THE EFFECTS OF YOKED PRISMS ON BODY POSTURE AND EGOCENTRIC PERCEPTION IN A NORMAL POPULATION

VASSILIS KOKOTAS

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Summary

The principal theme of this thesis is the effect of yoked prisms on body posture and egocentric perception. Yoked prisms have been clinically used in the management of a variety of visual and neuro-motor dysfunctions. Most studies have been conducted in pathological populations by studying the effects of prismatic adaptation, without distinguishing short and long term effects. In this study, postural and perceptual prismatic effects have been studied by preventing prism adaptation. A healthy population was selected in order to investigate the immediate prismatic effects, when there is no obvious benefit from their use for the individual.

Posturography was used to assess changes in weight distribution and shifts in centre of pressure (barycentre). In addition, photographic analyses were used to assess effects on posture on the x and z axis. Experiments with space board and visual midline shift were used for the evaluation of spatial perception and egocentric localisation. One pair of 8 Δ yoked prisms base left (BL) and one pair of 8 Δ yoked prisms base up (BU) were applied randomly and compared to a pair of plano lenses.

Results suggest that immediate prismatic effects take place on a perceptual level and are reflected on an altered body posture respectively without significant changes in weight distribution. Yoked prisms BL showed a rightward rotational effect on spatial perception by expanding space on the z axis when viewing through the base of the prism and constricting space through the apex of the prism. Body posture responded respectively to what was visually perceived by altering posture. A rightward shift and tilt of the head was recorded along with the hips shift and shoulders tilt in the dame direction. Additionally, right shoulder shifted backwards and an angular midline shift to the right was recorded. The egocentric localisation was affected by shifting the midline perception to the left. Yoked prisms BU resulted on a head shift forward and a reduction of the head-neck angle by bringing the chin closer to the chest. The egocentric localisation was altered on the vertical axis providing subjects the perception that their eye level was higher during the experiment.

In conclusion, yoked prisms seemed to induce changes in body posture, mainly in the upper body and head, without any significant changes in weight distribution. These changes are partially reflected in spatial perception tests and egocentric localisation before any prismatic adaptation takes place.

Keywords: (barycentre, midline shift, posturography, prism adaptation, spatial perception)

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CHAPTER 1 – INTRODUCTION

1.1 General introduction to yoked prisms

Yoked prisms are prisms of equal power positioned with their bases towards the same direction (Weiss & Brown, 1995). They are usually prescribed with bases in vertical orientation, both lenses base up (BU) or base down (BD), or in a horizontal orientation, both lenses base right (BR) or base left (BL). They can be even prescribed in oblique orientation but this approach is infrequently used (e.g. both lenses base up and right). Sometimes yoked prisms are referred to as 'conjugate prisms' or 'ambient lenses' (Kaplan, et al., 1996; Scheiman & Wick, 1994). Optometry, ophthalmology, psychology and neurology are examples of different disciplines that have used yoked prisms as a research and therapeutic tool.

Progressive spectacles usually incorporate yoked prisms of small amounts, called thinning prisms, for reducing thickness that is created due to differences in lens curvature at the upper and lower part of the lens (Cho & Benjamin, 1998). The prismatic power used in these cases is equal to 2/3 of the prescribed addition in BD format and usually do not exceed 2 Δ prismatic dioptres. This amount is in agreement with a study that examined subjective perception of different amounts of BD yoked prisms and showed that subjects could not significantly differentiate between 2 Δ BD and plano lenses (Sheedy & Parsons, 1987). This is also a probable explanation on the exaggerated forward head posture that is noted in progressive lens users in addition to the expected searching for the optimal zone on the lens according to their visual needs (Hills-Willford, et al., 1996).

The use of yoked prisms has been proposed in cases of nystagmus management (Metzger, 1950) and the same approach was reviewed again later (Fischer & Mahaphon, 2006). The idea is based on inducing shift of eye gaze towards the null point thus reducing head turn and tilt that are often present in these cases. The same principle can be applied in cases where there is diplopia due to oculomotor nerve palsy (Galbrecht, et al., 2007) or Grave's disease by guiding both eyes to the less diplopic gaze position. Since both eyes synergistically alter their primary gaze through yoked prisms, it is obvious that BD yoked prisms can be used in a symptomatic 'V pattern' esodeviation or 'A pattern' exodeviation case for reading in a down gaze position (Caloroso & Cotter, 1995). The application of yoked prisms can be also effective in cases of double elevator palsy (Garriott & Rouse, 1994).

Yoked prisms are also mentioned in managing fixation dysfunction with intermittent saccadic intrusions (Weissberg, et al., 2000) and reducing eye strain due to computer use (Lazarus, 1996). [1] Vertical yoked prisms also have an interesting effect on stereolocalisation. This effect has been investigated with the use of two overlapping polarized slides, known as Quoits vectograms (Stereo Optical Company, Inc., 8600 W. Catalpa Ave., Suite 703 Chicago, IL 60656 USA), which induce a stereoscopic effect relative to their disparity. Yoked prisms BU caused stereolocalisation to expand further away while BD yoked prisms induced the opposite effect bringing stereolocalisation closer compared to plano lenses (Hock & Coffey, 2000).

There is also a significant role for yoked prisms in enhancing rehabilitation in visual field defects (Margolis & Suter, 2006; Suchoff & Ciuffreda, 2004) or central scotomas (Romayananda, et al., 1982). The underlying principle is to transfer missing visual information to a more healthy and functional part of the retina. In order to achieve the desired results, Fresnel prisms or round prisms of very small diameter (Gottlieb Visual Field Awareness System), are usually attached in certain parts of the lenses or are dispensed, less frequently, in a full diameter lens form (Menezes, 2013).

Interestingly, using yoked prisms has been also proposed for modifying postural adaptation after cerebrovascular accidents, where patients experience a lean to the affected side of hemiparesis, known as Pusher's syndrome, and later a compensatory lean to the other side due to sensory-motor information and spatial perception systems (Padula, et al., 2009). Effects of yoked prisms on posture have been reported even in ankylosing spondylitis, a chronic inflammatory disease (Richer, 1986). More recently, the role of yoked prisms was highlighted in a case with bilateral sacroiliac joint dysfunction, where other interventions provided only minimal relief of symptoms (Robey & Boyle, 2013) and as a successful treatment in another case of persisting neck pain, after radical dissection (Bartley, et al., 2014). During neck dissection the sternocleidomastoid muscle is often removed, so the persisting pain can be due to a 'phantom muscle' phenomenon. This kind of usage is mainly implemented by behavioural optometrists during vision therapy / vision training sessions to address postural deficits of the body, head and eyes in order to develop and restore normal inter-sensory and perceptual-motor functions (Sutton, 1985). Early publications from the Optometric Extension Program were used as clinical guidelines for behavioural vision care practitioners in prescribing yoked prisms (Kaplan, 1978-1979; Kraskin, 1982).

According to research, cognitive functions are also affected, proving positive effects of yoked prisms when applied to patients suffering from neglect (Rossetti, et al., 1998). Behavioural modifications have been reported with the use of yoked prisms in psychiatric patients (Flach, et al., 1992), persistent non-malingering syndrome known also as Streff Syndrome (Leslie,

[1] Saccadic intrusions describe the condition of inappropriate saccades disrupting fixational stability.

2001) and in children in the autistic spectrum (Carmody, et al., 2001; Kaplan, et al., 1998; Kaplan, et al., 1996). Recently yoked prisms were used successfully shifting field by 20° in order to modulate the differences in hand temperature in unilateral upper-limb complex regional pain syndrome (CRPS), since it has been hypothesized that it's not the actual place of hands relative to body midline that alters temperature, as it is known in this condition, but their perceived location (Moseley, et al., 2013).

1.2 Optical and perceptual aspects of prisms

The main prismatic effect is to deviate a parallel or divergent beam of light towards the base of the prism, thus a subject perceives deviation of the light source towards the apex of the prism, as suggested by geometrical optics. The opposite effect appears when there is a convergent beam of light resulting in shifting the perceived light source towards the base of the prism. This is common in some ophthalmic instruments like the lensometer (Brown, 1995). Prismatic effect is dependent on the angle of incidence of light to the surface of the prism (Harris, 2011). There is a certain angle at which the deviation of light is minimum. Steeper or flatter angles of incidence will result in a more powerful prismatic effect (Figure 1). Chromatic aberrations are well documented with longer wavelengths of light spectrum (red) deviated less and shorter wavelengths (blue) deviated more. As a result, any observer is able to perceive blue fringes towards the apex and red fringes towards the base of a prism. The higher the prismatic power the greater the perceived chromatic aberration. However, prism performance is more complicated due to optical design and apparent distortions. Distortions of the image seen through a prism are dependent not only on the characteristics of the lens, but also on its relative placement in front of the eye.

Figure 1 Prismatic effectiveness in relation to the angle of incidence of light (from Suter & Harvey, 2011)

As a result, distortions are different when examined through different parts of the prismatic lens. Size and curvature distortions are of different magnitude when optical axis of the eye passes through the base or the apex of the prism. (Ogle, 1951). There is a difference in angular magnification in the base – apex meridian, providing an enlarged image through the apex of the prism and a compressed one through the base (Welch, 1978). There is also a general angular magnification of different amount in the base – apex meridian than parallel to the base, which can be attributed to astigmatic error, since rays passing through are of oblique incidence (Figure 2).

Figure 2 An indicative representation of the distortional pattern and the angular magnification in the base-apex meridian, induced by a prism (from Ogle, 1951).

In addition, a perceived curvature of the image parallel to the base is expected with the convex side towards the apex of the prism (Rock, 1975) (Figure 3). This induced curvature is also accompanied by a size reduction towards the apex of the prism (Kaufman, 1974). The whole image distortion can be perceived by an individual in two different ways. It can be perceived either as an image with distorted size along the base – apex meridian, but still in the frontal plane or as an image rotated around the vertical axis obeying size constancy and depth perspective rules (Figure 4). The distortions referred to above are for prisms with flat surfaces. The distorted image becomes more complicated if the lens is manufactured on spherical surfaces. In this case, base curve, vertex distance, thickness of the lens and the relative position in front of the eye become significant factors too.

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Figure 3 Distortion representation of space curvature parallel to the base (from Rock, 1975)

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Figure 4 Vertical size reduction towards the apex of the prism (from Kaufman, 1974)

Previous studies have shown that uncorrected myopes preferred to turn their head in a position where they were able to look through the apex of the prisms, no matter what the direction of the base was, reporting increased visual acuity (Streff, 1973). Whereas, uncorrected hyperopic patients preferred to turn their head in a position where they were able to look through the base of the prisms, also reporting increased visual acuity. Further investigation proved that relative thickness of the lens and the angle of incidence of the visual axis relative to the prism seem to create plus and negative lens effects towards the base and apex of the prism respectively. Using a 10 Δ lens of 6.75 base curve in a 40° angle of view could induce up to +0.89 DC through the base of the prism and up to -0.92 DC through the apex of the same lens.

Patients' behavioural reactions to yoked prisms have been reported (Forkiotis, 1995; Kaplan, 1978-1979; Sutton, 1985). Base up yoked prisms leads both eyes downwards inducing an increase in convergent and accommodation. The increase in convergent is supported by the tertiary action of the inferior rectus muscles inducing adduction, thus increasing accommodation (Super, 1995). Using such lenses for long periods has resulted in feeling that space and breathing were compressed (Forkiotis, 1995) while perceiving a body sensation of being stretched on a lateral basis (Sutton, 1985). Yoked prisms BD lead both eyes upwards increasing divergence and reducing accommodation. The increase in divergence is supported by the tertiary action of the inferior oblique muscles inducing abduction, thus reducing accommodation (Super, 1995). After long periods of use, in small amounts, breathing has been reported as being deeper and easier (Forkiotis, 1995) while also providing a relaxed body sensation (Sutton, 1985).

1.3 Prism adaptation and after-effects

Experiments noted that the initial effect of a displaced image was gradually adapted by subjects and readapted when prisms were removed (Gibson, 1933). For example, when an individual used a pair of yoked prisms base left causing a rightward shift, there was a clear tendency to overestimate pointing or reaching to the right by the same spatial amount as the value contained in the prism. After a number of attempts a recalibration takes place and the individual can point correctly again. Prism adaptation represents this natural mechanism of re-establishing a stable frame of reference. When prisms are removed a new misinterpretation of space is present and now individuals overestimate pointing or reaching to the left by the same spatial amount as the value contained in the prism. The term 'after-effect' or 'negative after-effect' is used to describe visual-motor adaptation back to its initial state after prism removal. This after-effect represents a secondary effect to prism adaptation. Even though the brain is aware that the prisms are removed, new attempts are needed in order to recalibrate. The same adaptation occurs, even if prism is applied in front of one eye only, with the fellow eye occluded.

Early research examined conditions that could enhance adaptation. Three conditions were examined including active movement, where subjects were allowed to move their hand, passive movement, where subjects' hand was moved by others, and no movement which served as a control condition. Results suggested that adaptation emerges only in active conditions (Held & Schlank, 1959). Perceptual and sensory-motor adaptation to vertical yoked prisms has been investigated and it was found that most occurred during the first 30 minutes (Huang & Ciuffreda, 2006). The after-effect seems to last for many hours, depending on the nature of activities and repeatability (Hatada, et al., 2006). Studies of healthy participants showed that when visuo-manual adaptation is used, then higher level processing related to body representation in space is affected, resulting in postural changes (Michel, et al., 2003). Applying yoked prisms for 20-minute daily sessions for five weeks indicated that positive results could be sustained up to six months (Serino, et al., 2009).

There are many brain areas involved in prism adaptation and after-effect. The use of fMRI in order to investigate where spatial recalibration takes place has indicated different brain areas at different phases of the process. During initial error detection, the anterior intraparietal sulcus seems to be activated followed by parieto-occipital sulcus, which plays a significant role in error correction. Cerebellar activity is enhanced with spatial realignment modifying responses of the superior temporal cortex (Luaute, et al., 2009).

1.4 Posture maintenance, egocentric perception and midline shift

Postural control is essential for movement serving as the background substrata for any kind of movement (Young, 2004). Postural control involves alignment and postural tone in a dynamic way. Resting postural tone is the automatic muscle activity providing tension and resistance against gravity. Muscle tension increase at necessary levels for stability in order to initiate movement. Each sensory system can differentiate postural tone. Within this frame it is also necessary to consider musculoskeletal components. Muscle strength and postural tone should be reviewed separately. Any movement is based on a proper postural alignment that is regulated by the sensory systems. This frame of reference will allow for synergistic co-activation (Magrun, 2012).

Visual, vestibular and somatosensory information are integrated to provide posture and balance stability, although their contribution is not equal depending on the conditions (Isableu, et al., 2010). A highly visual dependence has been reported in stroke (Bonan, et al., 2004) and elderly patients (Van Hedel & Dietz, 2004), while visual deprivation seems to reduce upper body stability in normal subjects, when tested in dynamic conditions (Iosa, et al., 2012). Congenital visual deprivation induces a larger variation in craniovertical angle compared to normal sighted subjects due to a forward-downward tilt of the head which can result in altered mandibular position, craniofacial and dental alveolar morphology (Dogan & Erturk, 1990). There is even a correlation between visual impairment and the severity of postural deformation in scoliosis compared to a control group with normal vision (Catanzariti, et al., 2001). Vestibular dependence has been reported before a turn when walking (Kennedy, et al., 2005) while people with autism depend mainly on somatosensory inputs (Masterton & Biederman, 1983). However, when standing on an unstable surface, visual and vestibular information become of greater importance (Peterka, 2002). This is supported by research showing that visual deficits are associated with increased fall risks in older people (Poulain & Giraudet, 2007; Brook-Wavell, et al., 2002) and decreased visual efficiency is closely related to postural stability (Anand, et al., 2003). A reduction in fall frequency after cataract surgery and restoration of vision seems a logical consequence (Schwartz, et al., 2005).

Viewing through different gaze positions can also have a significant effect on postural stability, as suggested by reduction of body oscillations during upright standing, when gaze is directed beyond or below eye level (Kapoula & Le, 2006; Ustinova & Perkins, 2011), and many brain areas which contribute to motor planning can be altered in their neural processing (Bedard, et al., 2008). Apart from directing both eyes in a different gaze position, yoked prisms create visual distortions, which have been proven to influence the body's vertical orientation (Carriot, et al., 2008; Keshner & Kenyon, 2009). Moreover, postural performance during prism adaptation has been shown to be dependent upon postural adjustments, strategic recalibration and spatial realignment, even at an after-effect level (Redding & Wallace, 2004).

To understand the role of vision in posture, a functional description of vision as a bimodal process is helpful in order to highlight other, less frequently reported, aspects of the visual process. Referred to as 'focal' and 'ambient' vision processes these two systems actually describe two different neurological mechanisms used for building up a personal visual experience (Trevarthen & Sperry, 1973). The focal visual process is mainly concerned with discriminating details and parts of the visual scene, while ambient visual process is mainly concerned about spatial aspects and the 'big picture'. Focal vision is referenced primarily to the occipital cortex, while ambient vision is composed of 20% of the nerve fibres from each eye travelling to the midbrain, where visual information is integrated with kinesthetic, proprioceptive and vestibular inputs at the superior colliculus level. The superior colliculus is one of the three main destinations, along with the lateral geniculate bodies, which in continuum project to the occipital cortex and pretectal nucleus. Apart from the nerve fibres emerging from the superior brachium of the optic tract, superior colliculus receives fibres from the occipital cortex through the lateral geniculate bodies and spino-tectal tract carrying information from spinal cord and medulla. It is known for its fundamental role in head and eye coordination and orientation serving as centre for integrating extraocular proprioceptive signals and spinal trigeminal nucleus (Klier, et al., 2003). There is also a reciprocal feedback pathway with reticular formation probably related to extraocular proprioception (Chen & May, 2000). This integration provides a perceptual frame of reference for posture, orientation and movement (Bron, et al., 1997), thus answering the fundamental question 'where am I' in addition to the dorsal and ventral streams answering 'where is it' and 'what is it' respectively (Goodale & Milner, 1992).

Spatial perception in relation to egocentric localisation is determined by a combination of oculocentric and extraretinal informative parameters. Oculocentric information is provided by the position of the projected object on the retina in relation to the fovea. Extraretinal information is provided by neural-motor signaling leading eye rotation and proprioception of the extraocular muscles (Fogt & Jones, 1996). Two main reference frames have been suggested in previous researches while investigating spatial perception changes: The ‘visual’ eye-head-centred frame and the ‘proprioceptive’ hand-head reference frame. The first one has been proposed in the diagnosis of Visual Midline Shift Syndrome (VMSS) in right brain damaged patients, showing left hemiparesis and rightward shift of midline (Padula, et al., 2009). The second frame of reference is mostly important when visual information is deprived, as it happens in experiments with subjects pointing straight ahead while blindfolded. Furthermore, visual open loop (VOL) pointing proposes an integrated way of measuring spatial localisation. Visual open loop pointing requires the subject to point towards a visual target but while having the arm hidden under a horizontal board. The technique has been proposed for clinical use (Valenti, 1996) and believed to reveal the association of ‘visual’ and ‘proprioceptive’ frames of reference (Wilkinson, 1971) as confirmed in experimental settings (Wallace & Garrett, 1975; Wallace, 1977).

The optical and perceptual effects of prisms have been described in this chapter along with some fundamental concepts on the prismatic adaptation and the after-effects observed following their removal. In addition, some critical aspects of postural maintenance and subjective perception of the body’s midline have been mentioned that would be helpful in understanding previous researches. In the next chapter the use of yoked prisms in several clinical and research areas is covered and the mechanisms for prismatic adaptation are approached in more details. The parameters that affect a natural standing posture and egocentric localisation are also analyzed in order to set the base for considering the experimental settings used in this research.

CHAPTER 2 – LITERATURE REVIEW

The prismatic effects, in terms of optical and perceptual transformations, were discussed in the first chapter. Prismatic adaptation and after-effects were also covered by describing their fundamental concepts. In addition, a review of the parameters supporting the upright posture was discussed along with the characteristics of the subjective midline perception. In this chapter a detailed review on the use of yoked prisms in clinical and research settings is presented from various discipline areas. A significant part of this chapter is dedicated to the review of the theories and mechanisms involved in the prismatic adaptation while more details are also provided on the parameters that affect posture and physiological egocentric localisation.

2.1 Critical review of the use of yoked prisms

A survey produced by the College of Optometrists in Vision Development showed that 90% of the responders were aware of yoked prisms usage, but only 21% of the most experienced and 10% of the newer practitioners actually prescribed them on a regular basis for home use or daily wear. In the same survey responders showed a preference to yoked prisms of 5 Δ or less when prescribing for home therapy purposes and larger than 6 Δ and even up to 20 Δ when used during in-office vision therapy programs (Kaplan & Carmody, 1997). This survey can be considered reliable amongst behavioural or developmental optometrists, who use yoked prisms as a diagnostic and therapeutic tool extensively. In addition, evidence suggests that in some conditions yoked prisms are used more frequently. A retrospective analysis of the records of 60 patients with acquired brain injury on the use of yoked prisms, showed that homonymous quadranopsia was the primary indication for yoked prisms prescription representing 58.3% of the cases. Visual neglect was the second indication for prescribing in 40% of the cases, while abnormal egocentric localisation was the primary concern in 11.7% (Bansal, et al., 2014).

2.1.1. Yoked prisms in autism

The beneficial effect of yoked prisms in the autistic population is clearly stated (Kaplan, et al., 1996; Kaplan, et al., 1998; Carmody, et al., 2001). However, those studies have been carried out by the same group and there is lack of research by other investigators. Besides, the beneficial effects reported seem to fade after three to four months. This could be explained as reaching a performance plateau, with the specific amount of prisms used or reaching the highest potentials of subjects' functional levels. Recently, a study on autistic children showed that yoked prisms increased electro dermal reactivity, which is indicative of increased emotional arousal and attentiveness, compared to placebo lenses. In addition, significant differences in heart rate were also recorded, especially in the low emotional arousal condition for the subjects wearing yoked prisms (Sokhadze, et al., 2012).

2.1.2 Yoked prisms in postural control

The evidence for the use of yoked prisms in postural control is based mainly on case reports, personal opinions and a few controlled studies (Jennings, 2000). The effects of yoked prisms on body posture have been investigated mainly in pathology groups. Patients who present hemiparesis after cerebrovascular accident usually have a tendency to lean to the affected side. This behaviour is unrelated to vestibular function and seems to be related to a more generalized disturbed perception of body position in space (Johannsen, et al., 2006). The body's tendency changes after a few weeks in many patients who then lean towards the unaffected side. This seems to be the result of reorganizing the available information from the sensory-motor system. The coexistence of a unilateral neglect, in almost 60% of cases, can support further asymmetries in body orientation (Adams & Hurwitz, 1963). The term Post Trauma Vision Syndrome has been used to describe the dysfunctional ambient visual process, which is usually accompanied by over-focalization on details, binocular dysfunctions and several compromises in higher cognitive processing (Padula, et al., 2009).

The use of yoked prisms in clinical cases of cerebrovascular accident and traumatic brain injury has been reported as beneficial (Benabib & Nelson, 1993) indicating that the form of binocular dysfunctions in such cases results from interference with ambient visual processing at the thalamic level (Padula, et al., 1994). Results of a study of 30 patients after cerebrovascular accident versus a control group highlighted the dynamic nature of the visual process in establishing a pre-conscious reference of visual midline in relation to changes emerging from hemiparesis. Participants were tested in terms of how they perceived their visual midline and postural orientation. Yoked prisms were effective in re-establishing the spatial frame in the patients' group through the ambient visual process and as a result support balance and posture (Padula, et al., 2009). The authors recognized that the study was limited to cerebrovascular accident patients, but highlighted that the same effects have been documented in neurological conditions such as multiple sclerosis, cerebral palsy, Friedreich's ataxia and Niemann-Pick syndrome (Padula, et al., 2007).

Management of abnormal head posture with vertical yoked prisms and vision therapy was advocated in a discussion paper (Tea, 2008), while another recent paper underlined the clinical value of yoked prisms in a case of sacroiliac joint dysfunction of an athlete whose rehabilitation program was limited in reducing pain and correcting posture, until BD prisms were prescribed. The initial five weeks program including popular chiropractic and orthotic techniques was of small benefit reducing the Numeric Pain Scale (NPS) from 7/10 to 5/10. Orthotics is customized artificial foot supports used to enhance the proper posture and balance the biomechanical inadequacies of feet and legs. Application of 2 Δ yoked prisms BD for two hours on a daily basis along with the program prescribed resulted in a total relief to 0/10 NPS in four weeks (Robey & Boyle, 2013). The authors noted that yoked prisms had a significant effect on relaxation of paravertebral and hip flexors, thus supporting paraspinal and hip flexor musculature. Results enabled hamstring muscles to engage in a more natural posture compared to the previous one which was characterized by forward head posture, kyphosis, hyperactive spinal extensors and overactive hip flexors.

