contra-lesional space in USI patients. However, their effects are relatively short-lived.[6] Top-down strategies, where patients have been trained to direct their attention voluntarily toward the neglected side, have had longer-lasting effects. However, these improvements were specific to the particular tasks trained.[6] In essence, many patients trained with top-down strategies have developed efficient splinter skills that they have difficulty translating to real-life daily activities. It is becoming more apparent that both top-down and bottom-up strategies may need to be used in conjunction with each other to produce the most effective and longest-lasting rehabilitation regimen.

As part of the multi-discipline rehabilitation team, optometrists have long used full field yoked prism in their management of visual field defects with and without USI. This technique optically shifts visual space from the non-seeing area into the intact field.[2,9-11] It also reduces the need for the patient to scan into the unseen area of inattention. Recent studies have shown that there may be more to the effect of yoked prism than just the optical shift they create. This is particularly evident in patients who experienced improvement in their USI symptoms after adaptation to base left yoked prism. Adaptation to a rightward displacement of the visual field (using base left yoked prism) has been shown to contribute to a reduction of USI symptoms. This effect remains even after the yoked prism is removed from the patient.

In 1998, Rossetti et al showed that prism adaptation (PA) ameliorated the shift of the subjective midline, the patient's perception of the "straight ahead" direction, to the right. (This type of PA is different than other phenomena of the same name that are discussed in the next section.) All patients in this study improved both in their manual body-midline demonstration and their performance on classical neuropsychological tests of neglect.[12] This study brought the concept of using PA as a treatment for left neglect to the forefront. The apparent beneficial effect of PA, paired with its non-invasive nature, make it an exciting and viable treatment option for USI patients. A multitude of further investigations have been done to determine why PA works, and how long its effects may last. The purpose of this paper is to review the current literature in an attempt to answer the following questions:

- What is PA and how is it done?
- Which symptoms of neglect are improved by PA?
- How long do the effects of PA last?
- By what mechanism(s) does PA work and what neural structures are involved?
- What are the implications for PA in terms of USI rehabilitation?

The research reviewed here was conducted by neuro-psychologists, and the terminology will reflect their non-optometric background. Nevertheless, it becomes evident that these studies have profound clinical implications for optometric management of patients with USI.

DISCUSSION

What is Prism Adaptation?

When optometrists use the term "prism adaptation," it may call to mind something known as the *prism adaptation test* used when performing a strabismus evaluation.[13] Another meaning refers to the effectiveness of compensatory prism with heterophoric patients.[14] In the research studies discussed in this paper, PA refers to something quite different: exposing patients to yoked prism while they perform a series of pointing movements toward a visual target.[5-7,12,15] Even after the adaptation is completed and yoked prism is removed, patients retain improvements in the signs of USI for a period of time.

The shift of patients' subjective concept of "straight ahead" to the right is a classic manifestation of left hemispatial neglect.[12] They tend to re-assign their subjective idea of straight ahead toward their right, away from their neglected field, so as to split their intact field down the middle. The first part of Rossetti et al's[12] study investigated how neglect patients adapted to a 10° lateral shift of their visual field with yoked prism, as measured by a manual pointing task. Eight patients with neglect and five control patients were blindfolded and asked to point straight ahead both before and after a brief period of PA. Before yoked prism exposure, all of the patients with neglect showed pointing errors that were shifted to the right. After adaptation to the base-left yoked prism, both neglect and control patients showed leftward shifts when asked to point straight ahead. For the patients with neglect, this leftward shift countered their original rightward shift in subjective straight ahead pointing, thus bringing their shifted idea of straight ahead back toward center. This first part of Rossetti et al's[12] experiment gave evidence that patients with neglect can adapt to a prismatic rightward shift of their visual field, and that PA promotes a close-to-normal post-test on a manual pointing task.

Rossetti et al[12] next set out to determine if this adaptation could improve performance on a series of neuropsychological tests of neglect including: line bisection, line cancellation, copying a simple five-item drawing, drawing a daisy from memory, and reading simple text. The neglect patients were randomly assigned to either the experimental group (who wore base-left yoked prism goggles) or the control group (wearing neutral goggles with flat, thick lenses). Both groups were given the battery of neuropsychological tests before prism adaptation (pre-test), immediately after removing the goggles (post-test), and two hours after removing the goggles (late test). Results of this study showed a statistically-significant performance improvement between the pre-test and both the post-test and late-test of the experimental group. The control group did not show a significant difference in performance. Thus, the dramatic improvement in performance on the neuropsychological battery was evident immediately after prism exposure, and was maintained fully two hours later.

