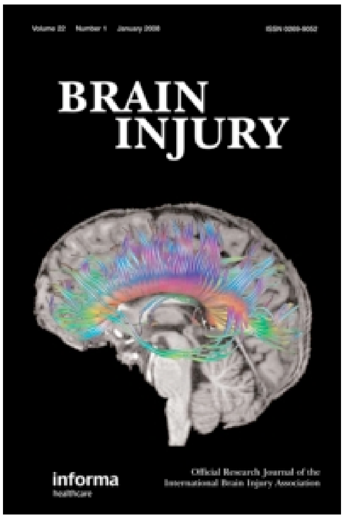

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Modifying postural adaptation following a CVA through prismatic shift of visuo-spatial egocenter

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Abstract

Objective: To demonstrate that Visual Midline Shift Syndrome (VMSS) following a cerebrovascular accident (CVA) can be corrected with yoked prisms.

Research design: This randomized study describes how the use of yoked prisms affects visual midline and documents the influence of yoked prisms on improving postural orientation.

Methods and procedures: Evaluation of VMSS and its correlation with postural lean during ambulation were studied in 30 post-CVA subjects and 30 controls.

Experimental interventions: Yoked prisms were used to treat VMSS by correcting posture and balance.

Outcomes and results: Over 50% of post-CVA subjects showed positive visual midline shift ($p < 0.001$; 95% confidence interval [CI], 0.660.93 for right CVAs and $p = 0.001$; 95% CI, 0.61–0.93 for left CVAs). A statistically significant proportion of those with a positive shift showed a decrease in shift utilizing yoked prisms ($p < 0.001$; 95% CI, 0.73–0.97 for right CVAs and $p = 0.001$; 95% CI, 0.07–0.39 for left CVAs). Additionally, over 50% of CVA subjects developed lean or drift away from hemiparesis and many subjects showed increased weight-bearing on the hemiparetic side with yoked prisms.

Conclusions: Yoked prisms are an effective means of treating VMSS in this population and may be useful in other neurological syndromes with visuo-spatial involvement.

Keywords: *Cerebrovascular accident (CVA), hemiparesis, prisms, vision, visuo-spatial, visual midline, egocenter*

Introduction

Following a cerebrovascular accident (CVA), individuals initially tend to lean toward the side of the hemiparesis. A long-term effect of this condition has been termed Pusher Syndrome. Johannsen et al. [1] showed that there is a severely disturbed perception of body orientation unrelated to vestibular dysfunction (e.g. a sensorimotor mismatch without vestibular dysfunction affecting position sense). This study suggests that it is caused by a disturbed representation of body-space orientation (e.g. spatial organization to maintain upright body position against gravity), in turn affecting leg-trunk orientation and causing a lean into the affected side and a 'push' away from the functional side. However, within the first few weeks many will develop compensations causing a tendency to lean away from the hemiparetic side. The assumption is that this phenomenon has a neurological cause related to the weakness of the paretic side. The significance of this trend is that the lean into the affected side (Pusher's Syndrome) and then the developed compensatory lean away from the affected side is due to a reorganization of information from

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sensorimotor systems in context with weakness from the paretic side.

In addition to leaning away from the paretic side following a CVA, it is also common to have a neglect of one's visuo-spatial awareness on the affected side. Adams and Hurwitz [2] reported that 60% of CVA patients had a unilateral neglect. Furthermore, spatial neglect will cause a postural imbalance, thereby causing weight-bearing asymmetry (e.g. inappropriate body-space orientation causing a lateral shift in perceived concept of upright posture against gravity) [3]. When persons exhibit neglect, not only do they miss seeing objects in the neglected field, but they will often twist and/or lean away from the affected visual field. The twisting or turning of their body will compromise the ability to maintain equal weight displacement between the lateral components of their body. Some individuals will torque their bodies to the extent that they are looking and turning their bodies 90° or greater away from their centre or midline. This deviation in body position is a phenomenon that has been interpreted as related to a lack of attentive awareness regarding a lateral aspect of the visual field. However, consideration that this phenomenon is due to mismatch between the spatial component of the visual process and sensorimotor information may offer greater insight as to its cause.

Rehabilitation following a CVA requires extensive physical and occupational therapy in an attempt to facilitate proprioceptive and spatial awareness on the affected side, through weight-bearing, to improve posture and balance. Feigenson et al. [4] reported that of patients receiving appropriate rehabilitative care, 20% had an increased length of stay related to CVA associated perceptual spatial problems.