In another preliminary investigation examining the effect of yoked prisms on the posture of patients with adolescent idiopathic scoliosis, researchers found positive changes presented with decreased angle of trunk misalignment, when 5 Δ yoked prisms base left were applied (Wong, et al., 2002). Subjects had a right thoracic curve pattern with left compensatory lumbar curve and responded positively to BL and BDL at axis 157.5°, but not at other axes or when higher prismatic amount of 10 Δ was used. Although the sample was extremely small, the results were in agreement with previous attempts showing that changing the skeletal muscle tone was possible in scoliotic patients with the application of low power prismatic lenses (Silva, 1992). In addition, the Fresnel prismatic lenses that were used are probably not characterized by the same optical, spatial and perceptual effects compared to flat or curved prisms.

One study that was designed for a normal population with no history of neurological, vestibular or visual disease examined yoked prisms effects by using moving platform posturography (Gizzi, et al., 1997). The experimental setup was created in order to provide quantitative description of postural stability and its dependence on different sensory information. Just as yoked prisms correct midline shift in neurological challenged patients, they may also affect healthy people in the same manner. In order to investigate this hypothesis 15 Δ yoked prisms BR were used and recordings were taken before prism application, immediately after their application, and after an hour of free navigation with the prisms on. Results showed that in every posturographic condition subjects experienced a shift in the centre of gravity towards right, even with eyes closed. Approximate shift was measured about 0.5° immediately after prism application and 0.75° after one hour, which seems small for the prismatic amount of 15 Δ BR. Unfortunately, only eight subjects participated in this study, which is a very small sample group. In addition, trials were not random and the research design did not meet single or double masked criteria. It should also be noted that no consideration was given to potential prismatic adaptation effects while changing conditions during the experiments. This fact may explain partially the recorded shift with eyes closed. The authors recognized some of these limitations and concluded that further research with additional smaller amounts of yoked prisms was necessary.

An unusual combination of vertical and lateral prisms was used in a study in order to detect changes on dynamic posturography concerning posture and gait (Gottshall, et al., 2006). Since centre of gravity is hard to quantify, centre of pressure (CoP) is usually used.

Measurement of CoP is defined as the displacement in the anterior-posterior and sideward directions within the base of support (Collins & De Luca, 1993). The CoP represents the weighted average of all the pressures over the surface of the area in contact with the ground (Winter, 1995), which is related to body sway. No significant effects were found on centre of pressure (CoP) in 80 participants, but mild to moderate effects were recorded in various walking conditions of the dynamic gait index. Results showed different effectivity in static compared to dynamic conditions, probably due to prismatic adaptation. Changes in gait were also documented when walking with yoked prisms BD resulting in a slower and more cautious pattern while no changes were found with yoked prisms BU (Errington, et al., 2013). Researchers suggested that the effects may be partially due to a perceived increased height, since many of the participants reported feeling taller. Based on these comments researchers proposed that this is in agreement with perception through the base of a prism resulting in minification, thus feeling more distant from the ground. As a result the feeling of increased real or virtual heights can lead to fear of falling (Cleworth, et al., 2012) explaining their cautious behaviour (Delbaere, et al., 2009). Although this idea may explain the results, BD prisms also result in a view of the environment as being at a higher level, thus creating a perception of standing on an ascent (Backus, et al., 1999). As a consequence, the body would lean to the front and subjects would probably increase step length and be less cautious, which is in contrary to what was measured.

An investigation of the effect of 5 Δ vertical yoked prisms on body posture (Suttle, et al., 2011) showed no effect on hip joint angle, torso angle and neck joint angle at different time intervals (before prism application, immediately after, at 10, 20 and 30 minutes, after removal) during different tasks. No statistically significant effects were found. Although prisms were applied in a random order, only six subjects participated in this study which is a small sample and no method is reported for prohibiting or considering prismatic adaptation during the different tasks.

2.1.3 Yoked prisms and visual neglect

The effect of yoked prisms on visual neglect has been extensively studied. Neglect represents a complex and heterogeneous disorder associated with right brain damage and less frequently left brain damage, resulting in failure to report or respond to stimuli presented in the opposite side of the lesion (Ringman, et al., 2004). A key study on left-hemispatial neglect initiated numerous studies on this topic (Rossetti, et al., 1998). Many of the symptoms present in this condition show a characteristic pathological shift of the subjective midline to the right. Results of this study showed significant improvements in midline perception and other neuropsychological tests in all six participants, who used yoked prisms base left. Results have been confirmed and positive effects are also reported in postural imbalance (Nijboer, et al., 2014), mental imagery tasks (Rode, et al., 2001), tactile process

(Maravita, et al., 2003) and auditory extinction (Jacquin-Courtois, et al., 2010). However, other studies do not support the beneficial effects of yoked prisms in neglect patients (Ferber & Murray, 2005; Sarri, et al., 2010) and more randomized controlled trials are needed (Rode, et al., 2006). The underlying mechanisms of prism adaptation in neglect patients are not fully understood. In addition, experiments based on inducing neglect-like conditions may not share the same mechanisms.

2.1.4 Yoked prisms in pain management

Another area of interest in yoked prisms application is the modification of the perception of pain. Studies conducted showed that perceived body midline shifted to one side when pain was present, thus providing evidence that visual and somatosensory systems are interdependent (Sumitani, et al., 2007a). Based on this concept, yoked prisms with enough power to induce a 20 degrees visual field displacement were applied towards the unaffected side, resulting in alleviating pathologic pain. In contrast, when the same amounts of yoked prisms were applied shifting field towards the affected side pain perception was exacerbated (Sumitani, et al., 2007b). Similar results have been obtained in cases of complex regional pain syndrome (Bultitude & Rafal, 2010). Adaptation to yoked prisms shifting visual field towards the unaffected side has successfully reduced pain and other symptoms, while exacerbation of the symptoms occurs, when the opposite direction of prisms is used. It is interesting that even thermoregulation deficits between the limbs seem to be visually dependent on perceived midline and not by the actual configuration of the limb. Alterations induced by prisms within a body-centred frame of reference are able to change individual's functional levels (Moseley, et al., 2013).

Although repeated clinical trials and double masked studies would be helpful to support the incorporation of yoked prisms in clinical practice (Barrett, 2009), it is not always applicable. One reason is that it is sometimes difficult to apply a placebo therapy in a control group that is credible. Another reason can be the lack of customized therapeutic approach by applying the same intervention, for example the same amount of prism in every subject. Effectiveness may be significantly secured in certain study designs, where slightly different treatment approaches are applied to participants. Pragmatic trials highlighting intervention as a 'complete package', including personalized treatments and interactive relationships with health care providers, are needed along with explanatory trials to identify the nature of therapeutic effect (Richardson, 2000).

2.2 Critical review of prismatic adaptation and after-effect concepts

The term 'prismatic adaptation' is used in the optometric literature mainly to describe alterations in horizontal or vertical vergences, when prisms are applied in front of one or both eyes in an asymmetrical form (BU and BD, both eyes BO, both eyes BI). In the non-optometric literature, the same term is referred to the characteristics of visual-motor adaptation after yoked prisms have been applied. Early experiments proved that active conditions are necessary for adaptation to take place (Held & Schlank, 1959). Prism adaptation has been shown to influence the visuo-motor system (Serino, et al., 2006), performance on a series of neuropsychological tests in patients with neglect (Rossetti, et al., 1998; Bultitude & Woods, 2010; Serino, et al., 2009; Luaute, et al., 2009), global/ local processing (Bultitude, et al., 2009), visual imagery (Rode, et al., 2001), and auditory processing (Magnani, et al., 2012; Jacquin-Courtois, et al., 2010).

2.2.1 Considerations on the adaptive process and after-effects

It seems that there is no correspondence between the initial perceived prismatic effect and the prismatic power of the lens. Research has shown that subjects perceive about 40% of the field displacement, even though they remain stable and prevented from watching their own body (Redding & Wallace, 2004). The apparatus used in that experiment was made of two wooden box-like shelves with an opening on subject's side in order to place their testing hand inside, a chin rest, and an occluding shelf just below their nose. All 24 participants in this research completed three experimental phases: The 'visual shift test' required subjects to report verbally when a moving target was in their midline before and after prism exposure while keeping their head still. Any differences between measurements before and after prism exposure indicate an after-effect measurement of the eye-head system. The 'proprioceptive shift test' required to point straight ahead of their nose while blindfolded. Any differences between measurements before and after prism exposure indicate an after-effect measurement of the hand-head system. Finally, the 'total shift test' required to point at a target by preventing eye contact with their hand. Any differences between measurements before and after prism exposure indicate an after-effect measurement of either or both eye-head and hand-head systems. Results suggest an early correction effect that is present in the first attempt of the hand to point towards the target, without being visually guided.

Postural adjustment, strategic recalibration and spatial realignment have been recognized to participate in prism adaptation and after-effects (Redding & Wallace, 2004). Cognitive judgment of straight ahead is another issue that is expressed by the tendency to perceive objects that are near to the straight ahead axis to be closer to that axis than expected according to the prismatic displacement (Harris, 1974). Repetition of pointing trials tend to reduce the initial error, thus pointing closer to the real target and further than the perceived one in as few as almost 15 trials. Visual feedback from the limb used for pointing over the distal part of the movement can reduce trials even more. In addition, if movement of the pointing limb is visually guided during the whole way to the target then initial error is almost absent even during the first attempt (Redding & Wallace, 1997).

Most studies on prism adaptation use one of the subject's arms for pointing to a target, after the prism has been introduced. The motor behaviour of this arm is used to measure the extension of the prismatic adaptation. Experiments have shown that there is little to no transfer of the prismatic adaptation to the fellow unexposed arm (Baizer, et al., 1999). Later researchers indicated the generalization of the process by demonstrating that walking, as a way for achieving prismatic adaptation, was also transferred to an arm pointing movement but not the *vice versa* (Morton & Bastian, 2004). The same research group contrasted previous results proving a clear generalization of prism adaptation from arm to leg and much less from leg to arm. These results suggest that standing or walking is insufficient to provide broad generalization during prism adaptation (Savin & Morton, 2008). Generalization across two different locomotor tasks has been proven, at least partially, suggesting that generalization is highly task-dependent (Alexander, et al., 2011).

Visual-motor adaptation is prohibited, when visual feedback is denied and slowed, if delayed (Kitazawa, et al., 1995). Another way to slow down adaptation is by slowing down motor responses on purpose (Redding & Wallace, 2000). Adaptation process was found to be independent of the time spent wearing prisms but mostly dependent on the number of visual and motor systems interactions (Fernandez-Ruiz & Diaz, 1999). Prismatic adaptation seems to have different effects in healthy people than in groups with pathological pain and visual neglect. Adaptation to vertical yoked prisms has been proved to be rapid in healthy people (Huang & Ciuffreda, 2006), but not in the previously mentioned groups, where the phenomenon needs prolonged time periods (Sumitani, et al., 2007b). A case report on persisting neck pain after radical neck dissection highlighted a 30% decrease in numbness within a two month period and 'virtually nonexistent' pain sensation after five months of repeated sessions, where desensitization techniques were applied along with the use of prismatic glasses (Bartley, et al., 2014). The explanation of this time difference in prismatic adaptation is not well understood but it is speculated that an established spatial discrepancy between the objective and subjective midline exists at a neurological level in the pathologic groups, preventing the prismatic effects (Kapoor, et al., 2001). Another approach suggests that pain management with yoked prisms is probably sharing the same mechanisms of mirror-therapy to relieve phantom-limb pain by reintegrating the mismatch that exists between proprioception and visual perception (Ramachandran & Altschuler, 2009). Dyslexic and developmental coordination disorder groups also showed significant reduced time in prism adaptation compared to control groups (Brookes, et al., 2007).

It has been documented that patients with left hemiparesis present a characteristic postural imbalance compared to patients suffering from right hemiparesis (Rode, et al., 1997). It has been suggested that this is due to the functionality of the right brain hemisphere, which is crucial for perceptual and premotor spatial processing of internal maps (Perennou, et al., 1997). Postural imbalance in left hemiparetic patients seems to be affected by adaptation to prisms base left and not by prisms base right. Results are also confirmed in a case of a left hemiparetic patient, whose adaptation to prisms base left was transferred to wheel-chair driving improvement after a single short time session which lasted for many hours (Jacquin-Courtois, et al., 2007) and in a case of dysgraphia due to right brain damage (Rode, et al., 2006). Thus, postural imbalance in left hemiplegic patients could be the result of distortions of an internal postural map (Tilikete, et al., 2001). The concept of altering the internal postural map is also supported by after-effects of visuo-manual adaptation on body posture in healthy individuals (Michel, et al., 2003). Interestingly, lateral postural after-effects were induced only by leftward shifting. The resulting adaptation caused a rightward bias, simulating a left neglect posture.

After-effect has been proposed as the 'true' measure of adaptation (Weiner, et al., 1983), although prism adaptation and after-effect are not related in a simple way. It has been shown that after-effect is closely related to the magnitude of adaptation and number of pointing attempts that took place, although the latter seems to be related to the persistence of the aftereffect (Fernandez-Ruiz & Diaz, 1999). Usually, reduced after-effect is present in cases of visuo-motor deficiencies (Morton & Bastian, 2004) suggesting and reconfirming that there is difference in adaptation and after-effect performance depending on the availability of visual information. Indeed, perceptual recalibration achieved based on visual feedback yields increased after-effect compared to proprioceptive-motor system performance (Clower & Boussaoud, 2000). After-effect can also appear exaggerated when conscious awareness of visual displacement is prevented (Michel, et al., 2007) or is of very low magnitude that is not detectable (Jakobson & Goodale, 1989). In contrast, when visual feedback is prevented the after-effect of the proprioceptive straight ahead seems to lasts longer, up to seven days, compared to the visual straight ahead which lasts up to two hours (Hatada, et al., 2006).

2.2.2 Short-term and long-term adaptation

In order to make use of the prismatic adaptation and after-effects in diagnostic and therapeutic interventions, their duration should be considered. Some of the main studies on the duration of prismatic adaptation are presented in Table 1. A small study for evaluating the effect of prismatic adaptation induced by spectacle lenses showed compensation was maintained for several days (Fogt & Henry, 1999). A single session of prismatic adaptation in a neglect patient can last for at least two hours, while in other cases it has been documented lasting up to several days (Farne, et al., 2002). Two sessions daily for two weeks resulted in improvement in a group of patients up to five weeks (Frassinetti, et al., 2002). Continuous sessions of two-week duration can maintain the effects for one to six months (Serino, et al., 2007), while in one case, where daily sessions were applied for three months, improvements were still present after two years (Nijboer, et al., 2011). In healthy subjects duration of after-effects perceptual changes seems to last for a few minutes, but unfortunately this is due to experimental set ups that have not examined the long-term effects.

A recent study examined the prismatic adaptation in healthy population and found that it lasted for at least 35 minutes with fluctuations in a limited time testing of 40 minutes meaning that the effects could be present even longer (Schintu, et al., 2014).

Summary of main studies on duration of prismatic adaptation		
Author, Date	Subjects (n) / study design	Training / Duration of effect
Fogt & Henry, 1999	Normal / Healthy (n=4) / Case study	One session / Up to 4 days
Farne, et al., 2002	Right Brain Damaged patients with neglect (n=13) / case-control study	One single exposure / At least 24 hours
Frassinetti, et al., 2002	Right Brain Damaged patients with neglect (n=13) / case-control study	Two daily sessions for two weeks / Up to 5 weeks
Serino, et al., 2007	Right Brain Damaged patients with neglect (n=21) / case-control study	Ten daily sessions over two weeks / 1 to 6 months
Nijboer, et al., 2011	Patient with hemispatial neglect (n=1) / case study	Daily exposure for three months / Up to 2 years
Schintu, et al., 2014	Normal / Healthy (n=40) / pre to multiple posts design	One session / At least 35 minutes

Table 1 Summary of main studies on duration of prismatic adaptation

In another study subjective adaptation was compared to objective sensorimotor adaptation to 20 Δ BD yoked prisms. In this study 'short-term' is used for describing the length of session for adaptation. A one-hour training session was considered as short-term. At the end of the session a mean objective adaptation of 51% was recorded in sensorimotor function.

Subjective results supported the objective results of rapid adaptation resulting in a mean subjective reduction of symptoms by 41.3% (Huang & Ciuffreda, 2006).

A review of 48 studies on prism adaptation training as a treatment for neglect patients underlined the lack of fundamental clinical protocols that would be necessary for application in everyday practice (Barrett, et al., 2012). Standards of care need improvement in terms of identifying responsive patients, short and long term effects and prismatic amounts used.

2.2.3 Neurological mechanisms involved in prism adaptation and after-effects

Two mechanisms have been proposed to induce adaptation (Redding, et al., 2005). The first describes the recalibration of the motor system based on the visual feedback of the hand participating in an eye-hand coordination reference task. The second describes a proprioceptive-motor system based on the felt position of the hand during the reference task. Both systems are available and the choice for activation is based according to information that is available, although research on simulating unilateral neglect in normal population suggests that low level sensory-motor adaptations play a very important role in right hemispheric cognitive function for spatial processing (Michel, et al., 2003).

Another theory suggests that adaptation does not take place unless a discrepancy between at least two sensory systems occurs (Kapoor, et al., 2001). Neglect performance can be due to perceptual-attentional 'where' bias (Rapcsak, et al., 1989) or due to motor-intentional 'aiming' system (Heilman, 2004; Striemer & Danckert, 2010) or both (Danckert & Ferber, 2006). One study used prismatic adaptation to left or right shifting prisms compared to control plano glasses. Left-shifting prisms reduced the 'aiming' bias while in the case of right-shifting prisms and control lenses the 'aiming' bias was not affected (Fortis, et al., 2011). These results are in agreement with selective amelioration of 'aiming' bias in neglect patients (Striemer & Danckert, 2010) providing evidence that prism adaptation primarily affects the 'aiming' system.

It has been also suggested that learning motor performance is based on two different processes. Explicit learning, which is based on strategic knowledge and implicit learning, which is based on changes taking place without conscious effort. It has been shown that experts and novices use these processes differently during prismatic adaptation (Leukel, et al., 2015).

The cerebellum is considered one of the major brain areas influencing prismatic adaptation since it can be viewed as a form of motor learning. Short-term and long-term visuo-motor learning has been extensively documented as being closely related to cerebellar function (Gilbert & Thach, 1977; Friston, et al., 1992; Imamizu, et al., 2000). In addition, the cerebellum's role in visual directed movement (Hallett, et al., 1991) and eye-hand coordination has been reported (Miall, et al., 2000). It can be considered as a mechanism for integrating previous motor performance and visual errors resulting from this performance. Its involvement in prism adaptation was suggested (Held, 1965) and confirmed in patients with cerebellar disorders (Kane & Thach, 1989). Similar conclusions were extracted by other studies, which examined different aspects of prismatic adaptation (Martin, et al., 1996a) (Martin, et al., 1996b). An ipsidirectional impairment of prism adaptation has been documented for a unilateral lesion of the anterior cerebellum (Pisella, et al., 2005).

Prism adaptation is a complicated process involving not only the cerebellum but other brain areas too. During a functional imaging positron emission tomography (PET) study, brain areas including the left thalamus, the left temporo-occipital cortex, the left medial temporal cortex and the right posterior parietal cortex were recognized as participating in prism adaptation in a group of left neglect patients (Luaute, et al., 2006). Parts that receive output signals from the cerebellum like the posterior parietal cortex (PPC) (Clower, et al., 2001) and the ventral pre-motor cortex (Dum & Strick, 2003) play significant role. Although, a later study on optic ataxia argued on the necessity of posterior parietal cortex in the process by showing normal prismatic adaptation (Pisella, et al., 2004), its role cannot be underestimated. It has been suggested that since posterior parietal cortex has been proved to be involved in cognitive monitoring of new visuo-motor correspondences (Sugio, et al., 1999), it is likely to participate in some form of reorganization and spatial re-alignment between visual and proprioceptive parameters. As a result, it has been proposed that the cerebellum plays an important role in adaptive realignment, while the posterior parietal cortex is involved mainly in the cognitive strategic compensating of the prismatic deviation. Dysfunction in one of these areas could result in increased action of the other, by strategic compensation or adaptive realignment (Pisella, et al., 2004).

Brain imaging in neglect patients have confirmed hypotheses involving the parieto-cerebellar network (Danckert, et al., 2008; Chapman, et al., 2010). Recently, involvement of parietal lobes in spatial remapping was investigated providing evidence that prism adaptation alters mainly the right parietal lobe. Spatial remapping is the construction of a stable perception of a visual environment even when this is continuously changing and results indicated improvement in patients with neglect symptoms and neglect-like performance in healthy population (Bultitude, et al., 2013). This is in agreement with research proposing that yoked prisms affect the internal map for space and body representations (Tilikete, et al., 2001). In addition, it has been suggested that prism adaptation may magnify or shift the part of space represented in the spared cortical hemisphere by creating a different distribution of spatial representation between hemispheres (Redding & Wallace, 2006). Thus, prismatic effects should not be considered as a passive tool for altering sensory information but as a dynamic tool involved in the sensorimotor process and related to multisensory integration and space representation (Rossetti, et al., 1998).

By using event-related functional magnetic resonance imaging (fMRI) researchers have been able to study brain activity before, during and after prism exposure, allowing for parametric analyses. During early prism exposure where error detection needs to be accomplished, the anterior intraparietal sulcus plays an important role. This area's activation has been documented clearly in an event-related fMRI study during visuo-manual adaptation (Danckert, et al., 2008). At a later phase, where error correction emerges, the parieto-occipital sulcus is involved. As spatial realignment is introduced activity in the cerebellum increases progressively suggesting promotion of neural activity in the temporal cortex which is activated during the late phase of adaptation related to spatial representation (Luaute, et al., 2009). Recently, research using fMRI on seven patients with left neglect indicated enhanced activity in bilateral parietal, frontal and occipital areas during line bisection and visual search tasks. These findings suggest that prism adaptation activates bilateral neural networks involved in spatial attention and awareness thus counteracting right hemisphere damage (Figure 5) (Saj, et al., 2013).

Aston University

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Figure 5 Brain activation during three different tasks in young adults and neglect patients before and after prism adaptation. Lesioned cortical regions are marked in dark gray shades. Light colours indicate brain regions activated relative to baseline activity (from Saj, et al., 2013).

2.3 Parameters influencing posture and postural sway

The ability to maintain a stable posture is based on visual, vestibular, and proprioceptive information. It has been documented that in healthy subjects standing on a firm base, posture is based on 70% somatosensory inputs while the vestibular system involves 20% and vision only 10% (Peterka, 2002). Any environmental change can alter these relative contributions and so does age (Poulain & Giraudet, 2007). Although the value of each system can be considered separately, it is the integration of the systems that seems to be the key in understanding more holistically the dynamics of posture. All three systems provide ample spatial information used in specification of postural state (Wade & Jones, 1997). In fact, the central nervous system might actively suppress visual information that is inconsistent with input from other sensory systems involved in postural control (Buchanan & Horak, 1987). Reflexive actions that co-ordinate body parts in order to keep an essential upright posture are called postural righting reflexes. Postural righting reflexes that are based on these systems include visual righting reflexes, labyrinthine righting reflexes, neck righting reflexes, body-on-head righting reflexes and body-on-body righting reflexes (Morningstar, et al., 2005). Since the action-perception circuit is important for the human interaction with the environment, it has been proposed that an important role of postural control is to provide a stable frame of reference for sensory and motor systems (Stoffregen & Riccio, 1990).

A frequently used method that has been applied for measuring the effect of visual stimuli in posture has been the measurement of the centre of foot pressure (CoP) (Benda, et al., 1994). It is generally accepted that CoP is related to body sway and reduced sway can be translated to increased stability, thus to better posture performance, although it has been suggested that people do not always attempt to minimize postural sway (Stoffregen, et al., 2000). The amplitude of postural sway can be regulated according to the visual task, despite the fixation distance, which is in contrast with earlier theories supporting the notion that goals beyond posture maintenance have no role in synthesis of postural control (Schoner, 1991).

2.3.1 The role of peripheral and central vision in posture

Vision provides a huge amount of information to the person concerning self-motion and environmental conditions, often overriding other sensorial information. ‘Focal’ and ‘ambient’ vision processes have been used to differentiate functional characteristics of visual performance (Wade & Jones, 1997). Although these two terms have not been used extensively in optometric literature, they are interestingly descriptive and useful when explaining functional aspects of visual perception and they have been often adopted by behavioural and developmental optometrists. Focal vision is the detection of physical characteristics, patterns and parts of our environment, while ambient vision is referred to spatial and motional characteristics of the surrounding (Gibson, 1979). Focal vision emerges mainly from central visual field, while ambient vision is mediated mainly from the peripheral field (Padula, 2012).