This study also provides evidence that PA may in fact act upon higher levels of cognitive spatial representation. This concept of improving clinical neglect symptoms with PA began a flurry of research into the specifics of PA, and Rossetti's results have been repeated by additional researchers.[5,6,8,15-21] Based on the effectiveness of PA on neglect symptoms, subsequent research focused on more clearly defining which symptoms of neglect were improved after PA, how PA improves these symptoms, and how long the effects last.

Which Symptoms of Neglect Are Improved by PA?

Rosetti et al's results led researchers to consider that PA may stimulate neuroplasticity related to multisensory integration and spatial representation.[12] It was unclear whether PA's effects were limited to tasks involving a visuo-motor response such as line cancellation, line bisection, drawing a daisy from memory, and other tests that Rossetti et al used.

Rode et al[21] explored whether PA could act on more than just a sensory-motor level, by improving mental space representation in patients with neglect. Their research used four subjects (two neglect patients and two control subjects) and involved testing the effect of PA on neglect at three levels: a sensory-motor level (a manual pointing task), an intermediate level (drawing a daisy from memory), and a motor-free cognitive level (a mental imagery task). In the latter task patients were asked to picture a map of France in their mind and name as many towns as possible on the map within two minutes. The subjects were exposed for three minutes to base left yoked prism which produced a 10 degree shift in their visual field. Results for each of the three testing areas were recorded before PA (pre-test), immediately after PA (post-test), and 24 hours later (late-test). On the sensory-motor level, the manual pointing test showed a leftward shift in all patients. The intermediate level task (daisy drawing) showed improved performance for both neglect patients in the post-test, with some retained improvement after 24 hours in the late-test. The mental imagery task also produced an interesting result. In the post-test, both patients with neglect showed an increase in the number of towns they had named on the left side of the map. In the late-test, the patients with neglect still showed an increase in the total number of towns named, but it was not statistically significant. Both control subjects showed no difference in the number of towns named before, immediately after, and 24 hours after PA. Rode et al's results indicate that PA may also stimulate cognitive processes in patients with neglect, at least at the level of mental imagery representation.

In another such study, Frassinetti et al[8] investigated which spatial areas of neglect PA improved: far space (extra-personal), near space (peri-personal), and/or on the patient himself (personal space). The results of this study indicate that neglect in far space and near space were significantly improved after PA, as tested through a room description test and object-reaching test respectively. In order to determine if the effect of PA on neglect existed in personal space, the Fluff Test was performed. This involved attaching pieces of adhesive paper to various body parts on the left side of a patient's body while the patient is blindfolded. The blindfold was then removed and the patient was asked to remove all the pieces of paper attached to his clothes in two minutes. The number of pieces not removed was recorded. The procedure was repeated after PA. The results indicated that neglect in personal space was not significantly improved.

Frassinetti et al's[8] study is important because the results confirm Rossetti[12] and Rode's[21] previous findings that PA is not only instrumental in the recalibration of visuomotor coordination, but that it also extends to affect the organization of higher levels of spatial representation. It is interesting that neglect symptoms in personal space did not show improvement. This might indicate that the cognition of personal space is not a higher-order visual spatial function. In terms of visual development, this possibility makes sense since the understanding of oneself occurs before one is able to understand the external visual world.[22] The improvement in neglect is evident not only in tasks that require a visuomotor response, but also in those that require only a non-visuomotor response (room description test and reading test).

Results of a study by McIntosh et al[23] support this idea that PA improves performance in both of these types of tasks. They reported that PA improved neglect on a haptic circle centering task, a spatial task that had no explicit visual component. For this test, the patient was blindfolded, and a 1cm thick square of plastic with a 30cm diameter circular groove cut into it was placed in front of her. The patient was asked to use her right hand to explore the stimulus before the test began by running her finger over the groove. In each experimental trial, the patient's finger was placed in the groove beginning at either North, South, East, or West with respect to her. She then traced around the circle until she reached the starting point, which was marked by the experimenter's finger. When her finger encountered the experimenter's finger, the patient was asked to move her fingertip to the center of the circle. Her accuracy in reaching the geometric center of the circle was recorded. McIntosh et al designed this task to be a tactile version of the line bisection test. They proposed that the patient's improved performance after PA reiterated the idea that PA also improved performance on tasks that were haptic in nature.

In 2006 Rode et al[24] reported on a patient whose spatial dysgraphia improved with PA. Although the report only included one patient, the results further support the aforementioned studies with larger numbers of subjects. All of these studies reinforce the idea that PA works on higher spatial representations in addition to visuo-motor coordination.