Prisms have been demonstrated to have a beneficial effect to improve visually guided action and perception [5, 6] as well as to affect posture among patients with CVAs [7]. Tilikete et al. [8] demonstrated improvement in daily life activities, such as postural balance and spatial orientation through the use of prism adaptation (e.g. the use of prisms to establish visual and sensorimotor awareness of the neglected field). Rode et al. [9] also found improvement in visuo-manual adaptation with prisms, thereby reducing visuo-spatial neglect. This further suggests that the prisms may activate brain functions related to multi-sensory integration.

A prism is a wedge of optical media typically made from plastic, glass or polycarbonate. Prisms are traditionally prescribed in glasses to compensate for a deviation in eye alignment. However, yoked prisms, as used in this study, are not for compensation but instead used to affect position sense and orientation to body space. A prism is shaped with an apex at the thin end and a base at the thick end of the prism. The angle of degree deviates a beam of light such that the image of an object will be shifted a centimetre (cm) per dioptre of prism at a distance of 1 metre (m). For example, five dioptres of prism deviates an image 5 cm at a 1 m distance. A prism shifts an image due to properties that compress space in one direction and expand space in another direction. Yoked prisms expand and compress space equally for both eyes. The expansion and compression of space through the use of yoked prisms becomes the rehabilitative utility to neutralize the sensorimotor distortion caused by mismatch between the affected (paretic) side and the non-affected side.

This study is designed to analyse the distortion in visuo-spatial dysfunctions (e.g. mismatch between visuo-spatial and sensorimotor information affecting position sense) related to hemiparesis and the effects of modifying these dysfunction through use of yoked prisms. Yoked prisms (i.e. two prisms introduced before the eyes with the base or thick ends of the prisms in the same direction) were used to counter the spatial distortion which can cause a shift in an individual's concept of egocentric midline (e.g. a pre-conscious organization through sensorimotor matching of the lateral and anterion-posterior axes related to perceived body centre for position sense).

Physiologic rationale

To explain the role of vision in affecting posture, balance and midline development, Trevarthen and Sperry [10] described vision as a bimodal processing system composed of both focal and ambient vision. The focal visual process is largely concerned with detail discrimination. This component of the visual process isolates on pieces and parts with limited ability to create relationships. It is analogous to seeing the 'trees' but not the 'forest' or, as some persons with traumatic brain injury (TBI) describe, they can see a nose, a lip and an ear but they cannot see a face. The process of focalization is referenced primarily to occipital cortical function. Focalization is supported by the ambient process which relates to spatial orientation (e.g. utilizing the framework of the visuo-spatial environment to match with sensorimotor information for body-space orientation). The ambient system comprises up to 20% of the nerves emanating from both eyes. These nerve fibres relay axons to the midbrain where visual information is matched with kinaesthetic, proprioceptive and vestibular sensorimotor information [11].

Ganglion cells from the retina can be traced from the optic nerve and chiasm to the optic tract where they reach three major destinations: (1) the lateral geniculate body for relay to the visual cortex, (2) the pretectal nucleus concerned with pupillary constriction and (3) the superior colliculus where they merge with input from the sensorimotor system [12]. The superior colliculus receives these nerve fibres from the optic tract through the superior brachium, from the occipital cortex via the optic radiations through the lateral geniculate body and from the spino-tectal tract completing connections with the sensorimotor systems from the spinal cord and medulla. This interaction and matching of retinal and sensorimotor information provides the input for posture, balance, movement and positional orientation [12].

Following this matching effect, a feed-forward mechanism communicates from the midbrain with the occipital cortex and many other areas of the brain to establish a spatial construct of visual domain as well as organization for other higher sensory and cognitive perceptual processes [7, 13]. For example, pre-conscious ambient and sensorimotor matching provides the spatial reference domain that becomes the base or platform for the awareness of higher cognitive processes such as seeing the detail, becoming aware of position sense, localizing a sound, anticipating change such as releasing from a point of visual fixation to another point of regard or to accurately visually track a moving object. From this bimodal model of visual function, the latter two examples are used to demonstrate that quick eye movements (saccades) and pursuit tracking require a balance between the bimodal visual processes. For example, to perform a saccade, simultaneous actions are required. First, one must have spatial anticipation of the destination of the moving object and, secondly, release from the current fixation point. Both of these actions are a function of the ambient visual process. The high velocity movement of the eyes causes a release of the visual image (e.g. the extra-ocular muscles cause what is termed as 'the shearing effect' causing the occipital cortex to cease the visual image during the high velocity movement of a saccade). The ambient process then delivers the eyes to the point of anticipated fixation. A pursuit tracking of a target is accomplished by a fixation (focalization on the moving target) and anticipation of the spatial/temporal trajectory of the target which is accomplished by both a feed-forward of spatial information by the ambient process as well as feed-back regarding temporal information from parietal and frontal lobes. A compromise of the ambient process will cause saccadic fixations to be inaccurate demonstrating over- or under-shooting of the eyes. An example would be losing place during reading tasks which require ambient release from focalization and an ambient spatial shift that accurately delivers fixation to the next word. During pursuits, a jerky quality of eye movements will be noted, often with fixation losses, if over-focalization and a lack of ambient spatial anticipation for following both persist.