In functional terms, focal vision answers to ‘what is it’ while ambient vision to ‘where is it’. This approach could be considered as parallel to ‘parvo’ and ‘magno’ visual pathways that neurosciences have identified as attempting to answer these two questions. Although parvo derives mostly information from the central visual field and magno from the peripheral visual field, we must recognize that they are not limited to those areas. The visual field areas for deriving information for each system actually overlap (Yoonessi & Yoonessi, 2011).

Researchers have investigated the potential relationships of focal and ambient vision with postural control by considering peripheral vision as dominant (Amblard & Carblanc, 1980; Brandt, et al., 1973) or peripheral and central as equally important (Bardy, et al., 1999; Piponnier, et al., 2009) or the complementary role of each other (Nougier, et al., 1998).

Results are contradictory and a possible reason for this could be the different field limitations given to the central and peripheral areas. For example, one study defines central field up to 10° (Nougier, et al., 1998), while another defines it up to 60° (Brandt, et al., 1973). From an anatomical point of view central vision could be defined up to 4° or 7° based on the cone distribution on the retina or the visual field projecting to the area of the visual cortex responsible to process central vision accordingly (Berencsi, et al., 2005).

Early studies found that body sway was two to three times larger, when eyes were closed compared to open (Edwards, 1946). Loss of the peripheral vision in patients with pathologic conditions, such as glaucoma and retinitis pigmentosa, has been determined as having significant effects on mobility performance and gait distribution, compared to age-matched normal subjects (Diniz-Filho, et al., 2015; Turano, et al., 1999; Geruschat & Turano, 2007; Black, et al., 1997). Increased body sway has been also reported in blind or low vision patients with Usher's syndrome (Pyykko, et al., 1991). When central vision was altered by simulating hyperopic conditions at a level of 20/200 (6/60), posture resulted in loss of stability (Friedrich, et al., 2008).

Another study indicated contrast sensitivity as more affective on posture rather than visual acuity (Lord & Menz, 2000). Planning gait adaptation is considered to be centrally dependent, while fine tuning of adaptive gait is considered to be peripherally dependent (Graci, et al., 2010). Peripheral vision seems to contribute significantly to the control of quiet standing as proven by smaller body sway (Berencsi, et al., 2005). These results are in agreement with previous experiments showing that use of visual information in general, during quiet standing, supports posture stability (Mitra, 2004). In contrast, when dynamic environmental visual stimulation is used during the experiments, like optic flow (Habak, et al., 2002) or a moving room (Warren & Kurtz, 1992), vision seems to react as attempting to counterbalance the continuously changing surrounding. This fact results in increasing body sway indicating that vision affects posture. Peripheral vision has been documented as more sensitive to forward-backward optic flow than right left motion (Stoffregen, et al., 1987). The body is trying to move towards homeostasis in an illusionary environment, as an attempt to regulate stability, proving that in quiet and dynamic conditions vision plays an important role.

2.3.2 The role of ecological optics in posture

The ecological approach to visual perception (Gibson, 1979), challenges the classical focal-ambient model in many aspects that could affect body posture. As we move in space or as environment moves around us, the optic flow at the extreme periphery of our visual field is almost parallel to the direction of motion. This flow has been termed 'lamellar flow' in contrast to 'radial flow' emerging from the centre of our visual field (Stoffregen, 1985). As a result, visual information used for the control of posture depends also on the geometric form of the field that creates visual flow. This model suggests that postural control and motion perception are not based solely on central and peripheral sensitivity, but also on structure of the optical flow field which can be lamellar or radial (Stoffregen, 1985). Even small changes in the optic flow during a relatively upright posture can induce compensatory sway (Lee & Lishman, 1975). Experiments have shown that peripheral perception affects body posture more when stimulation is of lamellar form and less when it is radially structured (Koenderink & van Doorn, 1981). It has been also suggested that changes in environmental dynamics result in postural changes (Riccio & Stoffregen, 1991).

More recent research has confirmed the value of optic flow and motion parallax with virtual reality displays showing that, by removing those clues, posture was not stabilized by vision (Kelly, et al., 2008). On the other hand, optic flow has been previously argued by the same group as the only visual stimulus to control posture, demonstrated with the presence or not of 3D stimuli in controlled optical flow conditions (Kelly, et al., 2005). It is also obvious that distance plays an important role in detecting retinal slips of our environment since precision is limited when viewing from a far distance. These changes could probably also take place when yoked prisms are applied, changing field curvature resulting in more lamellar or radial optic flow.

2.3.3 The role of binocular vision in posture

The importance of binocular vision is still not clear and remains debatable. It has been suggested that there is a preferred eye, the so-called ‘postural eye’, providing better performance in posture control. Experiments were done under monocular conditions and the dominant eye was recorded. It is interesting that the postural eye was not necessarily the dominant eye (Gentaz, 1988). The most obvious effect of binocular vision on posture has been documented in studies measuring body sway in strabismic compared to normal subjects. The strabismic group showed decreased stability even in cases, where visual acuity was normal in both eyes (Odenrick, et al., 1984). A study on strabismic participants showed increased body sway compared to a control group with normal binocular vision. It is interesting that researchers in that study included additional measurements during mental tasks in order to evaluate any further decrease in performance. The results showed no further reduction in stability but an increase close to the level of the control group, leading authors to the conclusion that reduced stability in the strabismic group was not due to lack of binocularity but probably related to poor proprioceptive oculomotor signals (Przekoracka-Krawczyk, et al., 2014), suggesting also that vision therapy and/or surgery could be of benefit. In fact, a study on postural control before and after strabismus surgery revealed that postural stability improved after successful surgical intervention, underlining that binocular visual perception and influences on extraocular muscles have been beneficial (Legrand, et al., 2011), even though body sway was increased immediately after the surgery (Matsuo, et al., 2006). In addition, changes in the direction and frequency of body sway were recorded before and after surgery. Increased antero-posterior oscillations of low frequency before surgery were transformed to increased medio-lateral oscillations of middle and high frequency after surgery (Legrand, et al., 2011). Body sway changes and postural stability in strabismic subjects seem to be dependent also on the type of correction. Correcting intermittent and constant exotropes with the appropriate prisms resulted in reduced performance due to visual, motor and perceptual changes with prismatic adaptation taking place one hour after the initial application (Matsuo, et al., 2010). On the other hand, strabismus-like induced conditions with application of a small vertical prism in front of one eye showed complex effects by increasing or decreasing postural stability depending on the eye wearing the prism and the viewing distance (Matheron, et al., 2007). Viewing distance is an important factor related to the type of strabismus as assessed in quite recent research the results of which indicated that postural stability was enhanced in proximal distance for convergent strabismus and distal for divergent strabismus (Gaertner, et al., 2013a).

Binocular vision has been shown to provide a postural advantage in a children population based study compared to those suffering from vertigo, due to vergences fusional dysfunction (Bucci, et al., 2009). Interestingly, the advantage of binocular stimulation, even in lack of fusion, has been highlighted in a study that showed increased stability with eyes open, compared to monocular viewing with dominant or non-dominant eye, despite the viewing distance or type of strabismus (Gaertner, et al., 2013b), although earlier studies had failed to find this relation (Fox, 1990; Isolato, et al., 2004; Le & Kapoula, 2006). Postural stability has been investigated in binocular, monocular eye-dominant conditions and in absence of visual information in a dark environment. Results indicated that stability was increased in binocular compared to monocular conditions, but the effect was also present in a dark environment (Fox, 1990). In contrast, other studies failed to find any differences with eyes closed or open in the dark (Paulus, et al., 1984). A later study examined stability with eyes open, dominant eye open, non-dominant eye open and both eyes closed. Results showed that at an individual level, binocular vision increased stability in only half of the participants supporting the concept of ‘postural eye’, while at a group level monocular and binocular conditions provided equally good stability in normal subjects (Isolato, et al., 2004). Similar results were obtained in another study highlighting the differences at an individual level (Guerraz, et al., 2000). It is still not clear, why only some individuals perform better in binocular than in monocular conditions especially since it cannot be attributed to visual input. Unfortunately, stereopsis measurements were not mentioned in those studies, thus underestimating the potential effect of 3D vision which has been proposed as an additional clue for posture stabilization (Kelly, et al., 2005).

The effect of gaze position and convergence has also been studied. A decrease in the surface of CoP has been documented, when gaze was oriented 15° above or below eye level at distance but this difference in performance was not present when looking at near where all positions of gaze induced the same limitation in the centre of pressure compared to distant viewing in primary gaze. In addition, distance viewing through prisms moved convergence to locate at 40 cm when the effect of pure convergence on posture was investigated. Again, prism induced convergence resulted in the same sway decrease as in natural converging conditions (Kapoula & Le, 2006). This is also supported by the fact that distance is an effective factor but only under binocular conditions (Le & Kapoula, 2006). It is possible that other mechanisms like proprioception or tonicity of extraocular muscles support or enhance this performance.

2.3.4 The role of proprioceptive, somatosensory and vestibular systems in posture

Focusing above or below eye level has been documented to reduce body sway (Kapoula & Le, 2006; Ustinova & Perkins, 2011). Early studies have suggested the role of extraocular muscles proprioception in balance and control of posture (Ushio, et al., 1980; Eber, et al., 1984) and their effect on altering tonicity of the neck muscles through a chain of brain-stem reflexes (Corneil, et al., 2004). The proposed neural circuit initiates at the proprioceptive afferents of the extraocular muscles situated in the trigeminal nerve and project to cerebellum, reticular formation and vestibular nuclei, which in turn are connected to spinal motor neurons and extraocular efferents. Proprioceptive signals may also project centrally through the ocular motor nerves (Gentle & Ruskell, 1997).

Head and neck position along with gaze direction are relevant to postural responses in standing and walking conditions (Ivanenko, et al., 1999). This fact proposes a model of a head-eyes frame of reference for controlling posture. Studies have underlined the importance of head stability in the critical process of locomotion (Grossman, et al., 1989) and body posture (Riach & Starkes, 1989). Activation of the neck muscles is necessary for cervical spine, visual and vestibular systems stability (Falla, et al., 2004). Stimulation of the neck muscles has been shown to result in an illusory predictive movement, which is related to the specific muscle (Roll, et al., 1991). When vibrations were applied to sternocleidomastoids a slow upwards displacement of the target was perceived, while a downwards displacement occurred, when trapezius and splenius muscles were stimulated. Although, vestibular system is important for orienting head in space, it is impossible for the semicircular canals or otoliths to inform the brain of the head angle relative to body without neck proprioception (Cohen, 1961).

In addition, there are muscular synergies between extraocular muscles, neck, trunk and lower limbs. There is evidence that head flexion or extension deteriorates postural stability

(Buckley, et al., 2005). Although at first sight this effect seems closely related to the vestibular function, it has been proposed that muscle-spindle proprioceptive inputs might create a sequence of signals starting from the feet towards the eyes in order to provide an internal representation of the body posture (Roll & Roll, 1988). The upright posture provides the most efficient alignment for the maximal integration of all sensory systems. Studies on Golgi tendons and muscle spindles indicate that proprioceptive information is the root for the postural maintenance (Young, 2004). The discovery of graviceptors in the trunk is important since they seem to contribute equally with otoliths in the eye, neck and limbs posture (Mittelstaedt, 1999).

The vestibular system is considered a major component of the informative system that regulates balance and orientation (Creath, et al., 2002). It consists of three semicircular canals, the utricle and the saccule. The role of the semicircular canals is to inform us about rotational acceleration. Each canal is located in a different plane for detecting different directional changes. The utricle and the saccule incorporate otoliths responding to gravity and linear acceleration of back-forth, up-down and side to side directions (Magrun, 2012). The vestibular nerve carries input from the utricle and saccule to the lateral vestibular nucleus which also receives signals from the cerebellum and optic tract. Vestibular nuclei then project to the thalamus, the superior colliculus, the reticular formation, the cerebellar flocculus and the lower vestibulospinal nuclei. The visual and the vestibular systems share much information through continuous interactions at a reflexive level. The visual system can initiate feedforward signals regulating vestibular system and vice versa.

2.3.5 Visual, vestibular and cervical interactions for postural control

There are eight reflexes including feedforward and feedback mechanisms between the eyes, the neck and the vestibular systems which are task related effecting interaction and integration (Moore, 2001). Among the most important to postural control are the vestibular ocular reflex (VOR) (Raphan & Cohen, 2002), the vestibular-spinal tract (Buttner-Ennever, 1999), and the dorsal and ventral spinocerebellar tracts (Bosco & Poppele, 2003). The VOR is important for maintaining a fixed gaze on an object by inducing proper compensatory eye movements to head rotations or accelerations. It can be further subdivided to the rotational vestibular ocular reflex which detects head rotations through the semicircular canals, the translational vestibular ocular reflex which detects linear acceleration through utricle and saccule, and the ocular counter-rolling response which regulates eye rotations during head tilt or rotation (Goldberg & Hudspeth, 2000). However, we constantly change fixation so VOR must be released in order to attend another stimuli (Buchanan & Horak, 1987). The vestibular spinal tracts can be considered as the efferent pathway of the vestibular ocular reflex that modulates neural activity for rapid postural adaptations. It is controlled by the cerebellum where visual, vestibular and cervical mechanoreceptive information are interpreted and compensatory reactions travel through these tracts. It originates in the lateral and medial vestibular nuclei with its tracts allowing for changes in trunk and extremities during sudden perturbations in static posture (Goldberg & Hudspeth, 2000). Dorsal and ventral spinocerebellar tracts are afferent pathways carrying information from the lower extremity to the cerebellum. This is termed pelvo-ocular reflex and serves to orient the body relative to head position and visual clues (Lewit, 1985). Signals from joints, skin, muscles spindle and Golgi tendons are connected to spinal interneurons through the afferent and the efferent spinal pathways. From the spinal interneurons emerge the spinocerebellar tracts, which will finally effect the visual-vestibular interaction (Bosco & Poppele, 2003).

There are also three connections serving postural control between visual and vestibular systems and cervical spine. Their actions are reflexive, supporting mainly vestibular ocular reflex or compensating for its function in case of vestibular loss of information and they all arise from receptors in the cervical spine (Chambers, et al., 1985; Bronstein & Hood, 1986). The cervico-ocular reflex serves to direct eye movements to changes in neck and trunk position. It is interesting that cervico-ocular reflex seems to increase response with application of plus lenses inducing magnification and decrease response with application of minus lenses inducing minification (Heimbrand, et al., 1996). Although cervico-ocular reflex is important for assisting posture in patients with vestibular dysfunctions, its importance is debatable in healthy subjects (Schubert, et al., 2004). The cervicocollic reflex serves to direct the position of head and neck relative to trunk and it is in close coordination with the vestibulocollic reflex, providing advanced sensitivity in changes on the vertical and horizontal plane respectively (Peterson, et al., 2001).

Other postural reflexes that contribute to homeostasis of a relaxed posture are skin and surface receptors on the extremities (Inglis, et al., 2002), somatic graviceptors within the viscera (Jarchow, et al., 2003), and baroreceptors within the circulatory system (McIntrye, et al., 2004). Despite the interactions and interconnections that have been mentioned it is important to note that visual input is of major significance independently from the gravitational force that affects vestibular and somatosensory systems. A study on astronauts during space flight showed a pronounced lean of the trunk forward with eyes closed compared to eyes open (Baroni, et al., 1999).

2.4 Critical concepts in visual midline and egocentric localisation

The information about the body’s localisation in space in order to execute a coordinated directed movement is termed as ‘egocentric localisation’, while the information about relative positions of objects to each other is termed ‘allocentric localisation’ and are based on various sensory inputs. Numerous different techniques have been proposed over the years for measuring egocentric and allocentric localisation based on different reference frames

(Houston, 2010). The ‘proprioceptive’ hand-head frame and the ‘visual’ eye-head-centred frame are the most commonly used in eye-hand coordination researches.

It is suggested that representation of space may be related to more than one co-ordinate system (Bisiach, et al., 1985). Since egocentric localisation is based on various sensory inputs there are three different conditions that have been proposed for examining the perceived midline in normal or neurologically challenged subjects (Table 2). The first, the ‘proprioceptive’ hand-head midline, has been recognized many decades ago by the researchers and has been extensively used in studies by preventing any visual stimuli. As a result the subject is supposed to subjectively point straight ahead based mainly on proprioceptive clues (Hatada, et al., 2006). Normal subjects present a tendency to point slightly to the left of the centre while subjects with right parietal lesions present a tendency to the right of the centre (Sarri, et al., 2008). Another study on left brain damaged patients indicated a leftward tendency in pointing (Chokron & Bartolomeo, 2000).

The second, the ‘visual’ eye-head midline, is predominantly visual in nature and request mentioning, for example, in cases where the subject has to detect the exact moment that a moving target is close to the perceived midline. Limiting information from proprioception of the extraocular and neck muscles is an important factor possessing the significance of the target’s velocity. If the target’s movement is too slow then proprioception may influence results. The testing environment should be empty of visual clues that could induce an artificial reference frame (Kapoor, et al., 2001) and this is probably one of the major parameters not properly applied in clinical settings. This method is well known among clinician specialized in visual rehabilitation and neuro-optometric fields. Patients with right brain lesions accompanied by left hemiparesis show a rightward shift tendency (Padula & Argyris, 1996), while right brain damaged patients with left inattention perform different when the target approaches from the right or left side (Farne, et al., 1998). Results can be reversed when testing post-acute stroke patients showing rightward tendency in 77% of the left brain damaged patients and leftward tendency in 79% of the right brain damaged group (Padula & Argyris, 1996).

The third component is the visual ‘open loop’ which prohibits eye contact with the hand pointing a visual target. Spatial boards or space boards have been used for decades mainly by behavioural optometrists providing insights into midline perception with low cost (Valenti, 1996). Visual ‘open loop’ pointing can be considered as the connecting link between the previous two components (Wilkinson, 1971) showing normal responses in right brain damaged patients (Sarri, et al., 2008). Even though it is extensively used in research studies it is better not to be considered as the sole method for evaluating egocentric localisation and midline perception because it has been shown to be contaminated by sensorimotor learning strategies (Redding & Wallace, 1993).

	'Proprioceptive' Hand – Head Midline	'Visual' Eye – Head Midline	Visual 'Open Loop' Midline
Hand proprioception	✓	✗	✓
Head proprioception	✓	✓	✓
Vision	✗	✓	✓

Table 2 Three frames of reference that affect egocentric localization, emerging from the integration of different sensory information. Red rings show the integrated sensory information. Note that in the Visual 'Open Loop' condition all three sensory information are available but partially integrated, with head proprioception as the joint parameter.

The perceived midline has been shown to be influenced by induced experimental pain towards the side of the pain, while application of vibration stimulation shifts midline to the opposite direction (Bouffard, et al., 2013). Thus, results suggest that perceived midline can be affected by various stimuli and in relation to the type of stimulation, probably as a part of reflexive protective mechanism.

CHAPTER 3 – Introduction to the experiments

3.1 Aims of the research

An extended review on the use of yoked prisms was covered in the previous chapter along with the mechanisms involved in prismatic adaptation. In addition, a literature review on multi-sensory and visual factors affecting body posture and egocentric localisation was conducted in order to provide the base upon which the rationale of this research is based.

The primary aim of this study is to investigate the direct, immediate effect of lateral and vertical yoked prisms on body posture, perception and egocentric localisation before any prismatic adaptation takes place. Previous researchers have investigated these effects mainly as results of prismatic adaptation while in many cases it is not clear if adaptation was enhanced or prevented. It is important to understand the initial effects that lenses have on human behaviour before any interaction alter perceptual and cognitive performance. This could provide a better insight as to what is primarily affected that sets the ground for the adaptation to take place. Adaptation can be influenced by the conditions, underlying pathology and cognitive strategies used by subjects thus providing different expressions of its nature. This is the main reason for studying the initial effects before any prismatic adaptation takes place.

A secondary aim of this study is to investigate any correlations between the perceptual and postural expressions of the prismatic effects. Any postural alterations could be the reflection of what is spatially or egocentrically perceived or *vice versa*. If yoked prisms have a significant effect on posture but not on perception, then it can be suggested that alterations in perception are the results of prismatic adaptation. If yoked prisms have a significant effect on perception but not on posture, then it can be suggested that alterations in posture are the results of prismatic adaptation. If yoked prisms have a significant effect on perception and posture, then it can be suggested that alterations do not need prismatic adaptation to take place.

A third aim of this study is to highlight any potential clinical applications of yoked prisms in the rehabilitative or preventative eye care fields. If body posture and spatial perception seems to be altered in a predictive way, then application of yoked prisms may be helpful in a series of acts in rehabilitative care. Although, the use of prisms has been suggested in low vision patients, their application is not always in a binocular yoked form. Patients with congenital or acquired neuro-muscular dysfunctions and patients experiencing neglect or spatial perception dysfunctions after a stroke could benefit from the application of yoked prisms.

Apart from the pathological groups, healthy subjects could also benefit in terms of preventative care. The extended use of computers, tablets and cell phones enhance ‘forward head syndrome’ resulting in neck and back problems (Edmondston, et al., 2008) and other postural asymmetries resulting in orthopedic dysfunctions. In these cases, the application of yoked prisms could assist in sustaining an appropriate body posture. Yoked prisms are also incorporated in the designs of all progressive addition lenses, so a deeper understanding of their postural and perceptual effects could benefit industry in designing lenses of increased performance. Although yoked prisms have been used by other disciplines in their research areas, prescription is up to optometry. Any clinical application could become a bridge for optometry to multi-disciplinary health care. The following chapters describe the experiments for evaluating the effect of yoked prisms on barycenter, body posture, spatial perception and egocentric localisation.

3.2 Ethics and exclusion / inclusion criteria

The study was approved by the Aston University Sciences Ethics Committee on 14th November 2012 – PhD Ethics application 379 and conducted in researcher’s optometric practice. All participants in this study were provided with an informational sheet and signed a consent form in Greek and English.

All participants were healthy adults and exclusion criteria included any history of ocular, vestibular, neurological or orthopedic pathology that could affect stability or induce discomfort, and any strabismus or nystagmus history. Participants were also asked about any medication that they have taken during the last 15 days. Inclusion criteria were at least 6/6 uncorrected or corrected with contact lenses acuity with each eye.

CHAPTER 4 – Experiment 1: Effects of yoked prisms on posturography and barycentre

In the previous chapter an extended literature review was conducted on the use of yoked prisms in different clinical and research areas. The underlying mechanisms and the supporting theories for prismatic adaptation and after-effects were also reviewed along with the parameters affecting body posture and egocentric localisation. Previous studies have investigated these effects mainly as results of prismatic adaptation while in many cases it is not clear if adaptation was enhanced or prevented. In this experiment prismatic adaptation was prevented and immediate prismatic effects on body posture were recorded in terms of weight distribution and centre of pressure during posturography.

4.1 Introduction

The majority of previous studies for investigating body responses to yoked prisms using posturography have been conducted in subjects with neurological conditions or sensory-motor dysfunctions (Johannsen, et al., 2006) and much less in normal population (Gizzi, et al., 1997). The time frames of exposure to yoked prisms are usually not mentioned in previous studies, so there are no clues as to how long subjects were exposed to prismatic effects. Most importantly, it is not mentioned whether subjects were engaged in any activities that could have enhanced prismatic adaptation.

The objective of this experiment was to investigate the effects of yoked prisms on the barycenter in a normal population during standing. Specific attention was given in preventing any prismatic adaptation during the experiment.

4.2 Method

4.2.1 Participants

Concerning experiment 1, given an effect size of 0.25 and a power level set at 0.95 (for a level of error of type I set at 0.05) the minimum required size for repeated measures ANOVA was 45. In this experiment 50 participants were included. Thirty-three (66%) were women. Regarding age, the mean age of the 50 participants was 36.14 years and the standard deviation (SD) was ±9.69. The minimum and maximum ages of the participants of the sample were 20 and 58.08 years respectively. All subjects were recruited from population that visited the optometric practice for a regular examination and sustained the criteria for participating in the study.