Lastly, Serino et al[6] investigated whether the PA's effects were generalized to different visuo-spatial functions. These included different distances from the subject (personal space and extrapersonal space), and different sensory modalities. More specifically, they investigated how PA affected visual exploration, internal visuo-spatial representation, and visuo-spatial competencies in activities of daily living (ADL). They reported that the effects of PA were not limited to tasks performed with the adapted limb (i.e. writing tasks performed with the right hand after that same hand had been used as the pointing hand during PA). Tasks that did not require a motor response also improved including: figure scanning, room description, and reading. ADL such as dialing a telephone, writing an address, sorting coins and telling time also improved after PA. In contrast to Frassinetti et al,[8] Serino et al found that neglect in personal space did improve based on performance of the Fluff Test under both visual and kinesthetic conditions. This indicated that both visual exploration and the patients internal body representation and awareness can also improve after PA. However, Serino et al's research found that PA does not improve neglect symptoms in proprioceptive sensitivity and motor functions.

The optometric application of ground-in yoked prism to improve the patient with USI's ability to be aware of the neglect side and to avert obstacles that may be hidden in this neglected area has previously been proposed.[1,2,10] In this regard the basis is solely the optical effect of the yoked prism. In view of the aforementioned studies, it is evident that yoked prism can do more than simply shift a patient's visual world optically. It not only improves accuracy in pointing tasks but can promote better attention to the neglected side in terms of handwriting, visual imagery, and awareness of one's surroundings.

How Long Do Effects of PA Last?

Another major question in terms of using PA for the rehabilitation of neglect relates to length of its effect. In Rossetti et al's study,[12] patients were exposed for two to five minutes to yoked prism that produced a 10 degree optical shift. The effect of PA lasted for at least two hours. Farne et al[25] found that the same exposure produced PA effects that were still measurable af-

Table 2: Summary of Research Studies Cited		
Study	**Conclusions**	**Duration of Effect**
Rossetti, et al (1998)[12]	PA* improves symptoms of neglect	At least 2 hours
Rode, et al (2001)[21]	Improvement on imagery tasks with no manual component	At least 24 hours
Farne, et al (2002)[25]	Disappearance of prism after-effect and re-appearance of neglect occurred around the same time	At least 24 hours
Frassinetti, et al (2002)[8]	Neglect symptoms improved only in patients who showed after-effect; Improvement noted in extra-personal and peri-personal space, but not personal space	At least 5 weeks
McIntosh, et al (2002)[23]	Improvement on spatial judgment task with no explicit visual component	At least 3 months
Angeli, et al (2004)[28]	PA reduced oculomotor bias and improved reading in neglect patients	Not assessed
Luaute, et al (2006)[18]	Brain regions involved in neglect: right cerebellum, left thalamus, left temporo-occipital cortex, left medial temporal cortex, right posterior parietal cortex	Not assessed
Newport and Jackson (2006)[17]	PA involves two mechanisms: spatial realignment (cerebellum) and strategic control (posterior parietal cortex)	Not assessed
Rode, et al (2006)[24]	PA improves spatial dysgraphia	24-48 hours
Serino, et al (2006)[15]	Resetting of oculomotor system leads to neglect improvement	At least 3 months
Serino, et al (2007)[6]	Improvement noted in extra-personal, peri-personal, and personal space; no improvement for motor functions	At least 6 months
Luaute, et al (2009)[16]	During PA: anterior intraparietal sulcus involved in error detection; parieto-occipital sulcus involved in error correction; cerebellum plays a role in spatial realignment	Not assessed
Serino, et al (2009)[5]	Visuomotor training alone may partially improve neglect, but PA improves neglect to a significantly greater degree	6 months

*PA: Prism Adaptation

ter 24 hours. Rode et al[21] demonstrated that some effects could be retained as long as 24 hours after prism exposure in their study on PA and visual imagery, though the effects were not as robust as immediately after prism exposure. Frassinetti et al[8] worked with subjects who underwent two weeks of PA training for 20 minutes each day, and found that the effects of PA lasted for at least five weeks. Serino et al[5] followed the same schedule of 20-minute treatments daily for five weeks, and found that their subjects retained the beneficial result up to six months post-treatment.

Clinically speaking, the relatively long-lasting effect of PA that has been reported may impact how optometrists care for patients with USI. As an alternative to prescribing ground-in yoked prism for full time wear for patients with neglect, vision therapy including 20 minutes of PA daily for five-week periods, repeated every six months may be just as beneficial. It could serve as an adjunct to vision therapy techniques that stress scanning into the affected field, or computer based therapies.[26] Table 2 summarizes the studies cited to this point.

By What Mechanism(s) Does PA Work and What Neural Structures Are Involved?

At one time, researchers considered the after-effect (improved pointing after the yoked prism was removed) to be of paramount importance in the amelioration of neglect with PA.[27] Studies such as Farne et al[25] and Rossetti et al[12] showed that prism after-effect and improvement in neglect symptoms disappeared around the same time. Thus, it seemed to follow that the after-effect was causing the improvement in neglect symptoms. However, Frassinetti[8] found that improvement on visuo-spatial tasks lasted for five weeks, while the prism after-effect vanished within 84 hours.