Himmelbach et al. [14] demonstrated that involvement of the superior colliculus in visual search tasks supports a dependency of superior colliculi activity on functions beyond oculomotor control and visual processing. A two-visual system model enabled Milner et al. [6] to predict that cortical dorsal streaming mediates normal visual-guided actions, while ventral streaming deals with visual information that is memory-based. Spatial information from the ambient visual process, delivered by the superior colliculus, provides the binding format of the fusion process for integrating the images from the right and left eyes [15].

Padula et al. [16] demonstrated that dysfunction of the ambient visual process interferes with amplitudes of binocular visual evoked potentials. Post Trauma Vision Syndrome (PTVS) was the name given to describe the dysfunction of ambient visual processing yielding over-focalization on detail, which can compromise higher cognitive processing (e.g. perception, memory, executive skill, etc.) and binocular vision functions (e.g. ability to scan, track converge the eyes, accommodate, etc). Nashold and Seaber [15] state that damage to the superior colliculus produces exotropia and diplopia. These binocular dysfunctions are common among TBI and similar to the characteristics and symptoms discussed by Padula et al., which documents that the binocular dysfunction is a result of interference with ambient visual processing at the level of the thalamus [16].

Dysfunction of the ambient visual process in relationship to mismatch between sensorimotor information also relates to concepts of visual midline organization (e.g. the pre-conscious ambient visual concept of the lateral and anterion-posterior axes related to the perceived body centre for sense of position), whereby a simple test can determine shifts in an individual's concept of egocentric visual midline [17]. Rossetti et al. [18] determined that pathological shift of the subjective midline will occur relative to left hemispatial neglect and that treatment with yoked prisms demonstrated improvement or reduction in neglect.

In practice, the use of yoked prisms have been shown to counter the distortion of compression and expansion of visual space caused by a CVA [17]. This can result in increased weight-bearing (e.g. realigning position sense and shifting weight more equally between affected and non-affected side) on the affected side by realigning internalized concepts of midline. For example, yoked prisms affect three-dimensional space. The base-end of the prisms will compress space in the lateral direction and expand space in the anterior/posterior direction. The apex-end of the prism will expand space in the lateral direction and compress space in the anterior/posterior direction. In turn, base-right or base-left yoked prisms will produce an equal compression and expansion of space for each eye, thereby affecting the interpretation of space through ambient visual process matching with sensorimotor information.

The concept of distortion of the ambient visual space/volume can be represented mathematically and graphically as in Figure 1.

The visuo-spatial volume is represented by axes x, y and z and radius from the egocenter, r. The concept of egocenter represents the relationship between the pre-conscious ambient and sensorimotor processes. The resulting compression and expansion of ambient visual space occurring as distortion is caused by a mismatch between ambient and sensorimotor information. This can be understood by changes in values of $x+$ and $x-$ as well as $y+$ and $y-$. For the purposes of this model, $z = r$. The shift of the visuo-spatial egocenter affecting the concept of visual midline and, as a result, egocentric directionality can be represented in equation (1):

$$\frac{x^2 + y^2 + z^2}{r^2} = 1 \qquad (1)$$

For example, if a subject in the control group demonstrated equality between the sum of the squared axes (i.e. $(x^+ - x^-)^2$, $(y^+ - y^-)^2$, $(z^+ - z^-)^2$) and the radius from the physiological egocenter (i.e. r^2), then the left side of the equation will equal one. This in turn demonstrates that the spatial volume of x, y and z are equivalent and the visual egocenter (midline) is centred. Therefore, the subject shows no bias or lean in the lateral or anterior/posterior axis. However, if there is a lateral shift for a subject in the experimental group such that $x-$ is greater than $x+$, in turn, $x-$ will be greater than one. This inequality indicates a shift in visual egocenter due to unequal ambient spatial volume, thereby coinciding with the angle of lean.

Purpose

The hypotheses being tested are: (1) that the shift in weight-bearing away from the hemiparetic side is due, at least in part, to a shift in the concept of visual midline; and (2) that yoked prisms with the base of the prism positioned opposite to the shift of visual midline can effectively realign the concept of visual midline. Thus, postural orientation while ambulating is corrected to a state similar to pre-CVA.