Variables concerning refractive status of monocular and binocular conditions were analyzed. The refractive status of the participants was as follows: The mean value of the right eye (RefractionRE), was -0.99 D and the SD was ±2.00 D. Minimum and maximum values were -7.37 D and +0.75 D respectively. The mean value of the left eye (RefractionLE) was -0.92 D and the SD was ±1.92 D. Minimum and maximum values were -7.87 D and +1.00 D respectively. The mean value of both eyes (RefractionBE) was -0.95 D and the SD was ±1.95 D. Minimum and maximum values were -7.62 D and +0.87 D respectively (Table 3)

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Age	50	38.08	20.00	58.08	36.1486	1.37112	9.69528	93.998
RefractionRE	50	8.125	-7.375	.750	-.99000	.284189	2.009518	4.038
RefractionLE	50	8.875	-7.875	1.000	-.92000	.271658	1.920911	3.690
RefractionBE	50	8.500	-7.625	.875	-.95502	.277092	1.959336	3.839

Table 3 Age, monocular and binocular refraction (Experiment 1)

4.2.2 Materials

The posturography platform of Comex SA (Loran Engineering Ltd., Via Bruno Buozzi, 40013, Bologna, Italy) was used functioning in a recording frequency of 50 Hz. Posturographic platforms are equipped with a layer sensitive to pressure. When a subject steps on it can record the different amounts of pressure applied to the layer, point by point, under each foot separately and transfer these data to the computer. The software used was Foot Checker 4 (Loran Engineering Ltd., Via Bruno Buozzi, 40013, Bologna, Italy) for measuring mean pressure percentages and sway area.

Three pairs of glasses were used. One pair had no prisms incorporated while the other pairs incorporated 8 Δ yoked prisms with the orientations of the prism bases placed either base up (BU) or base left (BL). All pairs were mounted in strap-on wide frames (Bernell Co, 4016, N. Home street, Mishawaka, IN 46545, USA) so they were easily adjusted. Previous studies have used yoked prisms between 5 Δ and 40 Δ. The amount of 8 Δ was selected as the one close to the maximum amount that usually can be incorporated in a prescription by ophthalmic lens manufacturers.

4.2.3 Procedure

Subjects were asked to choose randomly between three colours (red, blue, green) representing a pair of flat yoked prisms 8 Δ BU, a pair of flat yoked prisms 8 Δ BL and a pair of plano lenses not incorporating any prisms respectively.

The platform was connected to a laptop where the appropriate software analyzed the standing performance. The software provided a topographic pressure map of both feet for a specific time period. Since recording is not momentary the program can also provide information about shifts in the centre of pressure (CoP), which can be related to the sway performance of the standing posture. Mean pressure percentages were analyzed in quadrants representing the anterior and posterior part of each foot (Figure 6). The topography of each foot is presented in colour according to the pressure each area receives. Warm colours indicate increased pressure while cool colours indicate reduced pressure. In Figure 6 there is a screenshot showing the software's display, supplementary explanations are given in colourful text corresponding to the relative colourful ellipses. The body's barycentre was measured in the lateral and anterior-posterior axis in millimetres providing the maximum range of sway to the left, right, front and back (Figure 7). In this screenshot showing the software's display supplementary comments indicate the areas where data about the lateral, anterior-posterior and total maximum shift of the body's barycentre are shown. Two separate graphs show lateral and anterior-posterior shifts in barycentre during the recording time frame. Each graph presents continuous shifts of the left and right foot separately with red and blue lines respectively. The green lines show the resulting body's barycentre shift, which is also presented on the top part of the screen as an emerging ellipse and can be considered as an expression of body sway.

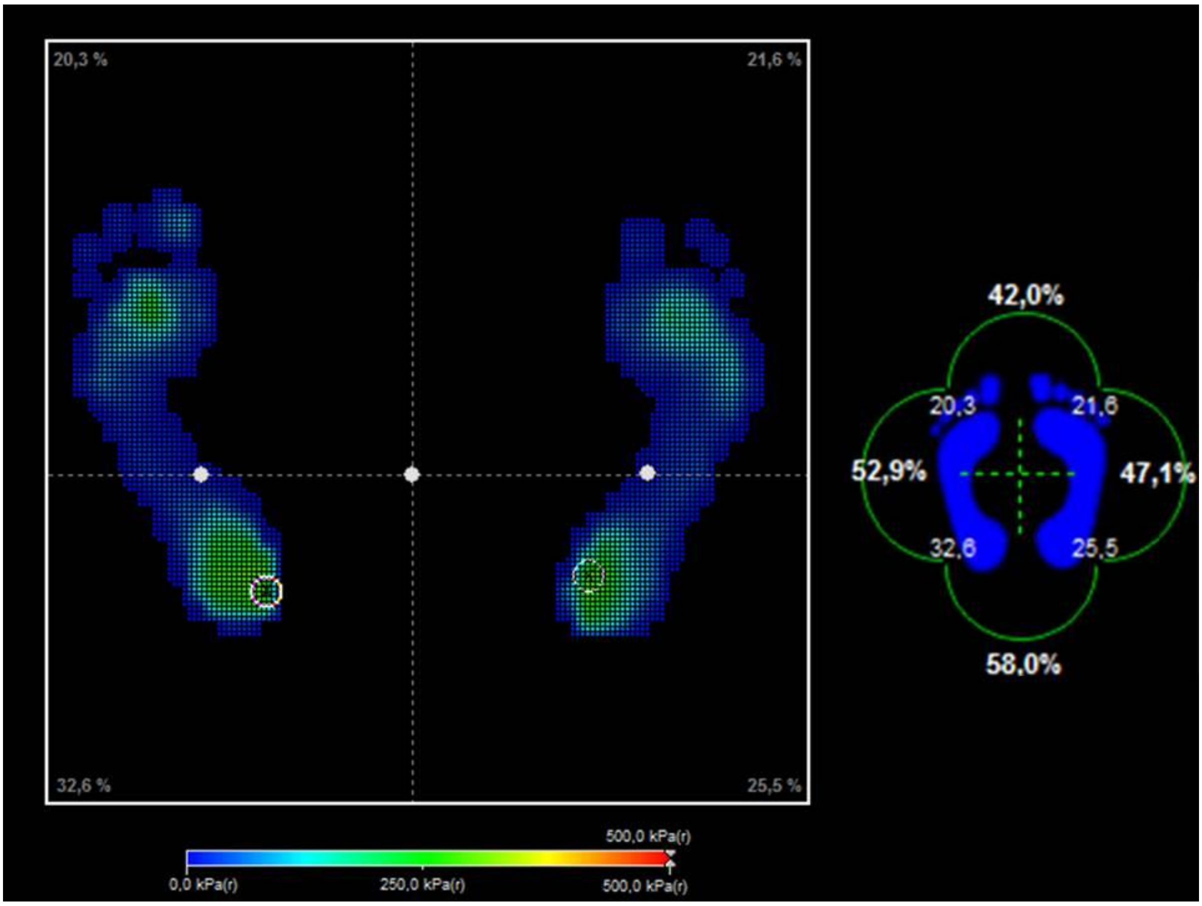


Figure 6 Foot Checker 4 display of mean pressure percentages. Percentages appearing on the four corners of the square represent the mean pressure of the anterior and posterior parts of the right and left foot. The diagram on the right duplicates the same data but also

provide the summation of the anterior and posterior parts for each foot and the summation of anterior and posterior parts for both feet.

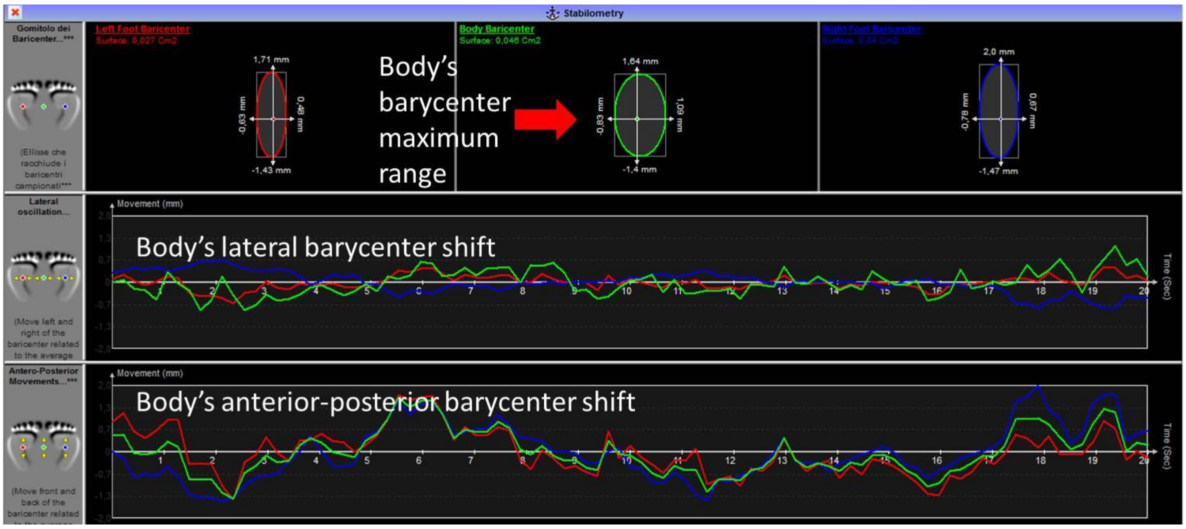


Figure 7 Foot Checker 4 display of the lateral and anterior-posterior maximum barycenter's shift

Subjects were asked to step barefoot on to the posturography platform and stand still in a natural and relaxed position viewing a single 6/9 letter at the distance of 3 m (Figure 8). Participants were asked to try to keep fixating on this single letter during the whole procedure and to avoid looking at extreme gaze positions. After one minute the first pair of prisms chosen randomly by the subject earlier was applied and after an additional minute the first recording took place for 20 seconds. Then the first pair was removed and a two-minute break was intervened before applying the second pair of prisms. During this period only small foot or body readjustments that would ensure a relaxed position were allowed and subjects remained on the platform. Application of the second pair was followed by a one-minute period and a new recording for 20 seconds was taken. The experiment ended after the third pair was applied following the same steps of two-minute break, one-minute wait with the new pair and the last 20-seconds recording.

Figure 8 Subject standing on the posturography platform (photograph author's own)

4.2.4 Statistical analysis

Statistical analysis was conducted with SPSS statistical software (Version 20, SPSS Inc., an IBM Company, Chicago, Illinois, USA). The Shapiro-Wilk test was used in order to test whether variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. One-way repeated ANOVA is suitable because the participants tested under three conditions (Plano, BU, BL) where the same persons. In case that the normality hypothesis was violated, both repeated measures ANOVA test and its non-parametric version, Friedman test (Table 6, columns (15) to (16)), were conducted, but all findings were discussed according to Friedman's test where medians are compared instead of means. It's worth mentioning though that the repeated measures ANOVA test is robust to violations of normality.

In the cases where the repeated measures ANOVA test has been used, it is conducted first a Mauchly's test of Sphericity (Table 6, columns (3) to (6)) in order to determine whether the variances of the differences between all combinations of levels of the within-subjects factor are equal. If p-value < 0.05 (Table 6, column (6)) which means that the sphericity assumption has been violated, an epsilon correction is performed using Greenhouse-Geisser and Huynh-

Feldt estimates (Table 6, columns (7) to (8)). So, if the minimum of these two values is below 0.75 the repeated measures ANOVA test is performed using a Greenhouse-Geisser correction otherwise a Huynh-Feldt correction is used (Table 6, column (9)). If p-value < 0.05, (Table 6, column (13)), the null hypothesis stating that the means between levels are equal has to be rejected.

In the cases where the Friedman test has been used, the null hypothesis is rejected if p-value < 0.05 (Table 6, column (16)).

ANOVA or Friedman (when the assumption of normality is violated) post hoc tests need to be performed in order to determine which groups differ in mean or median. Using SPSS 20, in case of ANOVA post hoc tests, multiple paired-samples t-test with Bonferroni adjustment are conducted, while in case of Friedman post hoc tests, pairwise comparisons are conducted using the Wilcoxon signed-rank test with a Bonferroni correction for multiple comparisons. If p-value < 0.05 (column 'sig' in case of ANOVA tests of column 'Adj.Sig' in case of Friedman tests) then the difference in means or medians between the two groups, for each pair of groups stated, is statistically significant (see column 'Mean Difference' (I-J) for ANOVA test or column 'Sample1-Sample2' for Friedman test).

4.3 Results

All descriptive characteristics of the parameters that were analysed are presented below in Table 4.

Variable Name	Mean	Median	Std. Deviation	Minimum	Maximum
WD_x_LF_Plano	49.7840	48.6500	4.64619	41.30	58.80
WD_x_LF_BU	49.6020	49.4500	4.84522	39.10	59.40
WD_x_LF_BL	49.3720	49.0000	4.75476	37.90	58.10
WD_x_RF_Plano	50.2160	51.3500	4.64619	41.20	58.70
WD_x_RF_BU	50.3980	50.5500	4.84522	40.60	60.90
WD_x_RF_BL	50.6240	51.0000	4.75830	41.90	62.10
WD_z_F_Plano	45.0180	45.8000	8.10731	30.00	67.00
WD_z_F_BU	45.8260	44.6500	7.67609	33.90	68.70
WD_z_F_BL	44.9940	44.2500	7.58719	26.30	67.00
WD_z_B_Plano	54.9820	54.2000	8.10731	33.00	70.00
WD_z_B_BU	54.1740	55.3500	7.67609	31.30	66.10
WD_z_B_BL	55.0060	55.7500	7.58719	33.00	73.70
WD_q_LF_Plano	22.0620	21.1000	4.70210	13.40	36.10
WD_q_LF_BU	22.4340	21.4500	4.63186	14.70	35.50
WD_q_LF_BL	22.0300	21.6000	4.59255	13.80	36.40
WD_q_LB_Plano	27.7240	28.3000	4.93953	16.10	39.40
WD_q_LB_BU	27.1780	27.4500	4.37867	14.80	37.30
WD_q_LB_BL	27.3420	27.8500	4.57491	17.10	40.70
WD_q_RF_Plano	22.9460	23.0500	4.96326	11.10	32.70
WD_q_RF_BU	23.3640	23.2000	4.48511	13.70	34.00
WD_q_RF_BL	22.9980	22.9500	4.68560	9.10	33.20

WD_q_RB_Plano	27.2600	27.2500	5.82952	14.10	38.50
WD_q_RB_BU	27.0220	27.1500	5.91875	13.30	38.20
WD_q_RB_BL	27.6340	27.6500	5.93387	15.90	38.50
Meta_L_Plano	2.0798	1.4250	2.72513	.57	17.36
Meta_L_BU	1.6142	1.4000	1.05425	.43	6.45
Meta_L_BL	1.6124	1.2850	1.14362	.56	6.42
Meta_R_Plano	2.0748	1.6700	1.75228	.53	10.62
Meta_R_BU	1.5722	1.1450	1.21625	.42	6.43
Meta_R_BL	1.4832	1.1200	.92604	.53	5.20
Meta_F_Plano	4.1748	3.5550	3.16942	.81	17.62
Meta_F_BU	3.9572	2.8100	3.49956	.73	15.88
Meta_F_BL	3.2464	2.8700	1.90609	1.04	10.74
Meta_B_Plano	4.2074	3.2100	3.09200	1.17	15.22
Meta_B_BU	3.7056	3.2650	2.51615	.66	14.48
Meta_B_BL	3.7454	2.7450	2.86096	1.01	11.86

Table 4 Descriptive characteristics (Experiment 1)

Abbreviations: WD: Weight Distribution / Meta: Meta-barycentre / x: x-axis / z: z-axis / q: quadrant / LF: Left Foot / RF: Right Foot / F: Front part both feet / B: Back part both feet / RF: Right foot Front / LF: Left foot Front / RB: Right foot Back / LB: Left foot Back / R; Right / L: Left / Plano: Plano lenses / BU: Base Up / BL: Base Left

The Shapiro-Wilk test was used in order to test whether variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. Variables WD_z_F_BU, WD_z_B_BU, WD_q_LF_BU, Meta_L_Plano, Meta_L_BU, Meta_L_BL, Meta_R_Plano, Meta_R_BU, Meta_R_BL, Meta_F_Plano, Meta_F_BU, Meta_F_BL, Meta_B_Plano, Meta_B_BU, Meta_B_BL are not normally distributed as their respective p-values < 0.05 (Table 5).

	Shapiro-Wilk		
	Statistic	Df	Sig.
WD_x_LF_Plano	.959	50	.084
WD_x_LF_BU	.986	50	.825
WD_x_LF_BL	.982	50	.650
WD_x_RF_Plano	.959	50	.084
WD_x_RF_BU	.986	50	.825
WD_x_RF_BL	.982	50	.634
WD_z_F_Plano	.975	50	.360
WD_z_F_BU	.940	50	.013*
WD_z_F_BL	.974	50	.325
WD_z_B_Plano	.975	50	.360
WD_z_B_BU	.940	50	.013*
WD_z_B_BL	.974	50	.325
WD_q_LF_Plano	.967	50	.182

WD_q_LF_BU	.953	50	.044*
WD_q_LF_BL	.973	50	.307
WD_q_LB_Plano	.982	50	.641
WD_q_LB_BU	.987	50	.838
WD_q_LB_BL	.959	50	.080
WD_q_RF_Plano	.980	50	.570
WD_q_RF_BU	.986	50	.808
WD_q_RF_BL	.984	50	.730
WD_q_RB_Plano	.985	50	.779
WD_q_RB_BU	.978	50	.475
WD_q_RB_BL	.969	50	.214
Meta_L_Plano	.438	50	.000**
Meta_L_BU	.778	50	.000**
Meta_L_BL	.784	50	.000**
Meta_R_Plano	.670	50	.000**
Meta_R_BU	.725	50	.000**
Meta_R_BL	.812	50	.000**
Meta_F_Plano	.805	50	.000**
Meta_F_BU	.739	50	.000**
Meta_F_BL	.878	50	.000**
Meta_B_Plano	.765	50	.000**
Meta_B_BU	.821	50	.000**
Meta_B_BL	.759	50	.000**
*. Significant at .05 level			
**. Significant at .001 level			
a. Lilliefors Significance Correction			

Table 5 Shapiro-Wilk test for normality (Experiment 1)

Abbreviations: WD: Weight Distribution / Meta: Meta-barycentre / x: x-axis / z: z-axis / q: quadrant / LF: Left Foot / RF: Right Foot / F: Front part both feet / B: Back part both feet / RF: Right foot Front / LF: Left foot Front / RB: Right foot Back / LB: Left foot Back / R; Right / L: Left / Plano: Plano lenses / BU: Base Up / BL: Base Left

In order to determine, whether there are any statistically significant differences between the sample means of three levels of a within-subjects factor (Plano, BU, BL) the one-way repeated measures analysis of variance (ANOVA) test was used for normally distributed variables (Table 6, columns (9) to (14)). The Friedman test was used in cases where variables were not normally distributed.

According to Table 6, both repeated measures ANOVA and Friedman tests indicate that for variables CoP to the right ($p < 0.05$) and CoP to the back ($p < 0.05$), the null hypothesis must be rejected. At least 2 groups have different means (or medians), suggesting that sway to the right and back was effected, showing reduction.

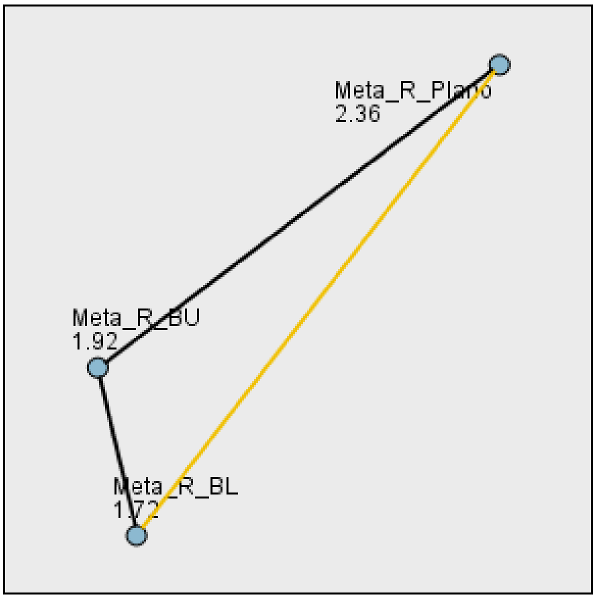
Experiment	Variable (factor: Plano, BU, BL)	Test of Sphericity						Repeated measures ANOVA test						Friedman test		Decision
		Mauchly's Test of Sphericity				Epsilon		Tests of Within-Subjects Effects								
		Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Source	F	Df		Sig.	Partial Eta Squared	Chi-Square	Sig.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1a	WD_x_LF	.938	3.092	2	.213	.941	.978	Sphericity Assumed	1.002	2	98	.371	.020	-	-	Retain the null hypothesis
1b	WD_x_RF	.938	3.076	2	.215	.942	.978	Sphericity Assumed	.980	2	98	.379	.020	-	-	Retain the null hypothesis
1c	WD_z_F	.886	5.794	2	.055	.898	.930	Sphericity Assumed	1.594	2	98	.208	.031	-	-	Retain the null hypothesis
1d	WD_z_B	.886	5.794	2	.055	.898	.930	Sphericity Assumed	1.594	2	98	.208	.031	-	-	Retain the null hypothesis
1e	WD_q_LF	.882	6.047	2	.049	.894	.926	Huynh-Feldt	1.104	1.852	90.727	.332	.022	-	-	Retain the null hypothesis
1f	WD_q_LB	.698	17.277	2	.000	.768	.788	Sphericity Assumed	1.150	2	98	.321	.023	1.289	.525	Retain the null hypothesis
1g	WD_q_RF	.922	3.891	2	.143	.928	.963	Sphericity Assumed	.943	2	98	.393	.019	-	-	Retain the null hypothesis
1h	WD_q_RB	.992	.387	2	.824	.992	1.000	Sphericity Assumed	1.413	2	98	.248	.028	-	-	Retain the null hypothesis
1i	Meta_L	.528	30.700	2	.000	.679	.692	Greenhouse-Geisser	2.051	1.358	66.554	.151	.040	1.127	0.569	Retain the null hypothesis
1j	Meta_R	.676	18.801	2	.000	.755	.774	Huynh-Feldt	4.799	1.548	75.862	.017	.089	10.720	0.005	Reject the null hypothesis
1k	Meta_F	.930	3.470	2	.176	.935	.970	Sphericity Assumed	1.966	2	98	.146	.039	1.960	.375	Retain the null hypothesis
1l	Meta_B	.908	4.623	2	.099	.916	.950	Sphericity Assumed	.732	2	98	.483	.015	6.040	.049	Reject the null hypothesis

Table 6 ANOVA test (Experiment 1)

Abbreviations: WD: Weight Distribution / Meta: Meta-barycentre / x: x-axis / z: z-axis / q: quadrant / LF: Left Foot / RF: Right Foot / F: Front part both feet / B: Back part both feet / RF: Right foot Front / LF: Left foot Front / RB: Right foot Back / LB: Left foot Back / R; Right / L: Left / Plano: Plano lenses / BU: Base Up / BL: Base Left

As the assumption of normality is violated for Meta_R and Meta_B, Friedman post hoc tests need to be performed in order to determine which groups differ in median (Figure 9 and Figure 10). Using SPSS 20, pairwise comparisons are conducted using the Wilcoxon signed-rank test with a Bonferroni correction for multiple comparisons. If p-value < 0.05 (Figure 9 and Figure 10, column 'Adj.Sig') then the difference in medians between the two groups, for each pair of groups stated in Figure 9 and Figure 10, column "Sample1-Sample2" is statistically significant.

Pairwise Comparisons



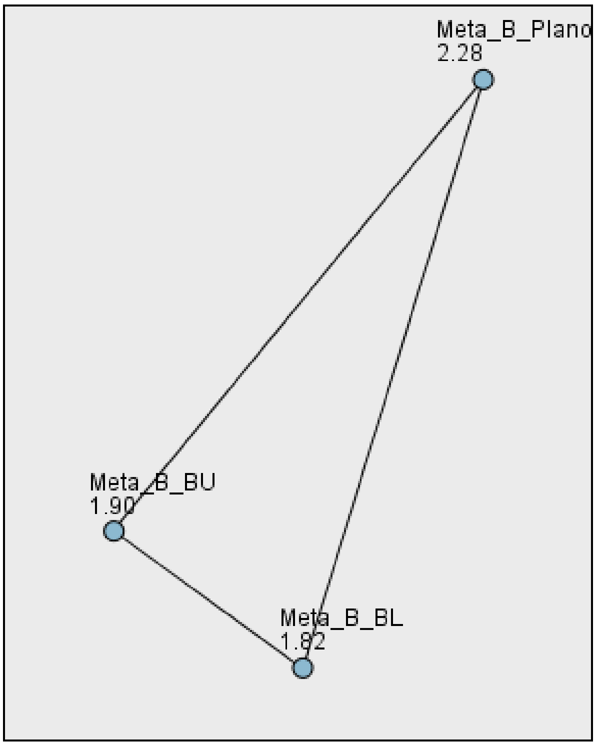
Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Meta_R_BL-Meta_R_Plano	.640	.200	3.200	.001	.004
Meta_R_BU-Meta_R_Plano	.440	.200	2.200	.028	.083
Meta_R_BL-Meta_R_BU	.200	.200	1.000	.317	.952

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 9 Pairwise comparisons for variable meta-barycentre rightwards (Experiment 1)

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Meta_B_BL-Meta_B_BU	.080	.200	.400	.689	1.000
Meta_B_BL-Meta_B_Plano	.460	.200	2.300	.021	.064
Meta_B_BU-Meta_B_Plano	.380	.200	1.900	.057	.172

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 10 Pairwise comparisons for variable meta-barycnetre backwards (Experiment 1)

According to Figure 9, it is determined that the median of CoP to the right with plano lenses (Mdn_{plano} = 1.67 mm) is greater than the median of CoP to the right with yoked prisms BL (Mdn_{BL} = 1.12 mm) ($p < 0.05$). In addition, according to Figure 10, it is determined that, after Bonferroni correction, there are no differences in medians of CoP to the back between the groups. As a result, only yoked prisms base left had a statistical significant effect showing reduction on the rightward body sway.