Angeli et al[28] postulated that PA effectually resets ocular scanning behavior by inducing a leftward eye deviation, which then facilitates the patient's exploration of the neglected side of visual space. Their study showed that a single PA session reduced the rightward oculomotor bias in patients with left neglect and improved reading. Angeli et al[28] held that as patients try to compensate for the mismatch between what they are seeing and where their hand is pointing by making a leftward correction in pointing. They are then forced to shift both their eyes and visual attention toward the side of their neglect (left side). Serino et al[15] described similar results.

In their most recent study, Serino et al[6] compared the effect of PA to visuomotor training without induced PA. They termed the latter condition, neutral pointing (NP). These researchers hoped to determine whether intense visuomotor training without PA promoted some recovery of neglect symptoms. The results indicated that while repetition of pointing movements toward visual stimuli improved performance in both the PA group and the NP group, the improvement was significantly larger in the group that used PA. Additionally, after the initial study, the NP group was subjected to PA, which resulted in further amelioration of neglect symptoms. These results are not entirely surprising since NP can facilitate a patient's improvement in his/her hand-eye coordination through repetition. As hand/eye coordination improves, visuomotor coordination improves. The patient will show improvement in pointing the eyes where the hand is located in space, even if it may, at times, point into the area of neglect. In this way pointing alone can provide some improvement in attention to the affected side. The patient becomes better able to point accurately even when the target encroaches upon or moves into the neglected area.

Serino et al[5] also cited the role of repetitious pointing in PA. They stated further that it employs an even more effective mechanism. It also provides a sensory-motor mismatch for which the patient needs to compensate. During PA the patient experiences a visual field shift. The patient then promotes a compensatory shift of the eye and hand reference frames to the left. As this compensation is made, error reduction (during PA) and after-effect (after PA) occur, showing that PA is happening.

It is unclear precisely which neural structures are involved in PA, but current research has proposed new theories. At one time, it was thought that PA occurred due to motor learning in the cerebellum.[17] Lesion studies in both humans and monkeys supported this proposition. Both monkeys with cerebellum ablation and humans with cerebellar lesions did not demonstrate PA.[17] In 1996, Clower et al[29] used positron emission tomography (PET) to directly examine brain areas activated during a

manual pointing task while the subjects wore yoked prism. They found that the posterior parietal cortex was activated. Luaute et al[16,18] produced further evidence to support this proposition. In 2006, Luaute et al used[18] functional imaging PET to examine which brain areas show increased bloodflow during prism adaptation. They found that PA occurs with a modulation of neuron activity in the right cerebellum, left thalamus, left temporo-occipital cortex, right posterior parietal cortex, and left medial temporal lobe. Their results suggest that PA ameliorates left neglect by recruiting intact brain areas that are responsible for controlling visuospatial output through short-term sensorimotor plasticity. Luaute et al[18] believe that PA may improve left neglect through modulation of the cerebral areas used in spatial cognition through a bottom-up signal generated by the cerebellum. Two mechanisms may be at play: strategic control generated by the posterior parietal cortex, and realignment by the cerebellum. To further investigate this concept, Luaute et al[16] produced research using event-related functional magnetic resonance imaging (fMRI) to investigate dynamic neural activity over the course of prism exposure and adaptation on healthy subjects. Results showed that in the early phase of prism exposure, the anterior intraparietal sulcus was used in error detection. The parieto-occiptal sulcus was implicated in error correction. During the course of prism exposure and adaptation, activity in the cerebellum progressively increased. This is consistent with the idea that the cerebellum plays a role in realignment, while the posterior parietal cortex is primarily responsible for error reduction and detection. It was also noted that due to the progressive nature of cerebellar activity during PA, the cerebellum may promote neural changes in the superior temporal cortex. The superior temporal cortex was activated during the late phase of PA, suggesting that it could mediate effects of PA on cognitive spatial representations.

Although further research is necessary to determine precisely how PA works to improve left neglect, it seems that more than one mechanism is at play.

CONCLUSION

Though the mechanisms by which PA works are not fully understood, its use has huge implications for the rehabilitation of USI. Not only can patients benefit from a reduction of symptoms and improved function due to PA, but a better understanding of how PA improves neglect symptoms could shed light on what causes neglect. This leads to better treatment modalities in the future. PA is a non-invasive treatment for left neglect, and its effects improve not only visuo-motor responses, but higher levels of spatial representation and cognition as well. Clinically, the optometric management of USI has long employed the use of yoked prism. The studies cited in this article suggest that it is more than geometric optics that play a role in the behavioral management of these patients.

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