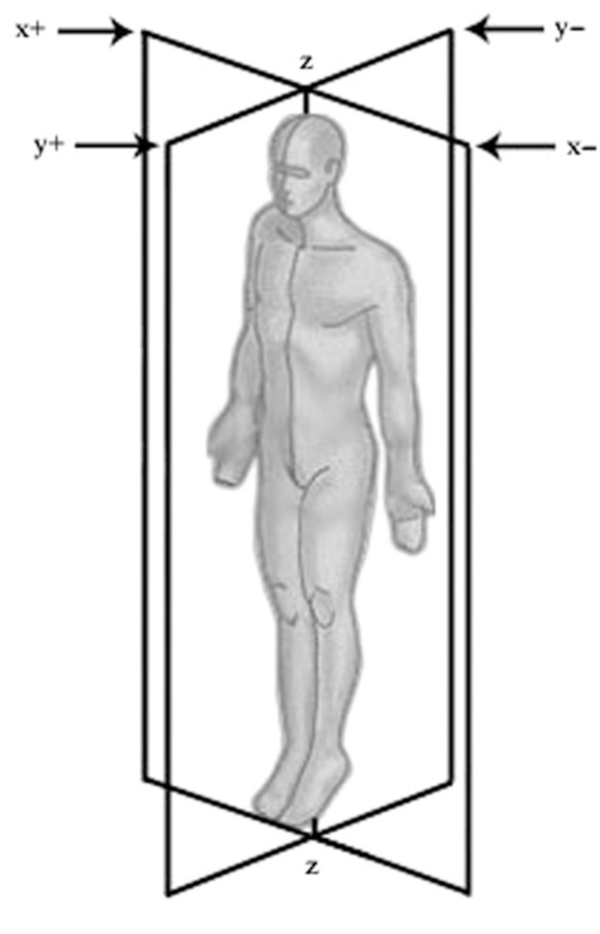

Figure 1. A graphical representation of ambient visuo-spatial volume affecting egocenter.

This study will demonstrate: (1) a correlation in direction of visual midline shift (VMS) to the side opposite the hemiparesis; (2) the influence of yoked prisms on realigning the visual midline; (3) the relationship of visual midline to postural orientation; and (4) the effectiveness of yoked prisms on influencing concepts of visual midline to affect posture.

Table I. Demographic characteristics of experimental and control subjects.

Characteristic	Post-CVA group	Control group
Mean age (years)	68 (SD 6.75)	63 (SD 6.12)
Age range	56–75	52–68
Right CVA	17	N/A
Left CVA	13	N/A
Female	15	12
Male	15	18

Methods

Design

In the design of this study, consideration was given to a double-blinded study. However, due to the thickness of the base-end and the spatial effect produced by the yoked prisms, masking of the placebo could not be insured. Therefore, each subject in the experimental group and control group was given a random assignment for use of a base-left or base-right yoked prism. The randomized assignment of the yoked prisms reduced the possibility of anticipation affecting outcome by the subject. A double-blinded study would not have reduced this anticipation and would have presented this confounding variable caused by the subject's awareness of using yoked prisms in contrast to the placebo.

Subjects

The study participants were either in an intervention group or a control group. Members for the intervention and control groups were seen in a clinical setting and chosen in a consecutive manner (sequential order of presentation) as each subject met the criteria for this study. In the intervention group, the mean age was 68 years (SD = 6.75) and 50% of subjects were male. The mean age of the control group was 63 years (SD = 6.12) and 60% were male. All subjects in this study met the following inclusion criteria: subjects were binocular (i.e. subjects with strabismus were not included in this study) with refractive correction equal to or less than ±2.00 dioptres; subjects were ambulatory and able to communicate. No subjects had greater than a ±0.50 dioptre anisometropia (unequal refractive power). No refractive correction was used during the testing and no subject had scotomas so that there would not be any spatial disorientation due to field loss. There were 30 adults in the intervention group, all of whom had had a CVA. The occurrence of the CVA in the experimental group ranged from 1–3 years. The 30 controls had no known neurological impairment. Seven females and 10 males were in the right CVA group, with eight females and five males in the left CVA group. Other demographic relationships between the subjects in the experimental and control groups are displayed in Table I.

Procedure

All subjects in both the experimental and control groups participated in all four aspects of testing. Testing conducted was part of a standard evaluation protocol developed and used in this clinical setting.