4.4 Discussion

The aim of this experiment was to investigate the effect of yoked prisms on weight distribution and body sway in sample of 50 healthy participants when standing in a natural and relaxed upright posture. Changes in weight distribution or body sway could suggest that yoked prisms have a significant effect on posture in a predictive way. This could be beneficial in many cases of rehabilitative and preventative care as an alternative option or supplementary approach to orthotics and orthopedic care.

Results of this study showed no statistically significant differences concerning weight distribution between the two feet or weight distribution between anterior and posterior parts of both feet. This means that the application of yoked prisms does not seem to result in any unnecessary weight distribution asymmetries and aggravating articulations. This is important, when considering incorporation of yoked prisms, in cases like progressive addition lenses, in healthy population.

Two explanations can be considered for these results. The first one is based on the fact that prismatic adaptation was prevented so no significant alteration can take place without adaptation. Secondly, it can be considered that the human body always tries to keep a homeostasis thus any change in weight distribution would not be beneficial in normal population as could be, for example, in hemiplegic patients who experience postural asymmetries. Previous studies investigating the effects of yoked prisms on posture have been conducted in subjects with pathological conditions or sensory-motor dysfunctions (Padula, et al., 2009).

When standing upright, there is minimal physiological body sway in all directions. Posturographic results showed a statistically significant effect when yoked prisms BL were applied by reducing physiological body sway to the right, thus increasing the tendency to set the centre of gravity to the left. This is in agreement with a previous study on healthy population using yoked prisms base right, which resulted in shifting centre of gravity rightward, towards the base of the prisms (Gizzi, et al., 1997).

In contrast, yoked prisms BU in the current study had no significant effects on CoP, which is not in agreement with a previous study using yoked prisms BD. Research on yoked prisms effects has shown temporary shift of the body’s centre of mass backward when base down prisms are applied (Jeske & Coffey, 1992). Although the opposite effect could be speculated concerning BU prisms, the biomechanical parameters need to be considered. Shifting of the body’s centre of mass backwards needs some compensatory body alterations in order to sustain the initial posture. Mechanics of the spinal cord and articulations’ range of motion enable for flexibility forward than backward. As a result, any shift of body’s centre of mass backwards is allowed since it is easier to be counterbalanced by bending forward. This could partially explain the difference between BU and BD performance in the two studies.

A more recent study, showed no significant effects on CoP in static conditions, but this are not comparable with the results of the current study, because the prisms used were diagonally oriented. (Gottshall, et al., 2006). Yoked prisms are usually used in lateral or vertical orientations for clinical and research purposes.

One of the significant optical effects of yoked prisms is the shift of perceived image towards the apex of the prisms thus the alteration of viewing gaze. Viewing through different gaze positions can alter neural processing in many brain areas that contribute to motor planning (Bedard, et al., 2008) and postural stability (Kapoula & Le, 2006; Ustinova & Perkins, 2011).

In addition, results highlighted the direct and immediate effect of yoked prisms in healthy adults, under conditions where prismatic adaptation was prevented. It is important to note that differentiation between short-term and long-term effects is usually not mentioned in previous studies. Previous studies also do not provide any information whether prism adaptation was prevented or enhanced.

4.5 Conclusions

Results of this experiment are important, because they set the base for analyzing further motor behaviour, like walking and other coordinated body movements, with yoked prisms. No statistically significant effects on weight distribution were measured with yoked prisms BU and BL by preventing prism adaptation. This provides also useful information for understanding prism adaptation by showing that any changes, occurring not in static but in dynamic conditions, should be examined in continuous time frames, since the initial condition is not affected.

The results suggest a statistically significant prismatic effect in shifting the barycentre only in the case of yoked prisms base left in healthy subjects, when prism adaptation is prevented. The barycentre was shifted to the left indicating the tendency of the postural sway even when changes in weight distribution are not detected.

CHAPTER 5 – Experiment 2: Effects of yoked prisms on posture

In the previous chapter the effects of yoked prisms on body posture were examined in terms of weight distribution and body sway. Although no significant changes were reported on weight distribution, postural changes should not be excluded. Shifts and rotations of upper or lower body parts and head could appear, while at the same time sustaining homeostasis and initial weight distribution status. In this chapter the second experiment is described in detail, where postural aspects are analyzed through photographic captures and the appropriate software.

5.1 Introduction

There are synergies between extraocular, neck, trunk and lower limb muscles (Roll & Roll, 1988) but the exact mechanisms of yoked prisms effects are not clearly defined. The primary aims of this study were to identify which parts of the body are initially affected before any prism adaptation takes place. It is important to understand which body parts are affected initially and which are secondary consequently affected in order to identify which cases could potentially benefit most by the application of the yoked prisms. Previous studies have mainly examined the effect of yoked prisms on spinal cord or head posture in isolation (Suttle, et al., 2011; Wong, et al., 2002). In this experiment different body parts are considered separately or in relation to each other during exposure to different pairs of yoked prisms, through photographic analysis. The objective is to detect any consistent shifts or tilts of the body on the x and z axis while standing in a natural position.

5.2 Method

5.2.1 Participants

Concerning experiment 2, given an effect size of 0.25 and a power level set at 0.95 (for a level of error of type I set at 0.05) the minimum required size for repeated measures ANOVA was 45. In this experiment 54 subjects were included. Among those subjects who participated in this experiment 39 of them participated also in experiment 1. Thirty-eight (70%) of the participants were women. Regarding age, the mean age of the 54 participants was 35.64 years and the standard deviation (SD) was ±9.09. The minimum and maximum ages of the participants of the sample were 20 and 58.08 years respectively. All participants were recruited from population that visited the optometric practice for a regular examination and sustained the criteria for participating in the study.

Variables concerning refractive status of monocular and binocular conditions were analyzed. For variable RefractionRE concerning the refractive status of the right eye, the mean was -1.07 D and the SD was ±1.94 D. Minimum and maximum values were -7.37 D and +0.75 D respectively (Table 7). For variable RefractionLE concerning the refractive status of the left eye, the mean was -1.01 D and the SD was ±1.88 D. Minimum and maximum values were -

7.87 D and +1.00 D respectively (Table 7). For variable RefractionBE concerning the refractive condition of both eyes, the mean was -1.04 D and the SD was ±1.91 D. Minimum and maximum values were -7.62 D and +0.87 D respectively (Table 7).

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Age	54	38.08	20.00	58.08	35.6456	1.23823	9.09912	82.794
RefractionRE	54	8.125	-7.375	.750	-1.07176	.264218	1.941600	3.770
RefractionLE	54	8.875	-7.875	1.000	-1.01389	.257162	1.889748	3.571
RefractionBE	54	8.500	-7.625	.875	-1.04285	.259993	1.910549	3.650

Table 7 Age, monocular and binocular refraction (Experiment 2)

5.2.2 Materials

For this experiment the application PostureScreen Mobile 5.2 (PostureCo, Inc., Trinity, Florida, USA) was used on an iPhone 4S. PostureScreen is based on PosturePrint, a web-based system for assessing posture, designed by the same team although supported by another company (BioTonix). As a result its validity and reliability is based on the same principles (personal communication with Dr. Joe Ferrantelli, PostureCo, Inc.). The reliability of evaluating posture (Dunk, et al., 2005) and the validity of head displacement estimation based on images has been published (Janik, et al., 2007) along with rib cage (Harrison, et al., 2007) and static pelvic posture changes in an upright position (Harrison, et al., 2008). The combined intra-examiner and inter-examiner correlation coefficients have been also investigated providing reliability for clinical use (Normand, et al., 2007). The combined inter-examiner and intra-examiner correlation coefficients were in the good (14/44) and excellent (30/44) ranges for clinical research, showing small standard error of measurements and mean absolute differences. The incorporated gyroscope of iPhone 4S is used by the application in order to create a frame of reference and ensure verticality of the photos to be taken. Further angular measurements during picture analysis were made with Screen Scales software (Talon-Designs, Willamette Valley, Oregon, USA) in full screen mode.

Three pairs of glasses were used. One pair had no prisms incorporated while the other pairs incorporated 8 Δ yoked prisms with orientations of the prism bases placed either base up (BU) or base left (BL). All pairs were mounted in strap-on wide frames (Bernell Co, 4016, N. Home street, Mishawaka, IN 46545, USA) so they were easily adjusted. Previous studies have used yoked prisms between 5 Δ and 40 Δ. The amount of 8 Δ was selected as the one closer to the maximum amount that usually can be incorporated in a prescription by ophthalmic lens manufacturers.

5.2.3 Procedure

Subjects were asked to choose randomly between three colors (red, blue, green) representing a pair of flat yoked prisms 8 Δ BU, 8 Δ BL and plano lenses respectively.

Especially for this experiment, all participants were required to wear clothes that enabled clear identification of the anatomical markers. Reflective stickers were applied to body parts in order to be used as reference points. These were acromioclavicular joint (AC), external side of shoulder at the cervical thoracic junction of the AC joint, episternal notch, anterior superior iliac spine (ASIS), external side of hip joint, external side of the knee joint, and frontal and external side of ankles (Figure 11).

When subjects were ready they were asked to stand still in a natural and relaxed position viewing a single 6/9 letter at the distance of 3 m. The participant's ID number along with their height and weight were inserted in the data area of the PostureScreen Mobile application. Two photos were taken under each condition, one frontal and one lateral. Participants were asked to try to keep fixating on this single letter during the whole procedure and not to look in extreme gaze positions. After one minute the first pair chosen randomly by the subject earlier was applied and after an additional minute the first frontal and right lateral picture was taken. Then the first pair was removed and a two-minute break was intervened, before applying the second pair. During this period only small foot or body readjustments were allowed in order to ensure a relaxed position. Application of the second pair was followed by a one-minute period and a new frontal and right lateral photo. The experiment ended after the third pair was applied following the same steps of two-minute break, one-minute wait with the new pair and the last frontal and right lateral photo taken.

At this point the operator was required to tap on the screen at exact points on the photos. These were right and left pupil, middle upper lip, acromioclavicular joint (AC), anterior superior iliac spine (ASIS), frontal side of right and left ankles, right external acoustic meatus (EAM), right shoulder at the cervical thoracic junction of the AC joint, right hip joint, right lateral knee, and right lateral ankle (Figure 11). Results provided by the application indicate forward or backward shift of the head, shoulder, and hips in reference to the vertical plane at the ankle point. Rightward or leftward shift of the head, shoulders, and hips are referenced to the vertical midline set at the middle distance of the ankles. In addition, the application provides results on rightward or leftward head, shoulder and hips tilt.

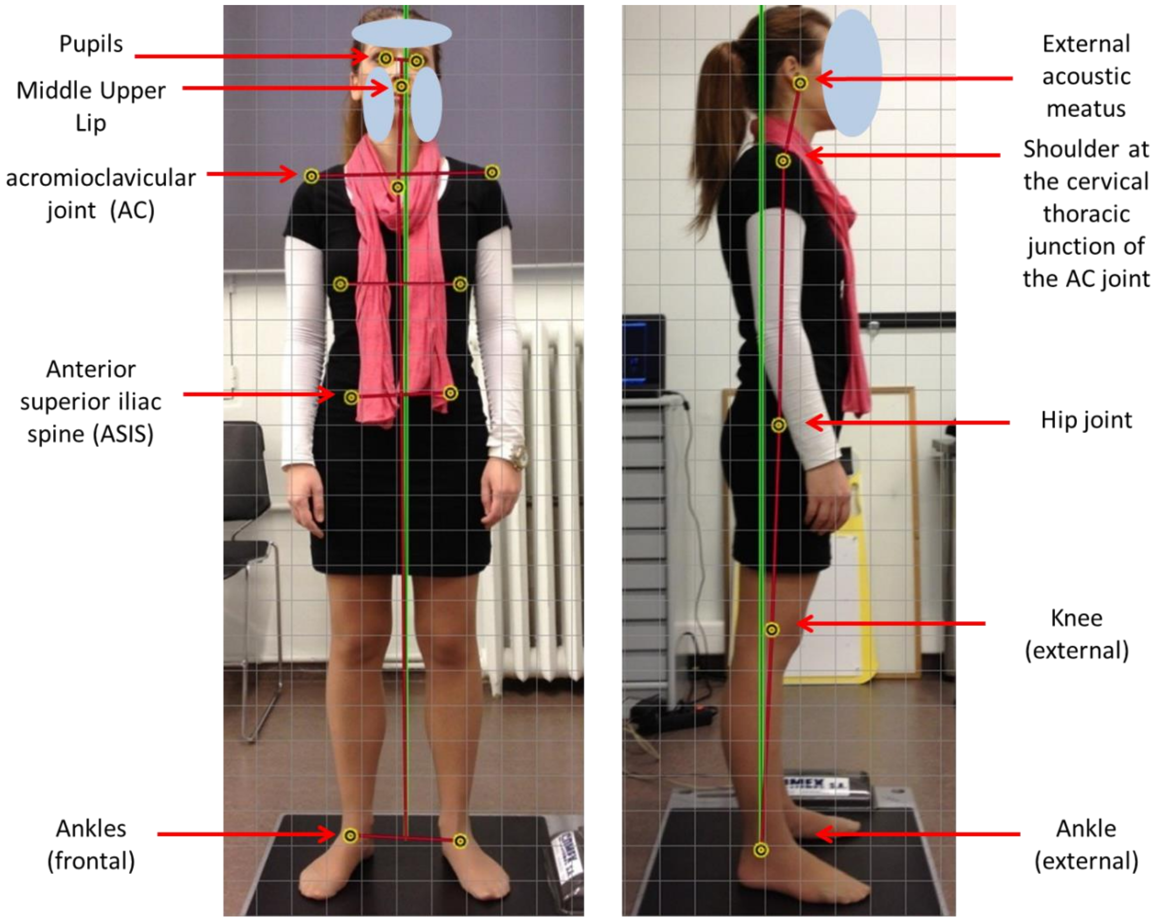


Figure 11 Reference points used in PostureScreen Mobile 5.2. The yellow dots correspond to the markers applied as needed in order to identify the body parts to be analysed.

In order to obtain more data on posture all photographs were transferred to a laptop, where more angles could be measured with the Screen Scales software (Talon-Designs, Willamette Valley, Oregon, USA). Usage of the same reference points of the lateral view was able to provide three more lateral angles: the head-shoulder angle (A), the shoulder-hips angle (B) and the hips-ankle angle (C) (Figure 12). One more angle termed angular midline shift was calculated from the frontal view photos. The angle is formed by the vertical axis and the line connecting the middle distance between ankles and the middle distance between the two eyes (Figure 13).

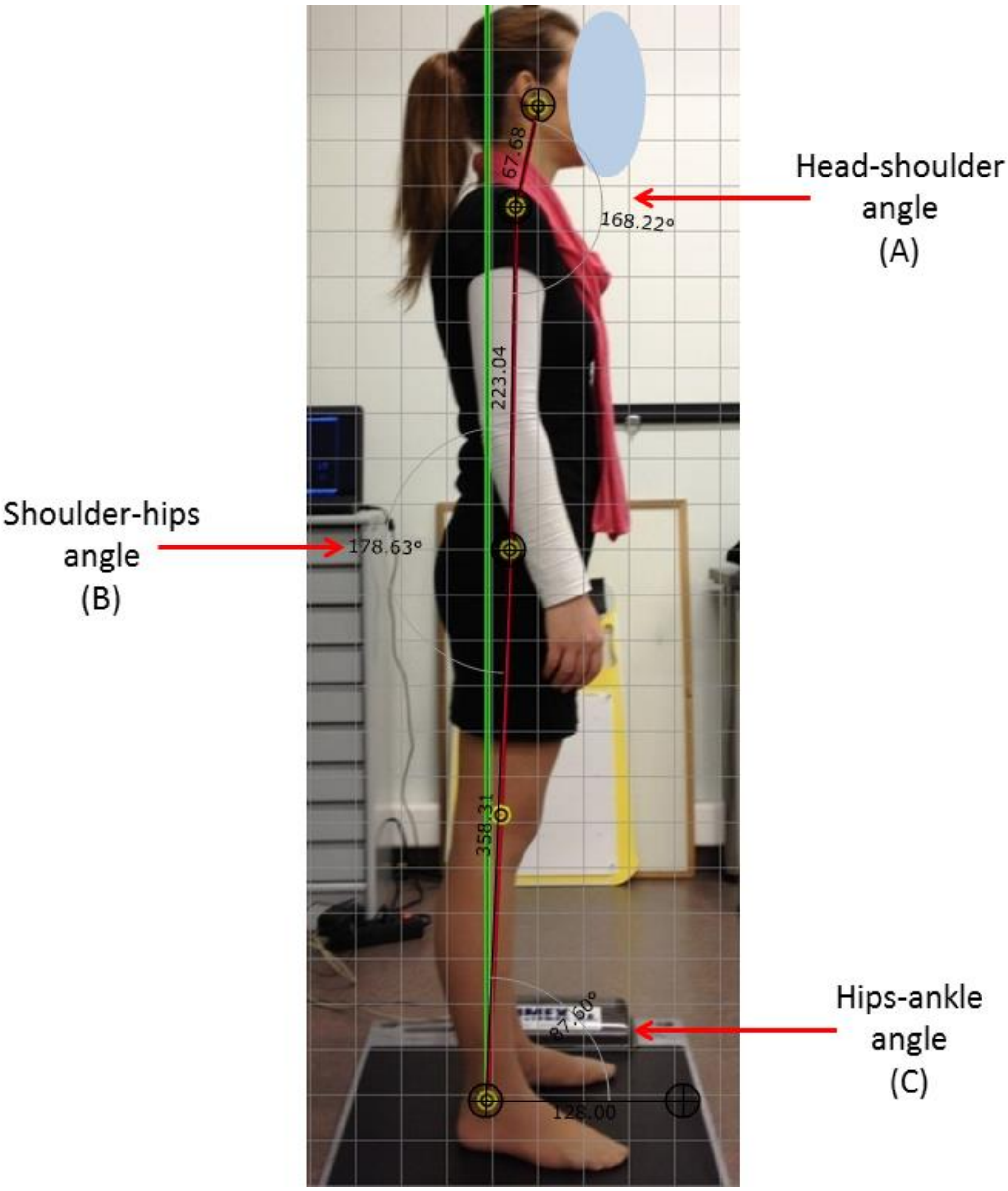


Figure 12 Angle measurements with Screen Scales. The head-shoulder angle (A) is formed by the external acoustic meatus – shoulder – hip joint points, the shoulder-hips angle (B) is formed by the shoulder – hip joint – ankle points, and the hips-ankle angle (C) is formed by the hip joint – ankle points along with the horizontal level.

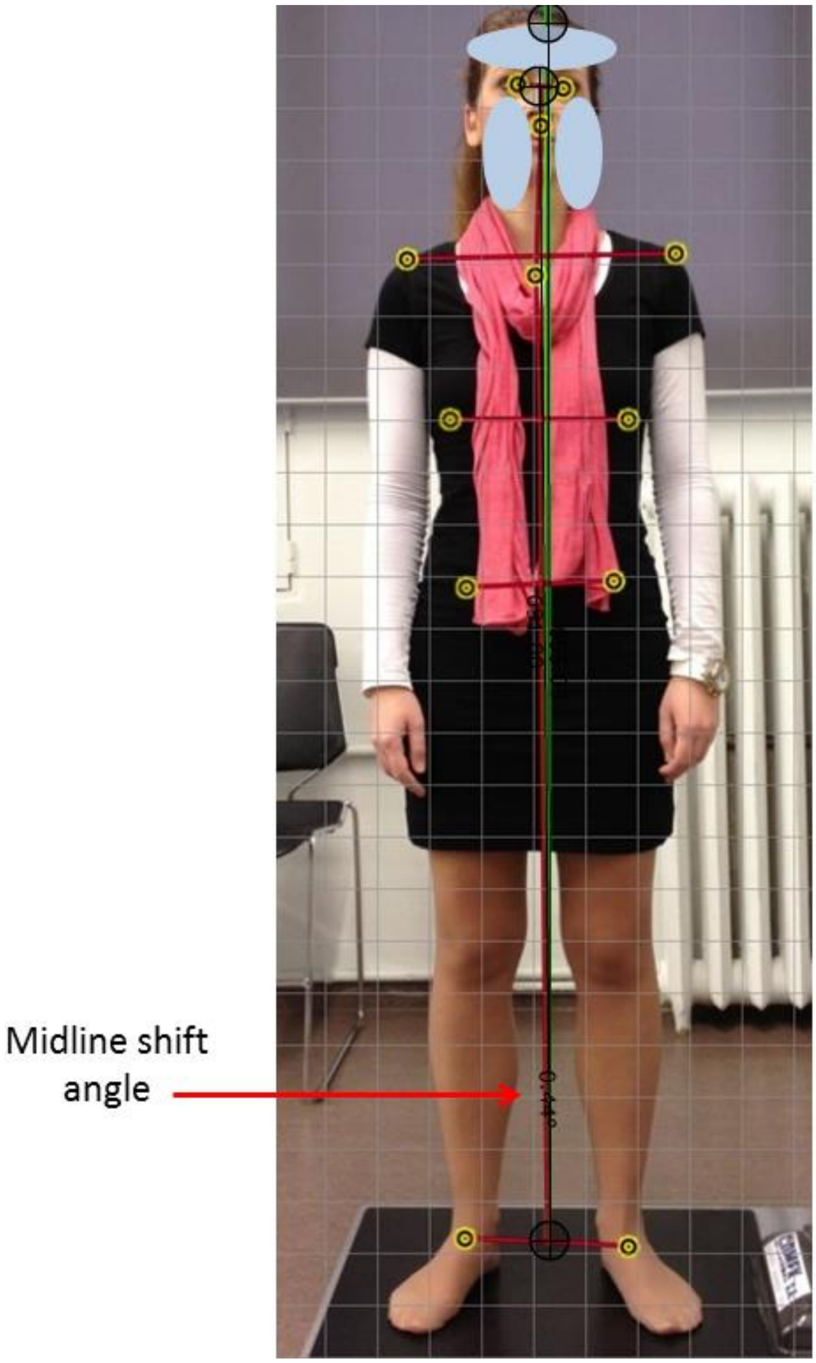


Figure 13 Midline shift angle measurement with Screen Scales

5.2.4 Statistical analysis

Statistical analysis was conducted with SPSS statistical software (Version 20, SPSS Inc., an IBM Company, Chicago, Illinois, USA). The Shapiro-Wilk test was used in order to test whether variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. One-way repeated ANOVA is suitable as the participants tested on three occasions (Plano, BU, BL) where the same persons. In case that the normality hypothesis was violated, both repeated measures ANOVA test and its non-parametric version, Friedman test (Table 10, columns (15) to (16)), were conducted, but all findings were discussed according to Friedman's test where medians are compared instead of means. It’s worth mentioning though that the repeated measures ANOVA test is robust to violations of normality.

In the cases where the repeated measures ANOVA test has been used, it is conducted first a Mauchly’s test of Sphericity (Table 10, columns (3) to (6)) in order to determine whether the variances of the differences between all combinations of levels of the within-subjects factor are equal. If p-value < 0.05 (Table 10, column (6)) which means that the sphericity assumption has been violated, an epsilon correction is performed using Greenhouse-Geisser and Huynh-Feldt estimates (Table 10, columns (7) to (8)). So, if the minimum of these two values is below 0.75 the repeated measures ANOVA test is performed using a Greenhouse-Geisser correction otherwise a Huynh-Feldt correction is used (Table 10, column (9)). If p-value < 0.05, (Table 10, column (13)), the null hypothesis stating that the means between levels are equal has to be rejected.

In the cases where the Friedman test has been used, the null hypothesis is rejected if p-value < 0.05 (Table 10, column (16)).