Part one: Visual midline shift. The initial step in the diagnosis of a subject with a VMS is qualitative (e.g. investigator observes the tendency of the subject to lean) since it requires observation of postural alignment and behaviour, as well as a determination of the side of the CVA (right or left). Each subject was seated before a blank wall and asked to position his or her head directly forward. A 30 cm wand was held vertically 45 cm in front of the right shoulder. The subjects were asked to follow the wand with eye movements only and to state when the wand appeared to be directly in front of their nose. The wand was moved in front of each subject's facial plane in a horizontal pattern from the right shoulder toward the left shoulder at a speed of ~4 cm per second, representing a subtended arc of ~70° from the bridge of the nose of the subject. The test was then repeated by moving the wand from the left shoulder toward the right shoulder. Two responses (i.e. a response by the subject reporting the wand to be at the perceived alignment directly in front of their nose when the wand was first moved left to right and then right to left) were recorded for each subject. During this test the investigator was seated indiscriminately to the left or right side of the subject at an ~30° angle to the subject's chair. This was carried out in order to lessen any influence of the investigator's position on the subject's responses. A response by the subject reporting the perceived alignment of the wand with the centre of their nose but actually shifted away from their hemiparetic side indicates a shift in the subject's perceived visual midline away from the hemiparetic side. A response away from the hemiparetic side was scored 'positive', whereas a report of the wand aligned toward the hemiparetic side was scored 'negative'. For example, subjects who had experienced a right CVA and demonstrated a left hemiparesis scored positive if the response was to the subject's right of physical midline.

Part two: Yoked prisms affecting the concept of visual midline. The test for visual midline shift was repeated with the subjects wearing a frame holding 12 dioptres of yoked prisms, initially with base-left and, subsequently, in the base-right position. The scores demonstrate the number of positive responses indicating a continued shift in the perception of visual midline away from physical midline. Each subject was tested with both prism configurations.

Part three: Postural orientation. The subjects were observed individually to stand and walk 5 m forward, turn around and return to the starting position without yoked prisms. Twenty-seven subjects in the intervention group utilized a cane or hemi-walker. A positive score represented a tendency to lean more than ~10° from an erect position and/or drift away from the hemiparetic side. A lean of 10° was chosen by the investigators because less than 10° could be potentially due to sway. A lean of 10° or greater was easily observed and was beyond variation in position due to normal movement.

Part four: The influence of yoked prisms on postural orientation. Each subject was fitted with 12 dioptres of yoked prisms. The amount of prism was chosen because 12° dioptres has the effect of 12 of spatial expansion and compression within the visual field. The spatial expansion and compression are a function of prism and are used to counter the effect of distortion and the resulting shift of visual midline in the ambient spatial field for subjects in the intervention group. Observations of each subject were made individually while standing then subsequently walking, as described in Part three. A 'positive' score was given if the subject continued to lean or drift away from the hemiparetic side. The 'positive' score related to the compression and relative expansion of spatial volume of equation 1 ($x = -x^{-}$) such that 10° of lean by a subject who was 6 feet (ft) tall would equate to:

$$\frac{(6-4)^2 + (6-6)^2 + (6-6)^2}{6^2} = 0.111 \qquad (2)$$

Thus, for a person who is 6 ft tall, more than 11 prism dioptres are required to observe a correction of at least 10° of lean. This could also be clarified as the egocenter experiencing ~2 ft of displacement in the x^{-}-direction. Twelve dioptres of prism were chosen to remain consistent for all test subjects.

Data analysis

This study analysed visuo-spatial dysfunction related to hemiparesis in post-CVA subjects and the effects of using yoked prisms to modify an individual's concept of visual midline. The test of proportions [19–21] was used to compare the proportion of subjects with a positive VMS in each part of the method to a hypothetical proportion. It was hypothesized that the following results would occur in the intervention group at a rate of 50%: subjects with a CVA would have a 'positive' VMS in order to correlate the VMS with the hemiparesis, subjects would have a tendency to lean or drift away from the hemiparetic side and, lastly, that use of appropriate yoked prisms would reduce the lean or drift as judged by observed postural changes. Based on the properties of the test of proportions, if subjects of the left CVA group or the right CVA group experienced 'positive' outcomes at a rate of 50% or close to that rate with at least 95% confidence ($p < 0.05$) then the results were statistically significant.

In contrast to the intervention group, the predicted results of the control group matched the null hypothesis. Yoked prisms should have no effect on correcting the VMS of control subjects since they are expected to have no VMS during the course of the trial. Therefore, a test of proportions is designed to show that, compared to the intervention group's rate of 50% positive effect, the group of control subjects should not have any characteristics of VMS at statistically significant levels. These characteristics include an initial shift of the visual midline and related lean. Furthermore, descriptive statistics were used to characterize the effect of yoked prisms on control subjects.

Results

Part one: Confirmation of visual midline shift

Table II shows the results of visual midline testing for right and left CVA subjects and compares those with positive shifts (perceived centre shifted away from the hemiparetic side) to those with negative shifts (toward the hemiparetic side).

Of subjects with a right CVA, 79% of the trials for these showed a positive response, indicating subjects' perceived VMS away from the hemiparetic side and with perception of visual midline deviating to the right of physical midline ($p < 0.001$; 95% confidence interval [CI], 0.66–0.93). A negative response or a VMS toward the hemiparetic side occurred in 21% of trials. This indicates a paradoxical shift of visual midline causing a push by the subject into the side of weakness. The paradoxical VMS may be a contributor to the effect observed in Pusher Syndrome.