ANOVA or Friedman (when the assumption of normality is violated) post hoc tests need to be performed in order to determine which groups differ in mean or median. Using SPSS 20, in case of ANOVA post hoc tests, multiple paired-samples t-test with Bonferroni adjustment are conducted, while in case of Friedman post hoc tests, pairwise comparisons are conducted using the Wilcoxon signed-rank test with a Bonferroni correction for multiple comparisons. If p-value < 0.05 (column ‘sig’ in case of ANOVA tests of column ‘Adj.Sig’ in case of Friedman tests) then the difference in means or medians between the two groups, for each pair of groups stated, is statistically significant (see column ‘Mean Difference’ (I-J) for ANOVA test or column ‘Sample1-Sample2’ for Friedman test).

5.3 Results

All descriptive characteristics of the parameters that were analysed are presented below in Table 8:

Variable Name	Mean	Median	Std. Deviation	Minimum	Maximum
HeSh_x_L_Plano	.6504	.3200	1.11280	-1.62	4.35
HeSh_x_L_BU	.8226	.6250	1.13518	-1.05	4.73
HeSh_x_L_BL	1.6880	1.1700	1.54585	-.41	7.06
HeTi_x_L_Plano	.7091	0.0000	2.61676	-5.80	6.10
HeTi_x_L_BU	.8111	0.0000	1.87009	-4.00	4.40
HeTi_x_L_BL	1.8241	0.0000	2.47294	-2.90	6.60
ShSh_x_L_Plano	1.6280	1.2750	1.38827	-.90	5.65
ShSh_x_L_BU	1.4696	1.2100	1.24638	-.68	5.72
ShSh_x_L_BL	1.8259	1.8650	1.26403	-.46	5.65
ShTi_x_L_Plano	1.1463	0.0000	2.20409	-6.20	5.60
ShTi_x_L_BU	1.2000	0.0000	1.96017	-3.70	4.80
ShTi_x_L_BL	2.0667	2.2000	2.33658	-2.70	7.50

HiSh_x_L_Plano	.7233	.6900	1.72776	-3.35	5.05
HiSh_x_L_BU	.6770	.6450	1.64390	-2.28	5.63
HiSh_x_L_BL	1.6107	1.4150	2.07216	-1.99	6.86
HiTi_x_L_Plano	.3000	0.0000	1.19512	-3.20	3.20
HiTi_x_L_BU	-.1000	0.0000	1.24537	-4.60	3.50
HiTi_x_L_BL	.2333	0.0000	1.29906	-5.40	3.00
HeSh_z_B_Plano	5.4952	4.8950	3.91830	-.97	17.44
HeSh_z_B_BU	6.4426	5.6450	4.55834	.21	23.30
HeSh_z_B_BL	5.3319	4.2100	3.70344	.69	17.75
ShSh_z_B_Plano	-4.4965	-3.5900	3.94253	-14.81	6.59
ShSh_z_B_BU	-4.2976	-3.6500	3.92011	-17.83	6.59
ShSh_z_B_BL	-4.7713	-4.7450	3.21647	-14.08	2.54
HiSh_z_B_Plano	2.9224	2.9050	2.72553	-3.12	11.87
HiSh_z_B_BU	3.2650	3.1450	3.10419	-3.25	15.61
HiSh_z_B_BL	2.5813	2.6850	3.00162	-3.16	12.49
MiShAn_L_Plano	.7441	.7800	.59137	-.54	2.03
MiShAn_L_BU	.6800	.7350	.77339	-.87	2.71
MiShAn_L_BL	1.2831	1.4800	.77015	-.43	3.13
HeShAn_Plano	160.0248	161.6500	9.35410	139.15	184.30
HeShAn_BU	157.9646	156.6000	8.98202	135.11	177.48
HeShAn_BL	160.1454	160.6000	7.99130	142.07	173.76
ShHiAn_Plano	172.6404	172.6150	3.65196	165.40	184.34
ShHiAn_BU	172.4909	171.7050	3.61042	164.11	186.39
ShHiAn_BL	172.4456	171.6600	3.74913	167.25	188.33
HiAnAn_Plano	86.2944	86.4250	1.91721	82.08	90.47
HiAnAn_BU	85.9317	85.8800	1.57370	82.57	89.69
HiAnAn_BL	86.2798	86.4700	1.65410	82.28	89.67

Table 8 Descriptive characteristics (Experiment 2)

Abbreviations: HeSh: Head Shift / HeTi: Head Tilt / ShSh: Shoulder Shift / ShTi: Shoulder Tilt / HiSh: Hips Shift / HiTi: Hips Tilt / MiShAn: Midline Shift Angular / HeShAn: Head-Shoulder Angle / ShHiAn: Shoulder-Hips Angle / HiAnAn: Hips-Ankles Angle / x: x-axis / z: z-axis / Plano: Plano lenses / BU: Base Up / BL: Base Left

The Shapiro-Wilk test was used in order to test whether variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. Variables having p-value < 0.05 are not normally distributed (Table 9). This is the case of almost all variables except: HiSh_x_L_Plano, HiSh_x_L_BU, HiSh_x_L_BL, ShSh_z_B_BL, HiSh_z_B_Plano, MiShAn_L_Plano, MiShAn_L_BU, MiShAn_L_BL, HeShAn_Plano, HeShAn_BU, HeShAn_BL, ShHiAn_Plano, HiAnAn_Plano, HiAnAn_BU and HiAnAn_BL.

Tests of Normality

	Shapiro-Wilk		
	Statistic	Df	Sig.
HeSh_x_L_Plano	.918	54	.001*

HeSh_x_L_BU	.885	54	.000*
HeSh_x_L_BL	.851	54	.000*
HeTi_x_L_Plano	.913	54	.001*
HeTi_x_L_BU	.833	54	.000**
HeTi_x_L_BL	.883	54	.000**
ShSh_x_L_Plano	.928	54	.003*
ShSh_x_L_BU	.932	54	.004*
ShSh_x_L_BL	.957	54	.050*
ShTi_x_L_Plano	.871	54	.000**
ShTi_x_L_BU	.853	54	.000**
ShTi_x_L_BL	.881	54	.000**
HiSh_x_L_Plano	.989	54	.905
HiSh_x_L_BU	.963	54	.097
HiSh_x_L_BL	.968	54	.150
HiTi_x_L_Plano	.590	54	.000**
HiTi_x_L_BU	.583	54	.000**
HiTi_x_L_BL	.571	54	.000**
HeSh_z_B_Plano	.926	54	.003*
HeSh_z_B_BU	.886	54	.000**
HeSh_z_B_BL	.866	54	.000**
ShSh_z_B_Plano	.907	54	.001*
ShSh_z_B_BU	.937	54	.007*
ShSh_z_B_BL	.984	54	.663
HiSh_z_B_Plano	.964	54	.103
HiSh_z_B_BU	.918	54	.001*
HiSh_z_B_BL	.950	54	.025*
MiShAn_L_Plano	.988	54	.849
MiShAn_L_BU	.987	54	.839
MiShAn_L_BL	.963	54	.096
HeShAn_Plano	.979	54	.450
HeShAn_BU	.987	54	.820
HeShAn_BL	.976	54	.344
ShHiAn_Plano	.958	54	.054
ShHiAn_BU	.901	54	.000**
ShHiAn_BL	.880	54	.000**
HiAnAn_Plano	.990	54	.920
HiAnAn_BU	.991	54	.952
HiAnAn_BL	.973	54	.272
*. Significant at .05 level			
**. Significant at .001 level			

Table 9 Shapiro-Wilk test for normality (Experiment 2)

In order to determine, whether there are any statistically significant differences between the sample means of three levels of a within-subjects factor (Plano, BU, BL) the one-way repeated measures analysis of variance (ANOVA) test was used for normally distributed variables (Table 10 in columns (9) to (14)). The Friedman test was used in cases where variables were not normally distributed.

Experiment	Variable (factor: Plano, BU,BL)	Test of Sphericity						Repeated meaures ANOVA test						Friedman test		Decision
		Mauchly's Test of Sphericity				Epsilon		Tests of Within-Subjects Effects								
		Mauchly's W	Approx. Chi-Square	Df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Source	F	df		Sig.	Partial Eta Squared	Chi-Square	Sig.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1a	HeSh_x_L	.985	.769	2	.681	.986	1.000	Sphericity Assumed	24.768	2	106	.000	.318	36.794	.000	Reject the null hypothesis
1b	HeTi_x_L	.963	1.968	2	.374	.964	1.000	Sphericity Assumed	6.512	2	106	.002	.109	9.834	.007	Reject the null hypothesis
1c	ShSh_x_L	.981	.977	2	.613	.982	1.000	Sphericity Assumed	2.925	2	106	.058	.052	4.884	.087	Retain the null hypothesis
1d	ShTi_x_L	.878	6.787	2	.034	.891	.920	Huynh-Feldt	8.790	1.840	97.504	.000	.142	11.589	.003	Reject the null hypothesis
1e	HiSh_x_L	.986	.757	2	.685	.986	1.000	Sphericity Assumed	7.321	2	106	.001	.121	-	-	Reject the null hypothesis
1f	HiTi_x_L	.999	.074	2	.963	.999	1.000	Sphericity Assumed	1.792	2	106	.172	.033	4.353	.113	Retain the null hypothesis
1g	HeSh_z_B	.976	1.241	2	.538	.977	1.000	Sphericity Assumed	12.989	2	106	.000	.197	32.009	.000	Reject the null hypothesis
1h	ShSh_z_B	.883	6.451	2	.040	.896	.925	Huynh-Feldt	1.136	1.850	98.029	.322	.021	6.689	.035	Reject the null hypothesis
1i	HiSh_z_B	.946	2.865	2	.239	.949	.983	Sphericity Assumed	2.570	2	106	.081	.046	2.577	0.276	Retain the null hypothesis
1j	MiShAn_L	.969	1.626	2	.443	.970	1.000	Sphericity Assumed	21.256	2	106	.000	.286	-	-	Reject the null hypothesis
1k	HeShAn	.961	2.053	2	.358	.963	.998	Sphericity Assumed	5.359	2	106	.006	.092	-	-	Reject the null hypothesis
1l	ShHiAn	.885	6.324	2	.042	.897	.927	Huynh-Feldt	.200	1.853	98.229	.803	.004	2.111	.348	Retain the null hypothesis
1m	HiAnAn	.932	3.690	2	.158	.936	.969	Sphericity Assumed	2.408	2	106	.095	.043	-	-	Retain the null hypothesis

Table 10 ANOVA test (Experiment 2)

According to Table 10 in:

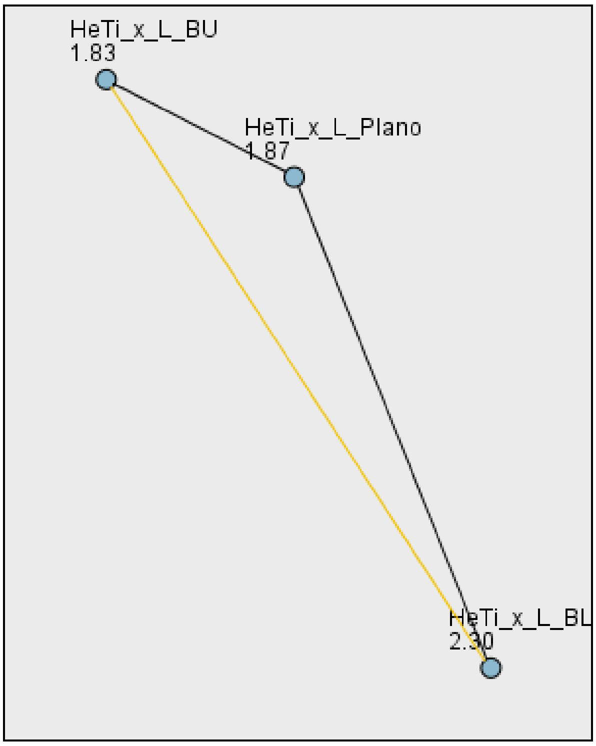
- Repeated measures ANOVA and Friedman tests indicate that head shift ($p < 0.001$), head tilt ($p < 0.05$) and shoulders tilt ($p < 0.001$) on the x axis were effected with yoked prisms base left, while a head shift ($p < 0.001$) on the z axis takes place when yoked prisms base up were applied.

- Repeated measures ANOVA test indicate that hips shift ($p < 0.005$) on x axis, angular midline shift ($p < 0.001$) are effected with yoked prisms base left while the head-shoulder angle ($p < 0.05$) was effected by the application of yoked prisms base up.
- Friedman test indicate that shoulders shift ($p < 0.05$) on the z axis were influenced by the application of yoked prisms base left.

In case of ANOVA post hoc tests, multiple paired-samples t-test with Bonferroni adjustment are conducted, while in case of Friedman post hoc tests, pairwise comparisons are conducted using the Wilcoxon signed-rank test with a Bonferroni correction for multiple comparisons.

According to Figure 14 comparison of medians suggest that yoked prisms BL ($Mdn_{BL} = 1.82$) had a statistically significant effect on head tilt ($p < 0.05$) compared to yoked prisms BU ($Mdn_{BU} = 0.81$), by increasing tilt to the right.

Pairwise Comparisons



Each node shows the sample average rank.

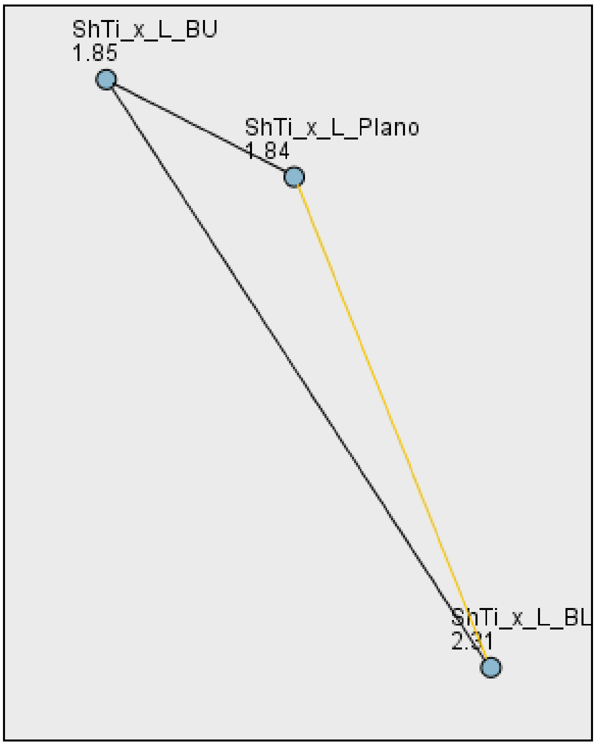
Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
HeTi_x_L_BU-HeTi_x_L_Plano	.037	.192	.192	.847	1.000
HeTi_x_L_BU-HeTi_x_L_BL	-.463	.192	-2.406	.016	.048
HeTi_x_L_Plano-HeTi_x_L_BL	-.426	.192	-2.213	.027	.081

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 14 Pairwise comparisons for head tilt on the x axis variable

According to Figure 15 comparison of medians suggest that yoked prisms BL (Mdn_{BL} = 1.86) had a statistically significant effect on shoulders tilt ($p < 0.05$) compared to plano lenses (Mdn_{Plano} = 1.27), by increasing tilt to the right.

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
ShTi_x_L_Plano-ShTi_x_L_BU	-.009	.192	-.048	.962	1.000
ShTi_x_L_Plano-ShTi_x_L_BL	-.463	.192	-2.406	.016	.048
ShTi_x_L_BU-ShTi_x_L_BL	-.454	.192	-2.358	.018	.055

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 15 Pairwise comparisons for shoulder tilt on the x axis variable

According to Table 11 and Figure 16 comparison of medians suggest that yoked prisms BL (M_{BL} = 1.61) had a statistically significant effect on hips shift to the right ($p < 0.05$) compared to plano lenses (M_{Plano} = 0.72) and yoked prisms BU (M_{BU} = 0.67).

Pairwise Comparisons of HiSh_x_L

(I) factor	(J) factor	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.046	.265	1.000	-.608	.700

	3	-.887*	.291	.011	-1.607	-.168
2	1	-.046	.265	1.000	-.700	.608
	3	-.934*	.269	.003	-1.598	-.269
3	1	.887*	.291	.011	.168	1.607
	2	.934*	.269	.003	.269	1.598

Table 11 Pairwise comparisons of hips shift on x axis variable

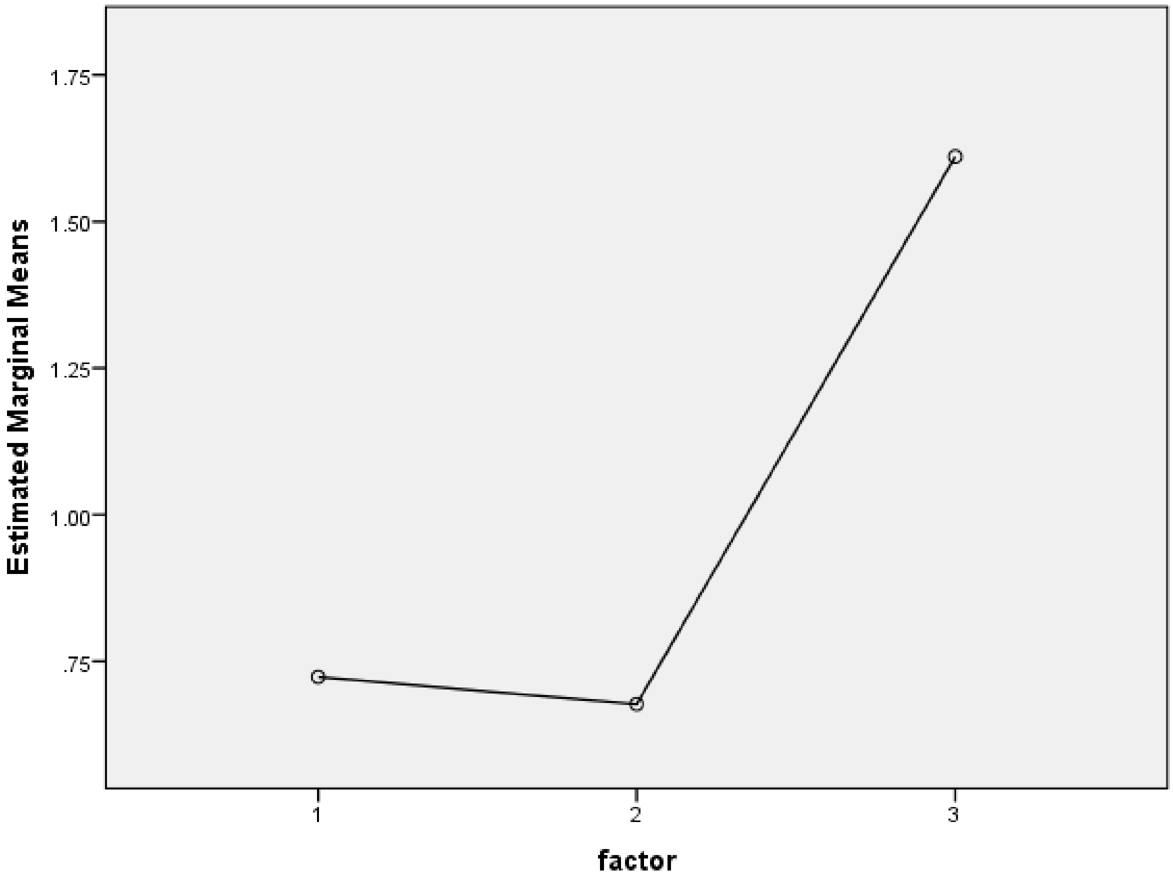
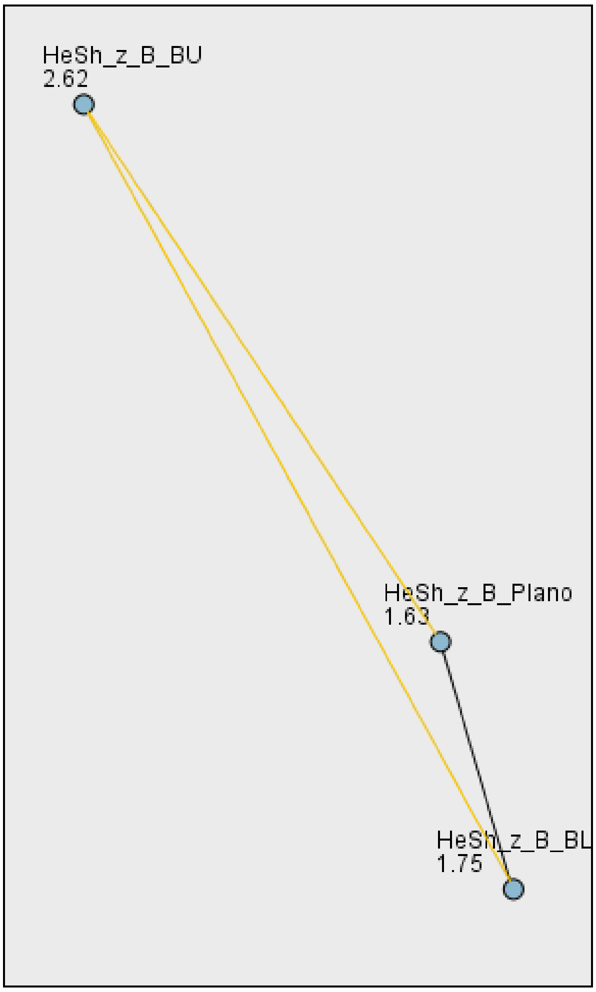


Figure 16 Estimated marginal means of hips shift on x axis variable

According to Figure 17 comparison of medians suggest that yoked prisms BU (Mdn_{BU} = 5.64) had a statistically significant effect on head shift forward ($p < 0.001$) compared to plano lenses (Mdn_{Plano} = 4.89) and yoked prisms BL (Mdn_{BL} = 4.21).

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
HeSh_z_B_Plano-HeSh_z_B_BL	-.120	.192	-.625	.532	1.000
HeSh_z_B_Plano-HeSh_z_B_BU	-.991	.192	-5.148	.000	.000
HeSh_z_B_BL-HeSh_z_B_BU	.870	.192	4.523	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 17 Pairwise comparisons for head shift on z axis variable

According to Table 12 and Figure 18comparison of medians suggest that yoked prisms BL (M_{BL} = 1.28) had a statistically significant effect on angular midline shift to the right ($p < 0.001$) compared to plano lenses (M_{Plano} = 0.74) and yoked prisms BU (M_{BU} = 0.68).

Pairwise Comparisons of MiShAn_L

(I) factor	(J) factor	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.064	.093	1.000	-.166	.294
	3	-.539*	.108	.000	-.807	-.271
2	1	-.064	.093	1.000	-.294	.166
	3	-.603*	.103	.000	-.857	-.349
3	1	.539*	.108	.000	.271	.807
	2	.603*	.103	.000	.349	.857

Table 12 Pairwise comparisons of angular midline shift variable

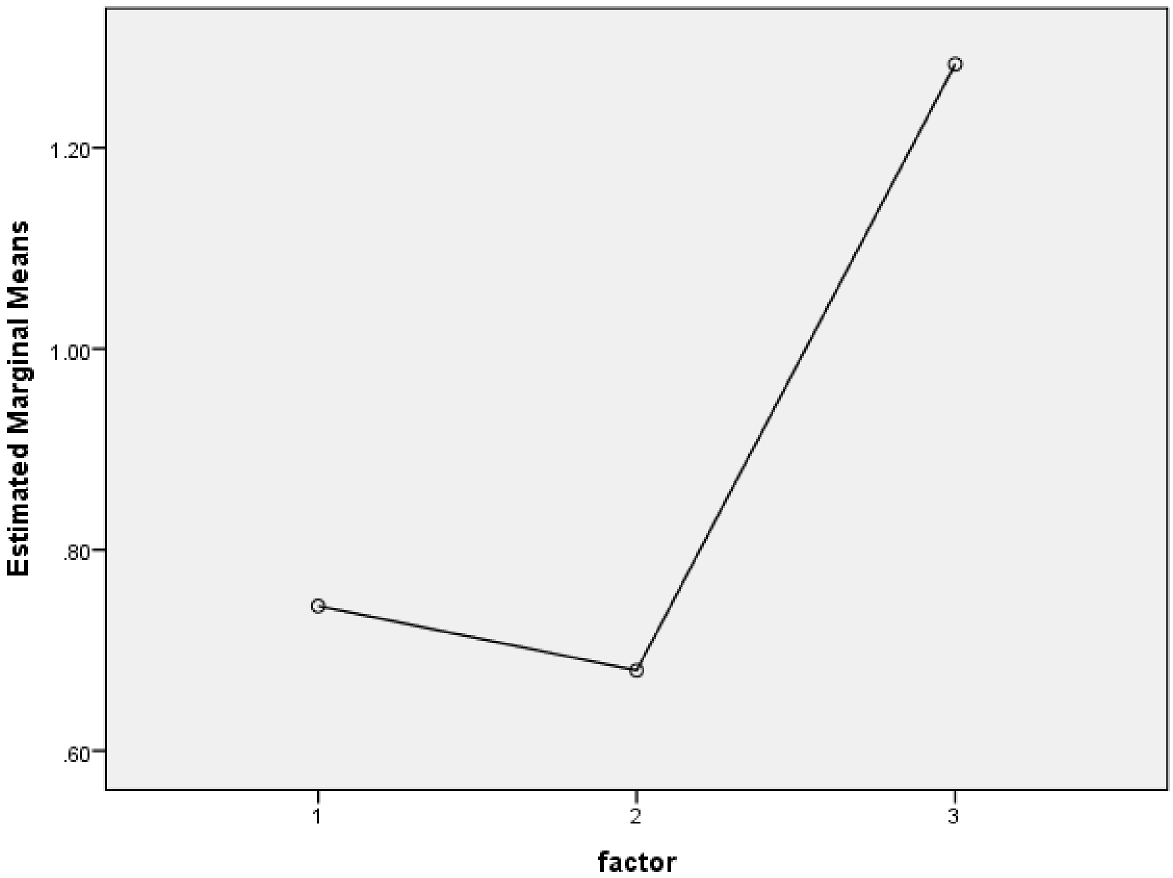


Figure 18 Estimated marginal means of angular midline shift variable

According to Table 13 and Figure 19 comparison of medians suggest that yoked prisms BU (M_{BU} = 157.96) had a statistically significant effect on the head-shoulder angle ($p < 0.05$) decreasing it thus bringing chin closer to the chest area, compared to plano lenses (M_{Plano} = 106.02) and yoked prisms BL (M_{BL} = 160.14).

Pairwise Comparisons of HeShAn

(I) factor	(J) factor	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	2.060*	.819	.045	.036	4.085
	3	-.121	.717	1.000	-1.893	1.652
2	1	-2.060*	.819	.045	-4.085	-.036
	3	-2.181*	.705	.010	-3.925	-.437
3	1	.121	.717	1.000	-1.652	1.893
	2	2.181*	.705	.010	.437	3.925

Table 13 Pairwise comparisons of head-shoulders angle variable

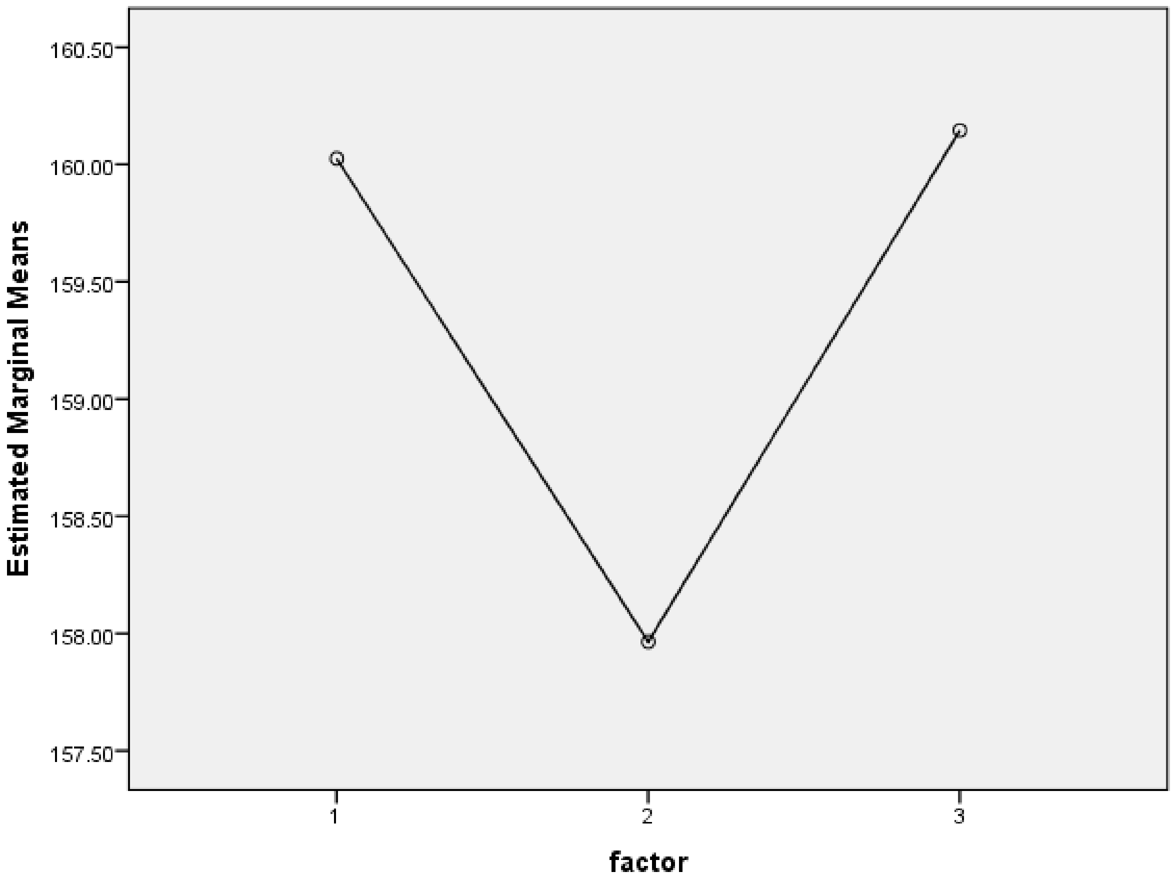


Figure 19 Estimated marginal means of head-shoulders angle variable

In summary, yoked prisms BL showed a statistically significant effect on head and hips shift to the right, on head and shoulders tilt to the right and on right shoulder shift backwards. Yoked prisms BL also induced a statistically significant angular increase of midline to the right. Yoked prisms BU showed a statistically significant effect on head shift forward and tilt downwards (Table 14).

Yoked Prisms	Effect	Statistical Test Used	p-value
Base Left	Head shift to the Right	Repeated ANOVA / Friedman	<0.001
	Hips shift to the Right	Repeated ANOVA	<0.005
	Head tilt to the Right	Repeated ANOVA / Friedman	<0.005
	Shoulders tilt to the right	Repeated ANOVA / Friedman	<0.001
	Right shoulder shift backwards	Friedman	<0.05
	Angular increase of midline to the right	Repeated ANOVA	<0.001
Base Up	Head shift Forward	Repeated ANOVA / Friedman	<0.001
	Head tilt Downwards	Repeated ANOVA	<0.01

Table 14 Summary of yoked prisms effects on body posture

5.4 Discussion

The aim of this experiment was to investigate the effect of yoked prisms on posture by examining shifts and tilts occurring in head, shoulder, and hips area when standing in a natural and relaxed upright posture. Yoked prisms base left induced a head and hips shift to the right while at the same time increased tilt of head and shoulders, as also angular midline tilt, to the right. An increase in shifting shoulder backwards has been recorded but since only right side lateral photos were taken the effect should not be considered in a symmetrical manner, meaning that only right shoulder has been affected. This was also observed real-time during the experiment underlining a simultaneous clock-wise rotational effect on the shoulders area. Yoked prisms base up had a significant effect by shifting head forward and decreasing the head-shoulder angle. It is important to note that prismatic adaptation was prevented highlighting the direct and immediate effects of yoked prisms on body posture.

Results suggest that yoked prisms effects are focused mainly on the head-neck-shoulders areas and more limited on hips. This is in agreement with studies conducted in a group of subjects with scoliosis showing a right thoracic curve pattern with left compensatory lumber curve, where yoked prisms base left had a significantly positive effect (Wong, et al., 2002).

Results are also in agreement with previous research showing that looking up or down increases proprioceptive signals of the extraocular muscles, resulting in modified activity of the muscles in the neck area through brain-stem reflexes, even when head is considered stable (Corneil, et al., 2004). The neck muscle system is considered an important factor mediating postural control (Vuillerme & Rougier, 2005). Apart from directing both eyes in a different gaze position, yoked prisms create visual distortions, which have been proven that alter body's vertical orientation (Carriot, et al., 2008; Keshner & Kenyon, 2009). A limitation of this study is that only one prismatic power in one vertical and one horizontal orientation was used. Therefore, postural status may have shown additional changes if higher or lower prismatic powers in more directions were used.

5.5 Conclusions

The results of this experiment have shown that there are mainly lateral and vertical effects on posture, when yoked prism base left or up are applied respectively. Results have also shown that the main effects of yoked prisms on body posture take place mainly in the head and shoulder areas and less in the hips area.

Findings of this experiment are important because they highlight the close relationship of the visual system with the tone of neck muscles and with shoulders and hips area, without any prism adaptation. This fact sets the basis for investigating therapeutic interventions for postural asymmetries and pathologies of movement affecting mainly the upper body.

CHAPTER 6 – Experiment 3: Effect of yoked prisms on spatial perception

In the previous chapters the effects of yoked prisms on body posture were examined. Head, shoulders and hips areas were mainly affected while maintaining homeostasis and weight distribution unaffected. All these effects could be attributed to changes in spatial perception or considered to emerge independently. In this chapter the third experiment is described in detail in order to investigate if spatial perception is altered without prism adaptation. If this hypothesis is true then postural and perceptual changes occur simultaneously and not as consequences of the prismatic adaptation process.

6.1 Introduction

The optical and perceptual effects of prismatic lenses could have a direct impact on the human spatial perception (Reading, 1985). Distortions created by a prism could interfere with individual's ability to judge size, distance and subjective perceptions of space-time values (Forkiotis, 1995). The objective of this experiment was to investigate the relationship between direct optical effects and subjective spatial transformation with minimal prismatic adaptation.

The space board was originally introduced by Valenti in the late 1980s as a clinical approach to investigate subjects' misperception of objects location in space (Valenti, 1996). The idea was based on an earlier testing concept called 'touch points' proposed by Streff (Harris, 2011). The technique of 'touch points' involved the examiner standing in front of the subject and holding a finger vertically pointing downward at the eye level. Each subject was asked to look at the finger and move his index finger upwards in order to touch the finger of the examiner in a single, fast, and ballistic type of movement. Misalignments were translated as misjudgments of space and the procedure could be repeated by introducing lenses or prisms to change the performance. The original space board was made of a flat thin wooden board approximately 16'' x 24'' with a large curved notch cut off on one side in order to fit under subject's nose. The examiner was holding the space board horizontally in a way that subject's eye contact with his or her own hands was prevented. A paper of appropriate size was placed underneath the board and markers with needles were set up on the visible to the subject side of the board. Needles passing the board were creating a small hole on the paper showing the exact place of the markers. Subjects were then asked to stand up holding a pen and mark underneath the board the exact position of the markers as perceived.

The space board enables perceptual evaluation in a visual 'open loop' environment. This has been suggested as the condition associating the 'proprioceptive' hand-head frame and the 'visual' eye-head centred frame of reference, for testing spatial perception (Wilkinson, 1971). Since the eye contact with subject's hands is prevented, no self-corrections can be made during pointing with the marker. The recorded locations can provide a personalized spatial map for each subject. Later, Harris modified extensively board settings and marker placement, and suggested that subjects should face an open view rather than a blank wall as was originally proposed (Harris, 2011).

6.2 Method

6.2.1 Participants

Concerning experiment 3, given an effect size of 0.6 and a power level set at 0.95 (for a level of error of type I set at 0.05) the minimum required size for paired t-test was 32. In this experiment 33 subjects were included. Twenty-six (78.8%) were women. Regarding age, the mean age of the 33 participants was 32.48 years and the standard deviation (SD) was ±8.13. The minimum and maximum ages of the participants of the sample were 20 and 58.08 years respectively. All participants were recruited from population that visited the optometric practice for a regular examination and sustained the criteria for participating in the study.

Variables concerning refractive status of monocular and binocular conditions were analyzed. For variable RefractionRE concerning the refractive status of the right eye, the mean was -0.71 D and the SD was ±1.60 D. Minimum and maximum values were -5.25 D and +0.50 D respectively (Table 15). For variable RefractionLE concerning the refractive status of the left eye, the mean was -0.64 D and the SD was ±1.45 D. Minimum and maximum values were -5.00 D and +0.50 D respectively (Table 15). For variable RefractionBE concerning the refractive condition of both eyes, the mean was -0.67 D and the SD was ±1.52 D. Minimum and maximum values were -5.12 D and +0.50 D respectively (Table 15).

Age, Refraction RE, Refraction LE and Refraction BE

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Age	33	38.08	20.00	58.08	32.4806	1.41638	8.13650	66.203
RefractionRE	33	5.750	-5.250	.500	-.71591	.279576	1.606041	2.579
RefractionLE	33	5.500	-5.000	.500	-.64015	.253745	1.457657	2.125
RefractionBE	33	5.625	-5.125	.500	-.67803	.266275	1.529631	2.340

Table 15 Age, monocular and binocular refraction (Experiment 3)

6.2.2 Materials

For conducting this experiment a commercially available space board was used (VTE StressPoint Co., Via Modena, 20099, MI, Italy) in order to record the perceptual spatial alterations created by yoked prisms. A small bubble level was attached on one side underneath the board so the examiner could assure the appropriate horizontal position of the space board during the experiment. Three out of nine available markers in the central row on the x axis were used in combination with the pre-marked recording sheets (Figure 21). Differences between the three attempts were measured in centimetres (cm) for each marker in reference to the x and z axis using a ruler.

Three pairs of glasses were used. One pair had no prisms incorporated while the other pairs incorporated 8 Δ yoked prisms with orientations of the prism bases placed either base up (BU) or base left (BL). All pairs were mounted in strap-on wide frames (Bernell Co, 4016, N. Home street, Mishawaka, IN 46545, USA) so they were easily adjusted. Previous studies have used yoked prisms between 5 Δ and 40 Δ. The amount of 8 Δ was selected as the one closer to the maximum amount that usually can be incorporated in a prescription by ophthalmic lens manufacturers.

6.2.3 Procedure

Subjects were asked to choose randomly between three colors (red, blue, green) representing a pair of flat yoked prisms 8 Δ base up, 8 Δ base left and plano lenses respectively. Participants were asked to stand up engaging a natural comfortable position, facing an open empty space. A space board was gently rested on their shoulders with the appropriate foamed plastic supports (Figure 20). The space board carried three aligned markers: one in the middle, one on the right and one on the left. A prepared piece of paper was carefully attached, on the unseen side of the board (Figure 21). The first randomly chosen pair of glasses was applied in front of their eyes and subjects were given a color felt-tipped pen, corresponding to the current pair they were wearing, in their dominant hand. Then, they were asked to look directly at one of the markers on the board and with a single attempt try to point the corresponding location as if touching it with their felt-tipped pen. Participants were asked to do the same with all three markers. After completing the procedure the first pair was removed and a two-minute break was offered before applying the second pair. During this period only small foot or body readjustments that would ensure a relaxed position were allowed. Application of the second pair was followed by the same instructions using a different color felt-tipped pen. Finally, the experiment ended after the third pair was applied following the same steps and again using a felt-tipped pen of different color.

Figure 20 Demonstration of the appropriate placement of space board

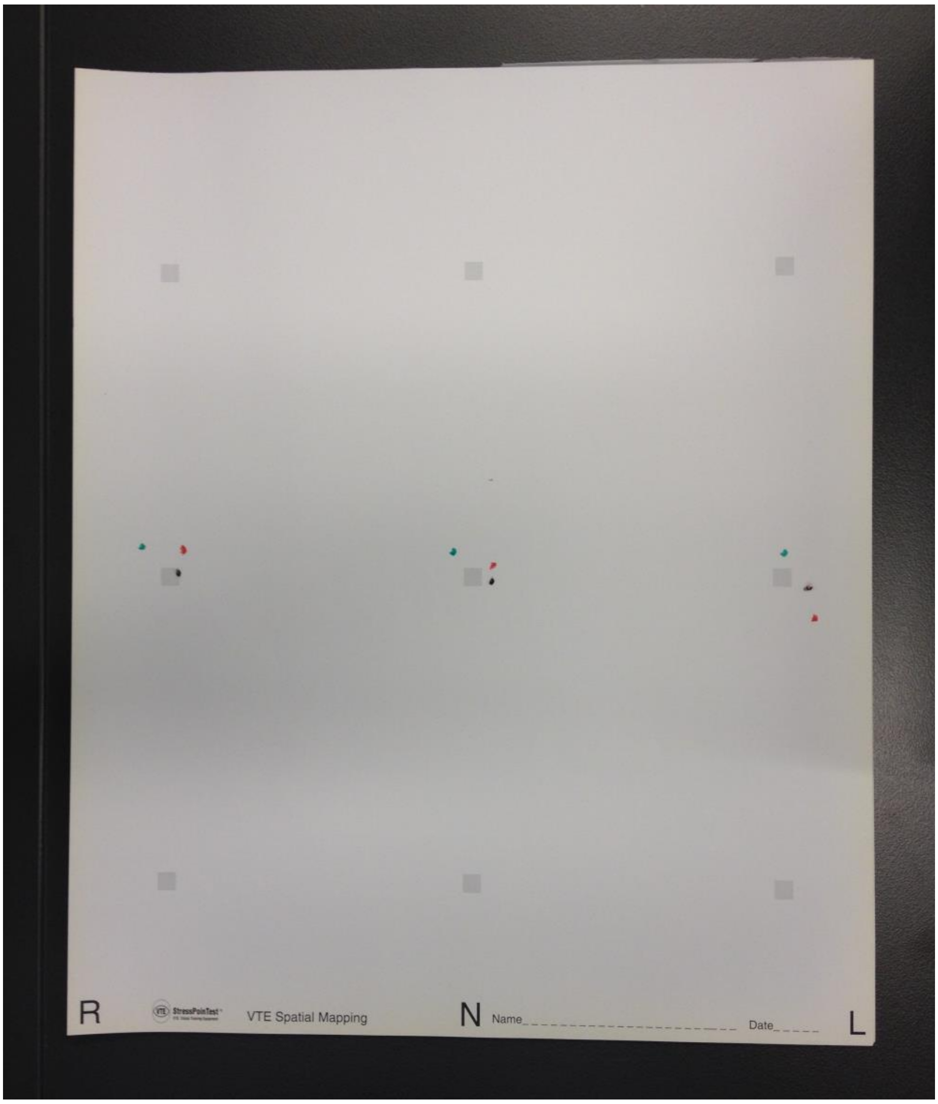


Figure 21 The recording sheet for space board

6.2.4 Statistical analysis

Statistical analysis was conducted with SPSS statistical software (Version 20, SPSS Inc., an IBM Company, Chicago, Illinois, USA). The paired-samples t-test is used in order to determine whether there is a statistically significant mean difference between the two related pairs of observations, as the same group of participants has been matched in one characteristic with two occurrences (BU and BL). This method requires that the difference between the two paired variables follows a normal distribution. For this reason, the Shapiro-Wilk test was used in order to test whether difference-variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. Data for variables having p-value < 0.05 are not normally distributed. Therefore, in this case, the Wilcoxon signed-ranked non parametric test was preferred, which tests whether there is a statistically significant difference in medians (although the paired-samples t-test is considered to be robust against the normality assumption).

6.3 Results

Descriptive statistics concerning experiment’s 3 variables, such as mean, median, standard deviation, minimum and maximum values, are presented in Table 16. Mean differences between BU and BL compared to plano lenses without incorporated prisms, are shown in Figure 22 along with standard deviations.

Experiment’s 3 variables

Variables	Mean	Median	Std. Deviation	Minimum	Maximum
RFP_x_L_BU	.5485	.3000	1.13168	-1.70	3.25
RFP_x_L_BL	.5697	.5000	1.36690	-1.95	4.10
RFP_z_B_BU	1.0833	1.0000	1.57265	-2.20	3.95
RFP_z_B_BL	-.1091	-.4000	2.24491	-5.25	5.60
CFP_x_L_BU	.1076	.0500	.75768	-2.10	1.40
CFP_x_L_BL	.3758	.3500	1.00562	-2.20	3.55
CFP_z_B_BU	1.0076	1.1000	1.78781	-3.25	4.30
CFP_z_B_BL	1.4742	1.3500	1.94567	-1.35	6.65
LFP_x_L_BU	-.0455	-.2500	1.08925	-3.00	2.20
LFP_x_L_BL	-.4106	-.2000	1.37896	-4.70	2.70
LFP_z_B_BU	.5470	.6000	1.23907	-1.85	3.90
LFP_z_B_BL	2.4955	2.0000	1.95242	-.60	7.10

Table 16 Descriptive characteristics (Experiment 3)

Abbreviations: RFP: Right Fixation Point / CFP: Central Fixation Point / LFP: Left Fixation Point / x: x axis / z: z axis / BU: Base Up / BL: Base Left

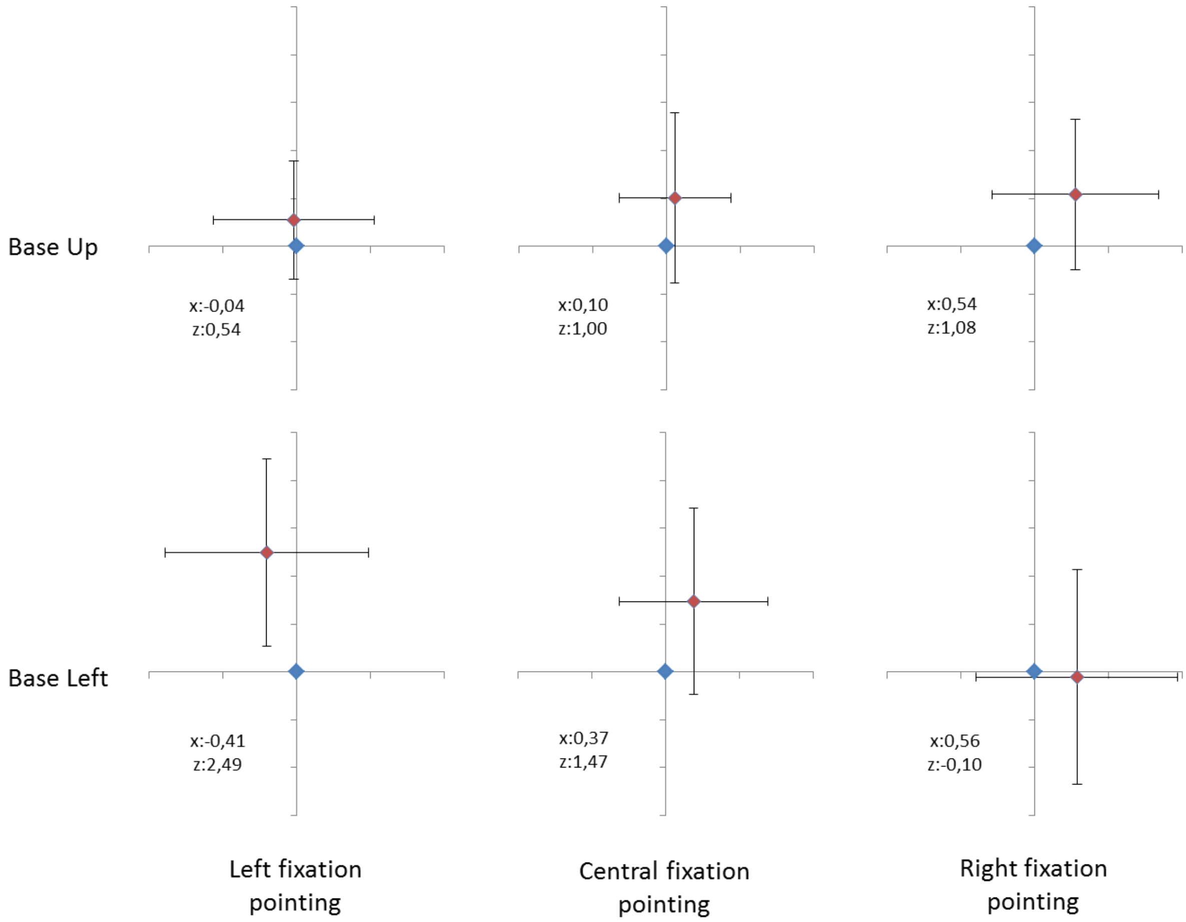


Figure 22 Mean differences between BU and BL compared to plano lenses along with standard deviations

The Shapiro-Wilk test was used in order to test whether difference-variables are normally distributed. For p-values < 0.05 we must reject the null hypothesis of normality. Data for variables having p-value < 0.05 are not normally distributed. It is concluded (Table 17), that only the difference between BU and BL concerning the left fixation point on the z axis (p-value < 0.05) was not conforming to the normality assumption.