For the subjects with a left CVA and right hemiparesis, 77% of trials resulted in a positive response with subjects demonstrating a perceived concept of visual midline to the left side, away from the hemiparesis ($p = 0.001$; 95% CI, 0.61–0.93). There was a negative response in 23% of these trials.

In the control group, only 6% of trials showed a shift to the right and in only 1% of trials was there a shift to the left. The visual midline shift in the control group was not statistically significant ($p = 0.31$; 95% CI, −0.031–0.098).

Part two: Placements of yoked prisms

Table III depicts the results of the use of yoked prisms on midline shifts by looking at how many positive shifts (leaning away from the hemiparesis) occurred while using the prisms.

When testing those subjects with a right CVA and left hemiparesis, use of appropriate base-left yoked prisms decreased the positive responses (i.e. VMS away from the hemiparetic side) by 85% ($p < 0.001$; 95% CI, 0.73–0.97). However, the use of base-right yoked prisms in the right CVA group resulted in a decrease in positive responses of only 26%. For those with a left CVA and right hemiparesis when testing with base-left yoked prisms, there was a decrease of positive responses in 24%. However, the left CVA group experienced a 77% decrease in positive VMS with base-right yoked prisms ($p = 0.001$; 95% CI, 0.069–0.39).

The control group showed no bias to either base-left or base-right yoked prisms, with 45% of trials showing a left shift with base-left yoked prisms and 43% of trials showing a right shift with base-right yoked prisms. Due to the effect of the base-left and base-right prism neutralizing subjects' bias in the control group, there is no measure for statistical significance.

Part three: Looking for lean

Part three evaluated the postural orientation of the subjects as to observed lean or drift while ambulating without yoked prisms. The results are shown in Table IV.

Of subjects who had a right CVA, 94% developed either a lean or drift away from the hemiparetic side or positive lean and only one subject leaned or drifted into the hemiparetic side or negative lean ($p < 0.001$; 95% CI, 0.83–1.0). Of the subjects with a left CVA, 77% leaned or drifted away from the

Table II. Shifts in visual midline for all subjects.

Characteristics	Positive VMS trials	Negative VMS trials	Right shift trials	Left shift trials	No shift trials	*p*-value	95% CI
Right CVA	27	7	N/A	N/A	0	<0.001	0.66–0.93
Left CVA	20	6	N/A	N/A	0	0.001	0.61–0.93
Control	N/A	N/A	4	1	55	0.31	−0.031–0.098

Table III. Modification of VMS using yoked prisms.

Characteristics	Positive shift trials with base-left yoked prisms	Positive shift trials with base-right yoked prisms	Left shift with base-left yoked prisms	Right shift with base-right yoked prisms	*p*-value	95% CI
Right CVA	5	25	N/A	N/A	<0.001	0.73–0.97
Left CVA	20	6	N/A	N/A	0.001	0.069–0.39
Control	N/A	N/A	27	26	N/A	N/A

Table IV. Direction of lean or drift while ambulating.

Characteristics	Positive lean/drift	Negative lean/drift	Right lean/drift	Left lean/drift	No lean/drift	*p*-value	95% CI
Right CVA	16	1	N/A	N/A	0	<0.001	0.83–1.0
Left CVA	10	3	N/A	N/A	0	0.02	0.54–1.0
Control	N/A	N/A	2	1	27		
Left lean/drift						0.31	−0.031–0.098
Right lean/drift						0.14	−0.023–0.16

hemiparetic side and only 23% leaned or drifted towards it ($p = 0.02$; 95% CI, 0.54–1.0).

In the control group 80% of the subjects showed no lean or drift. Members of the control group did not lean or drift frequently enough for there to be any correlation between posture and the absence or presence of a VMS ($p = 0.14$; 95% CI, −0.023–0.16 for right lean and $p = 0.31$; 95% CI, −0.031–0.098 for left lean).

Part four: Correcting lean

Part four evaluated the use of yoked prisms for modifying the VMS to influence posture and balance during weight-bearing and ambulation.

Table V shows that for right CVA subjects 82% showed improvement in weight-bearing with appropriate prisms ($p < 0.001$; 95% CI, 0.64–1.0). Thus, only 18% continued to lean away from the hemiparesis when fitted with base-left yoked prisms. For left CVA subjects, only 15% continued to lean away from the hemiparesis with base-right yoked prisms, while 85% showed an improvement in weight-bearing with base-left yoked prisms ($p < 0.001$; 95% CI, 0.65–1.0). However, with base-left yoked prisms the abnormal lean into the hemiparesis persisted for most right CVA subjects.

In the control group, nearly half of the subjects leaned toward the base side of the yoked prisms. The data for this group demonstrate that both base-left and base-right yoked prisms will put control subjects off-balance.

Discussion

Over the past several years the authors have observed visuo-spatial dysfunctions related to hemiparesis and the effects of modifying them with yoked prisms [17, 22]. Others have documented the effect of short-term prism adaptation on both visuo-spatial neglect and postural imbalances following right hemispherical damage [23]. Redding et al. [24] emphasized that prism exposure evokes three kinds of adaptive or compensatory processes: postural adjustments involving visual capture and muscle potentiation, strategic control for recalibration of target position and spatial realignment of various sensory motor reference frames. However, the authors assert that this is the first study to attempt to verify these clinical observations [25].

Results of this study confirmed the observations that most post-CVA subjects have a shift in the perceived concept of egocentric midline opposite the side of hemiparesis and that this shift can be clinically reduced and moved towards physical midline in the majority of cases through the use of yoked prisms. Of considerable clinical importance is the fact that this study was also able to show that the lean or drift away from the hemiparetic side was consistent with the shift in the visual concept of egocentric midline and that in 80% or more of the subjects VMS could also be reduced with yoked prisms.

The characteristics of shift of perceived egocenter demonstrated by subjects in this study have been given the name Visual Midline Shift Syndrome (VMSS). Results of this study raise some important points that need to be considered clinically regarding the short- and long-term rehabilitation needs of patients with VMSS. These results demonstrate that the visual process is dynamically involved in establishing a pre-conscious organization of visual midline relative to neurological changes occurring from a hemiparesis. The study also shows that this distortion in visuo-spatial processing produces a lean and/or drift away from the hemiparetic side. This will reinforce the inability to establish weight-bearing on the affected side. This distortion is a function of a relative compression and expansion of space through ambient spatial and sensorimotor pre-conscious mismatch that occurs following a neurological event such as a CVA.

Visuo-spatial neglect involves the lack of conscious awareness of either the left or right visual field. The lack of spatial awareness in one field is produced by the person's predilection to focal stimuli (e.g. something that catches the individual's attention in the opposite field) and is a function of the parietal and occipital cortices. However, a lack of ambient spatial sensorimotor matching at the pre-conscious level may be related to the conscious sensory neglect. It was clinically observed that when an individual with a field neglect physically touches or holds an object in the neglected field there is

Table V. Effects of yoked prisms on direction of lean or drift while ambulating.

Characteristics	Positive lean/drift with base-left yoked prisms	Positive lean/drift with base-right yoked prisms	p-value	95% CI
Right CVA*	3	14	<0.001	0.64–1.0
Left CVA*	11	2	<0.001	0.65–1.0
Control**	13	15	N/A	N/A

*Positive lean or drift is away from the hemiparesis for CVA subjects.
**Control group subjects show left lean with base left yoked prisms and right lean with base right yoked prisms.

increased awareness of objects in the neglected field. Therefore, these clinical observations suggest that VMS may also reinforce visuo-spatial neglect on the affected side due to the spatial distortion produced by ambient and sensorimotor mismatch causing the shift in visual midline or egocenter. Recognizing that VMS showed statistical significance in favour of shifting in the direction of lean and away from the hemiparetic side, it would appear that VMS may interfere with maximizing rehabilitation potential for weight-bearing and ambulation.

It has been noted that physical and occupational therapists often use mirrors in front of patients in order to provide feedback about postural orientation. The therapist uses the mirror to provide feedback through conscious awareness about body-spatial orientation. However, this is an attempt to provide feedback about position that should have been organized through the feed-forward pre-conscious ambient and sensorimotor match of information which produces a feeling of body position upright against gravity. Frequently, doctors and therapists report that when patients are in front of a mirror they can establish an erect posture, but when the mirror is removed the patient returns to a position of leaning and drifting away from the hemiparetic side. This may indicate that, without pre-conscious spatial orientation by ambient and sensorimotor match to produce feed-forward to the cortices, over-focalization will occur in conjunction with spatial distortion, ultimately interfering with awareness of the complete visuo-spatial field. In turn, yoked prisms have been shown to affect neglect. By rehabilitating the spatial function through yoked prisms, it is suggested that realignment of the visual midline in addition to affecting neglect will potentially affect rehabilitation outcome.

Conclusion

This study has documented: (1) the correlation between the perceived shift of visual midline (egocenter) and postural imbalance following a left or right hemispherical CVA; (2) yoked prisms affect concept of visual midline; and (3) yoked prisms are effective in shifting the perceived concept of visual midline, thereby affecting balance and posture for subjects with a left or right hemispherical CVA and corresponding lean.

These conclusions are centred around the bimodal visual process and, in particular, the ambient or spatial visual process in its relationship to sensorimotor function affecting balance, posture and movement. Spatial orientation involves the pre-conscious effect by ambient visual processing in conjunction with kinaesthetic, proprioceptive and vestibular matching. Higher order awareness of spatial orientation related to parietal and occipital lobe functioning occurs through focalization following pre-conscious organization of spatial information through ambient and sensorimotor matching at the level of midbrain. The importance of this pre-conscious process of ambient visuo-spatial mismatch with sensorimotor information thereby causing a VMS and ultimately being a component affecting posture and balance following a CVA should not be under-estimated.

The use of yoked prisms has shown to be effective in re-establishing the visuo-spatial relationships made by ambient sensorimotor processing relative to a perceived pre-conscious concept of egocenter. In turn, the realignment of egocenter or visual midline through the use of yoked prisms has demonstrated a direct correlation in supporting posture and balance for these subjects with left and right hemispherical CVA.

The implications of this research suggest that yoked prisms are an effective means for use in the rehabilitation of persons with right and left hemispherical CVAs. Furthermore, individuals with hemiparesis demonstrating a shift in concept of the egocenter or visual midline will benefit from use of appropriate yoked prisms to maximize potentials through prescribed rehabilitation programmes. Individuals with a hemiparesis following a CVA often reach a limit to progress in physical therapy. According to these findings, subjects in the experimental group had completed physical therapy and still demonstrated an imbalance in posture during ambulation as well as a VMS. Despite being 1–3 years post-CVA, posture and balance were improved after yoked prisms were introduced to affect the VMS.

Following studies of spatial neglect, Rossetti et al. [18] stated that 'if prism adaptation can influence higher level spatial representations, then this result raises an intriguing question regarding the putative causal role of subjective midline shift on other common features of neglect' (p. 167). The present study shows that VMS is correlated with lean following a CVA. Moreover, this study demonstrates that yoked prisms directly affect ambient and sensorimotor matching of information to influence posture against gravity by altering the ambient spatial volume. The results confirm that the rebalancing of spatial volume through the ambient process affects posture and balance. The direction of placing the base-end of yoked prisms opposite the direction from the lean is similar to the direction used by Rossetti et al. to affect neglect.

While the Visual Midline Shift Test (VMST) is effective statistically in correlating perceived visual midline with postural lean following a CVA with hemiparesis, it is a subjective test and requires a response by the subject. Due to the subjectivity of the test, VMST responses will vary. It is ineffective for an individual who is non-communicative as well as for those who are not upright. If VMST is going to be used in a clinical setting responses should be averaged and the clinician should observe posture and balance of the individual during ambulation.

The present research emphasizes a lateral shift of VMSS. However, in clinical settings the authors have found that there is often a shift of visual midline in the anterior or posterior direction in combination with a lateral shift. Clinically, it is suggested that yoked prisms be utilized at an oblique axis to affect the lateral and anterior-posterior shift that often accompanies the visuo-spatial dysfunction, as previously discussed.

Future research should incorporate weight-bearing pressure-sensitive walk plates to evaluate weight-bearing. This will provide a quantitative means to directly measure the shift in weight bearing in lateral as well as anterior-posterior axes. Yoked prisms can then be incorporated to affect the VMS produced by the CVA. The pressure-sensitive plates can be used to quantitatively measure the effect of realigning the visual midline, thereby affecting posture and balance. In addition, research is needed to evaluate the function of the ambient visual process related to functional components of vision such as pursuits and saccades.

The significance of this research is that it demonstrates that the ambient visual process is an important contributor together with sensorimotor information for the development of pre-conscious organization of balance and posture affected by CVA. Furthermore, yoked prisms are an effective means to counter the visuo-spatial distortion that occurs following a CVA. The practical importance of this study is that yoked prisms can be prescribed for persons with hemiparesis following a CVA and utilized in conjunction with prescribed physical therapy as well as for those who are no longer receiving therapy. Prescribed yoked prisms can be incorporated into therapy programmes but must be used in accordance with professional licensing guidelines. It is recommended that an optometrist who practices neuro-optometric rehabilitation or an ophthalmologist be included as part of the interdisciplinary rehabilitation team.

Although this study only evaluated subjects who had suffered a CVA, similar problems affecting spatial orientation and balance have been observed in other populations of neurologically-challenged persons such as those with parietal lobe lesions, TBI, multiple sclerosis, cerebral palsy, autism, Friedreich's ataxia and Niemann-Pick Syndrome [26, 27]. These findings may also offer expanded opportunities for the diagnoses of visuo-spatial problems as well as new clinically-relevant treatment possibilities for these populations.

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