	Shapiro-Wilk		
	Statistic	df	Sig.
(1) RFP_x_L_BU	.980	33	.779
(2) RFP_x_L_BL	.978	33	.721
Diff1 = (1)-(2)	.958	33	.231
(3) RFP_z_B_BU	.982	33	.835
(4) RFP_z_B_BL	.958	33	.220
Diff2 = (3)-(4)	.952	33	.153
(5) CFP_x_L_BU	.947	33	.108
(6) CFP_x_L_BL	.940	33	.069

Diff3 = (5)-(6)	.951	33	.147
(7) CFP_z_B_BU	.984	33	.885
(8) CFP_z_B_BL	.959	33	.238
Diff4 = (7)-(8)	.951	33	.147
(9) LFP_x_L_BU	.968	33	.437
(10) LFP_x_L_BL	.961	33	.278
Diff5 = (9)-(10)	.981	33	.820
(11) LFP_z_B_BU	.975	33	.631
(12) LFP_z_B_BL	.946	33	.104
Diff6 =(11)-(12)	.920	33	.018*

*. Significant at .05 level

**. Significant at .001 level

Table 17 Shapiro - Wilk test for normality (Experiment 3)

From Table 18 it is remarked that only the variable for yoked prisms BU was statistically significant greater (1.08 cm ± 1.57 cm) than variable for yoked prisms BL (-0.10 cm ± 2.24 cm) concerning the right fixation point on the z axis ($p < 0.001$), with a medium effect size d = 1.19 / 1.72 = 0.69. Results suggest that yoked prisms base left induced a closer perception of the right fixation point on the z axis.

Paired Samples t-test

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	RFP_x_L_BU - RFP_x_L_BL	-.02121	1.06419	.18525	-.39856	.35613	-.115	32	.910
Pair 2	RFP_z_B_BU - RFP_z_B_BL	1.19242	1.72220	.29980	.58176	1.80309	3.977	32	.000***
Pair 3	CFP_x_L_BU - CFP_x_L_BL	-.26818	.88748	.15449	-.58287	.04651	-1.736	32	.092
Pair 4	CFP_z_B_BU - CFP_z_B_BL	-.46667	1.71458	.29847	-1.07463	.14130	-1.564	32	.128
Pair 5	LFP_x_L_BU - LFP_x_L_BL	.36515	1.25807	.21900	-.08094	.81124	1.667	32	.105

***. Significant at .0005 level

Table 18 Paired samples t-test (Experiment 3)

For the difference between prisms BL and BU on the left fixation point on the z axis where the data are not normally distributed, the Wilcoxon signed-ranked non parametric test was preferred, which tests whether there is a statistically significant difference in medians (although the paired-samples t-test is considered to be robust against the normality assumption).

Ranks

		N	Mean Rank	Sum of Ranks
LFP_z_B_BL - LFP_z_B_BU	Negative Ranks	3[a]	6.50	19.50
	Positive Ranks	30[b]	18.05	541.50
	Ties	0[c]		
	Total	33		

a. LFP_z_B_BL < LFP_z_B_BU

b. LFP_z_B_BL > LFP_z_B_BU

c. LFP_z_B_BL = LFP_z_B_BU

Wilcoxon Signed Ranks Test [a]

	LFP_z_B_BL - LFP_z_B_BU
Z	-4.664[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 19 Ranks and Wilcoxon signed Ranks test (Experiment 3)

In this experiment, in 30 of the 33 participants variable of yoked prisms BL (Mdn = 2.00) was significantly increased in median compared to variable of yoked prisms BU (Mdn = 0.60) concerning left fixation point on the z axis, ($p < 0.001$) (Table 19). Results suggest that yoked prisms base left induced an expended perception of the left fixation point on the z axis.

Results showed that yoked prisms BL had a statistically significant effect on the z-axis compared to yoked prisms BU, by increasing perceived distance on the left side (vision through base of the prisms) and decreasing on the right side (vision through apex of the prisms) (Figure 23).

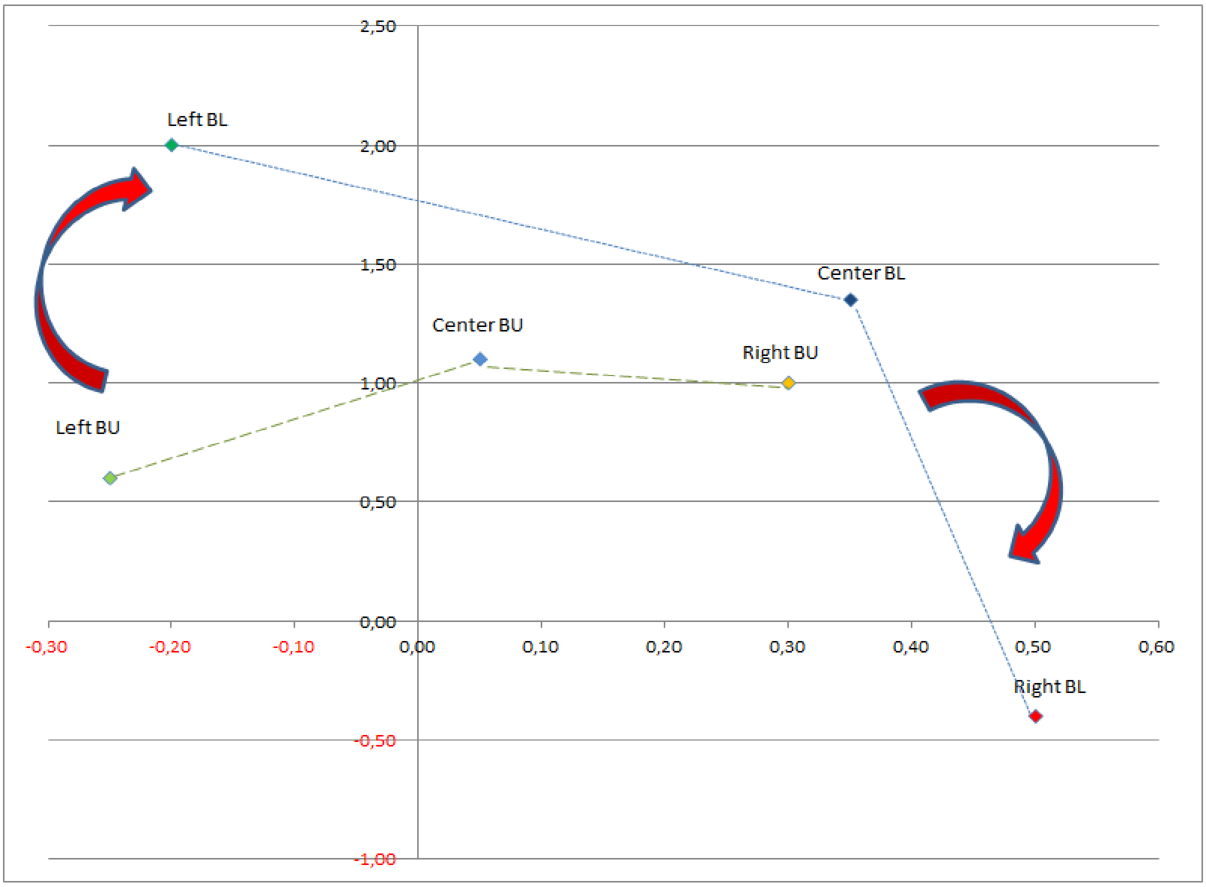


Figure 23 The differences in median values for BU and BL yoked prisms compared to plano lenses on the left, central and right fixation points, expressed in centimetres (cm).

6.4 Discussion

The objective of this experiment was to investigate the effect of yoked prisms on spatial perception. It is important to understand whether these effects are related to postural alterations recorded during the previous experiments. Prismatic adaptation was prevented since hand pointing to the fixation targets was hidden during the whole procedure under the space board disrupting eye contact with the hand. Results suggest that spatial perception is altered simultaneously and respectively to postural changes. It is well known that prisms displace perceived images towards the apex. It is interesting that in this experiment the most significant effect was measured on the z-axis inducing as a result a rotational perception of the visual scene.

Results of this study are in agreement with early studies showing that optical and perceptual effects of prismatic lenses (Reading, 1985) could directly affect human spatial perception. Transformation of the space in a rotational way towards the apex of the prism was the most significant effect of yoked prisms. Although the effects seem to be of small magnitude it should be highlighted that the measuring distance was within arm’s length. As a result, the expansion of the shifting and rotational effects when looking in further distances, can have a significant impact on spatial perception. Distortions created by a prism could interfere with individual’s ability to judge size, distance and perceptions of personal time-space values (Forkiotis, 1995). The positive and negative refractive effect observed through the base and apex of a prism respectively in early studies, could explain the rotational effect recorded in this experiment (Streff, 1973). Since a plus lens would result in relaxation of accommodation, the fixation point observed through the base of the prism could be perceived further away. The opposite happens when the fixation point is observed through the apex of the prism, where the refractive effect mimics a minus lens, thus increasing accommodative demand and perceiving it as closer in space.

The recorded effect seems to be in agreement with the prismatic effects on posture investigated in the second experiment. Postural changes seem to be reflected on the spatial board testing. The rotational effect of yoked prisms BL on the shoulders area and tilts to the right on the head and shoulders can be considered an expression of what is spatially perceived and recorded on the space board. Results showed that yoked prisms BL increased the perceived distance on the z axis on the left side (vision through base of the prisms) and decreased on the right side (vision through apex of the prisms) (Figure 23).

A similar rotational effect can be probably perceived with the yoked prisms base up that were used in this experiment, but in order to be recorded a similar board should have been proposed with its orientation on the y-z axis instead of the x-z axis that was actually used.

6.5 Conclusions

The space board enables evaluation of spatial perception and can be a valuable clinical tool. It is based on visual ‘open loop’ pointing environment, which has been suggested as the condition associating the ‘proprioceptive’ hand-head frame and ‘visual’ eye-head centred frame of reference. The results of this experiment are important because they suggest that yoked prisms can have a significant rotational spatial effect related to changes in body posture apart from just shifting the perceived image towards the apex of the prisms. Yoked prisms base left resulted in expanded perception of space on the z axis corresponding to the view through the base of the prisms. The opposite is true for the view through the apex of the prisms, which resulted in a constricted perception of space on the z axis. This effect seems to be more important than just shifting the perceived image towards the apex of the prism as geometrical optics suggests. Consideration of this prismatic effect on visual perception could provide evidence for using yoked prisms as therapeutic tools for patients with perceptual dysfunctions.

CHAPTER 7 – Experiment 4: Effect of yoked prisms on egocentric localisation

In the previous chapter the effects of yoked prisms on spatial perception and their relationship with the alterations on body posture as recorded in the previous two experiments were discussed. Results showed that there is a significant rotational spatial effect altering the 'where is it' perception but yoked prisms could also have an effect on the egocentric localisation reflecting the 'where am I' perception. In this chapter the fourth experiment is described in detail for investigating any changes that occur in perceiving body's midline and eye level height.

7.1 Introduction

It has been suggested that sensorimotor processing in relation to a perceived preconscious concept of egocentre are responsible for visuo-spatial perception (Padula, et al., 2009). Neurologically challenged persons often experience spatial orientation dysfunctions, vestibular problems and visual midline shift. Yoked prisms have been suggested as a treatment method in those cases in order to re-establish the appropriate perceptual frame (Padula, et al., 2009).

The objective of this experiment is to investigate immediate yoked prism effects in healthy subjects by using the same protocol for neurological patients as suggested by previous studies.

7.2 Method

7.2.1 Participants

Concerning experiment 4, given an effect size of 0.6 and a power level set at 0.65 (for a level of error of type I set at 0.05) the minimum required size for wilcoxon signed ranks test for paired samples was 19. In this experiment 19 subjects were included. Twelve (63.2%) were women. Regarding age, the mean age of the 19 participants was 37.65 years and the standard deviation (SD) was ±8.17. The minimum and maximum ages of the participants of the sample were 25.42 and 53 years respectively. All participants were recruited from population that visited the optometric practice for a regular examination and sustained the criteria for participating in the study.

Variables concerning refractive status of monocular and binocular conditions were analyzed. For variable RefractionRE concerning the refractive status of the right eye, the mean was -1.24 D and the SD was ±2.19 D. Minimum and maximum values were -7.37 D and +0.75 D respectively (Table 20). For variable RefractionLE concerning the refractive status of the left eye, the mean was -1.23 D and the SD was ±2.22 D. Minimum and maximum values were -7.87 D and +1.00 D respectively. For variable RefractionBE concerning the refractive condition of both eyes, the mean was -1.24 D and the SD was ±2.20 D. Minimum and maximum values were -7.62 D and +0.87 D respectively (Table 20).

Age, Refraction RE, Refraction LE and Refraction BE

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Age	19	27.58	25.42	53.00	37.6584	1.87468	8.17153	66.774
RefractionRE	19	8.125	-7.375	.750	-1.24342	.504138	2.197487	4.829
RefractionLE	19	8.875	-7.875	1.000	-1.23684	.509674	2.221617	4.936
RefractionBE	19	8.500	-7.625	.875	-1.24016	.506189	2.206428	4.868

Table 20 Age, monocular and binocular refraction (Experiment 4)

7.2.2 Materials

For conducting this experiment a commercially available Wolff wand (Figure 24) was used (Optometric Extension Program Foundation, 2300 York Road, Timonium, Maryland, U.S.A.). A Wolff wand consists of a stick with a shiny metallic ball on the top, either silver or golden. This ball provides a clear upright mirror reflection which is an ideal target for keeping accommodation and sustained attention active. A stable chair was used for the participants facing a blank wall providing no fixation points.

Three pairs of glasses were used. One pair had no prisms incorporated while the other pairs incorporated 8 Δ yoked prisms with orientations of the prism bases placed either base up (BU) or base left (BL). All pairs were mounted in strap-on wide frames (Bernell Co, 4016, N. Home street, Mishawaka, IN 46545, USA) so they were easily adjusted. Previous studies have used yoked prisms between 5 Δ and 40 Δ. The amount of 8 Δ was selected as the one closer to the maximum amount that usually can be incorporated in a prescription by ophthalmic lens manufacturers.

Aston University

Illustration removed for copyright restrictions

Figure 24 The wolf wand fixation rods. Only one (silver ball) was necessary for this experiment.

7.2.3 Procedure

Subjects were sitting on a stable chair facing a plain wall and were asked to look straight ahead. There were no fixation targets in order to avoid using them as a reference point relative to their perceived midline. A 30 cm fixation rod (Wolff wand) was used (Figure 24), set up vertically 45 cm away from the left shoulder of the subjects. The rod was then moved with a steady velocity of about 4 cm per second towards to the right side and subjects were asked to verbally mention when they feel that the rod was exactly in front of their nose. The same procedure was repeated one more time from right to left. The investigator was seated to the left or right side respectively at an approximate 30 degrees angle to the subject's chair, in order to avoid any influence of his position to the results. Small marks were applied on the floor to assure the appropriate position. The rod was then set up horizontally 45 cm away from their eyes at a position higher than their eye level, slightly above their forehead, and moved downwards with a steady velocity of about 4 cm per second. Subjects were asked to verbally mention when they perceived the rod at their eye level. The procedure was repeated by moving the rod upward from a lower than their eye level position, just below their chin.

Only subjects who performed normally at the initial trial (indicating the position exactly in front of their nose and eyes, marked as '0'), were included to the experiment. Subjects were asked to choose randomly between three colours (red, blue, green) representing a pair of flat yoked prisms 8 Δ BU, a pair of flat yoked prisms 8 Δ BL and a pair of plano lenses not incorporating any prisms respectively. Then, the first randomly chosen pair of yoked prisms was applied and the procedure described above was repeated, followed by the second pair of yoked prisms after a two minutes break. Any shifts of their perceived midline to the right or down were marked as '-1' and any shifts to the left or up as '+1'.

7.2.4 Statistical analysis

Statistical analysis was conducted with SPSS statistical software (Version 20, SPSS Inc., an IBM Company, Chicago, Illinois, USA). In this experiment, the dependent variables are ordinal, so both Wilcoxon Signed Ranks test and Sign test are used. In both tests, the null hypothesis that the median difference between the paired values is equal to zero is tested against the alternative hypothesis that the median difference between the paired values differs from zero.

7.3 Results

Both Wilcoxon Signed Ranks test and Sign test were used and all medians of the variables are presented in Table 21.

Medians			
HBL_RtoL	HBL_LtoR	VBU_UtoD	VBU_DtoU
1.0000	1.0000	1.0000	.0000

Table 21 Medians (Experiment 4)

Abbreviations: HBL: Horizontal Base Left / VBU: Vertical Base Up / R: Right / L: Left / D: Down / U: Up

From Table 22 and Table 23 it is determined that there statistically significant difference in medians using binomial distribution between variables of the initial condition which equals to plano lenses, yoked prisms BL when the fixation rod was moved from right to left (p = 0.035), left to right (p = 0.000), and yoked prisms BU when the fixation rod was moved from up to down (p-value = 0.001). There is no statistically significant difference between the variable of the initial condition and yoked prisms BU when the fixation rod was moved from down to up (p > 0.05). Results suggest that yoked prisms base left shifted the midline perception to the left and yoked prisms base up shifted eye level perception upwards only when the target moved from up to down.

Frequencies

		N
ZeroMedian - HBL_RtoL	Negative Differences[a,d,g,j]	12
	Positive Differences[b,e,h,k]	3
	Ties[c,f,i,l]	4
	Total	19
ZeroMedian - HBL_LtoR	Negative Differences[a,d,g,j]	15
	Positive Differences[b,e,h,k]	0
	Ties[c,f,i,l]	4
	Total	19
ZeroMedian - VBU_UtoD	Negative Differences[a,d,g,j]	14
	Positive Differences[b,e,h,k]	1
	Ties[c,f,i,l]	4
	Total	19
ZeroMedian - VBU_DtoU	Negative Differences[a,d,g,j]	9
	Positive Differences[b,e,h,k]	2
	Ties[c,f,i,l]	8
	Total	19

a. ZeroMedian < HBL_RtoL

b. ZeroMedian > HBL_RtoL

c. ZeroMedian = HBL_RtoL

d. ZeroMedian < HBL_LtoR

e. ZeroMedian > HBL_LtoR

f. ZeroMedian = HBL_LtoR

g. ZeroMedian < VBU_UtoD

h. ZeroMedian > VBU_UtoD

i. ZeroMedian = VBU_UtoD

j. ZeroMedian < VBU_DtoU

k. ZeroMedian > VBU_DtoU

l. ZeroMedian = VBU_DtoU

Table 22 Frequencies (Experiment 4)

Test Statistics[a]

	ZeroMedian - HBL_RtoL	ZeroMedian - HBL_LtoR	ZeroMedian - VBU_UtoD	ZeroMedian - VBU_DtoU
Exact Sig. (2-tailed)	.035[b]	.000[b]	.001[b]	.065[b]

a. Sign Test

b. Binomial distribution used.

Table 23 Sign test (Experiment 4)

From Table 24 and Table 25 it is determined that there is not any statistically significant difference in medians between the variables of yoked prisms BL when the fixation rod was moved from right to left (Mdn = 1.00) and left to right (Mdn = 1.00), ($p > 0.05$). The conclusion stands between the variables yoked prisms BU when the fixation rod was moved from up to down (Mdn = 1.00) and down to up (Mdn = 0.00), ($p > 0.05$). Results suggest that the direction of the moving target makes no difference in this test.

Wilcoxon Signed Ranks Test – Ranks

		N	Mean Rank	Sum of Ranks
HBL_LtoR - HBL_RtoL	Negative Ranks	1[a]	3.50	3.50
	Positive Ranks	6[b]	4.08	24.50
	Ties	12[c]		
	Total	19		
VBU_DtoU - VBU_UtoD	Negative Ranks	8[d]	5.50	44.00
	Positive Ranks	2[e]	5.50	11.00
	Ties	9[f]		
	Total	19		

a. HBL_LtoR < HBL_RtoL

b. HBL_LtoR > HBL_RtoL

c. HBL_LtoR = HBL_RtoL

d. VBU_DtoU < VBU_UtoD

e. VBU_DtoU > VBU_UtoD

f. VBU_DtoU = VBU_UtoD

Table 24 Wilcoxon signed ranks test - Ranks (Experiment 4)

Wilcoxon Signed Ranks Test [a]

	HBL_LtoR - HBL_RtoL	VBU_DtoU - VBU_UtoD
Z	-1.897[b]	-1.897[c]
Asymp. Sig. (2-tailed)	.058	.058

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Table 25 Wilcoxon signed ranks test (Experiment 4)

Sign test confirms results of the Wilcoxon Signed-rank test as shown in Table 26 and Table 27. There was not any statistically significant difference in medians between variables of yoked prisms BL when the fixation rod was moved from right to left (Mdn = 1.00) and left to right (Mdn = 1.00), (p > 0.05), as well as, between variables of yoked prisms BU when the fixation rod was moved from up to down (Mdn = 1.00) and down to up (Mdn = 0.00), (p > .05).

Sign Test – Frequencies

		N
HBL_LtoR - HBL_RtoL	Negative Differences[a,d]	1
	Positive Differences[b,e]	6
	Ties[c,f]	12
	Total	19
VBU_DtoU - VBU_UtoD	Negative Differences[a,d]	8
	Positive Differences[b,e]	2
	Ties[c,f]	9
	Total	19

a. HBL_LtoR < HBL_RtoL

b. HBL_LtoR > HBL_RtoL

c. HBL_LtoR = HBL_RtoL

d. VBU_DtoU < VBU_UtoD

e. VBU_DtoU > VBU_UtoD

f. VBU_DtoU = VBU_UtoD

Table 26 Sign test – Frequencies (Experiment 4)

Table 5b: Sign Test

	HBL_LtoR - HBL_RtoL	VBU_DtoU - VBU_UtoD
Exact Sig. (2-tailed)	.125[a]	.109[a]

a. Binomial distribution used

Table 27 Sign test (Experiment 4)

7.4 Discussion

Two main reference frames are recognized in previous researches. The ‘visual’ eye-head-centred frame and the ‘proprioceptive’ hand-head reference frame. The second one is mostly important when visual information is deprived, like in experiments with subjects pointing straight ahead while blindfolded. The first reference frame has been proposed in the diagnosis of Visual Midline Shift Syndrome (VMSS) and research provided high correlation in right brain damaged patients showing left hemiparesis and rightward midline shift. In these cases yoked prisms base left have been proved beneficial shifting midline to the left towards midline. Results from this experiment seem to be in agreement with studies with neurologic patients showing an egocentric localisation towards the base of the prism in normal population (Padula, et al., 2009). Results showed statistically significant effects on both horizontal and vertical egocentric localisation when prismatic adaptation was prevented.

Yoked prisms base left induced a midline shift to the left. Yoked prisms base up induced an altered perception of eye level upwards but only when the moving target was approaching from up to down. A possible explanation can be based on the prismatic spatial phenomena in combination with the vertical expansion of the visual field. Humans' vertical visual field is expanded more downwards than upwards in reference to primary gaze. In addition, prisms tend to expand visual field towards the apex and constrict towards the base (Figure 2). As a result, when the moving upwards target is viewed through a base up prism, the velocity could be perceived as gradually decreased, even though it is stable, thus giving a false perception of approaching the eye level earlier.

The approaching side of the target towards midline did not show any correlation to the results thus it is not a significant parameter when introducing the test. This could be partially explained by the symmetrically experienced lateral visual field in reference to midline compared to the asymmetrically experienced vertical visual field in reference to the eye level.

7.5 Conclusions

Egocentric perception can be easily examined with the Visual Midline Shift Test. The results of this experiment are important because they suggest a statistically significant effect of yoked prisms on visual midline perception and eye level perception in healthy subjects, when prism adaptation is prevented. Yoked prisms base left shifted egocentric perception to the left and yoked prisms base up shifted eye level perception higher in healthy population. Results also suggest that direction of the moving target is not a significant factor in applying the testing procedure. The effect of yoked prisms on egocentric localisation, as recorded in this experiment, should come into consideration, when yoked prisms are applied for the rehabilitation of nystagmus, hemianopia or other dysfunctions in order to prevent establishing an altered body perception in space.

CHAPTER 8 – General discussion

8.1 Strengths

The aim of this research was to investigate the effect of yoked prisms on body posture, spatial perception and egocentric localisation. Participants in this study were healthy adults and prismatic adaptation was prevented, so results reflect the initial direct effect of prisms. This is an important parameter because up today studies were based on the effects observed after prismatic adaptation in pathological groups (Padula, et al., 2009; Wong, et al., 2002). One study that was conducted in a healthy group and analyzed measurements immediately after the application of 15 Δ yoked prisms, included only eight subjects, which is a very small sample (Gizzi, et al., 1997). The prismatic power selected for this research was 8 Δ which is an amount that can be incorporated in an ophthalmic lens. Other studies have used very strong prisms that can show significant effects but are rarely used and difficult to tolerate in everyday use (Brookes, et al., 2007). The effectiveness of yoked prisms on body posture, spatial perception and egocentric localisation could be fully or partially related to each other or otherwise unrelated. Studying their correlations is a significant aspect of this research providing a better insight into whether spatial perception and/ or egocentric perception lead changes in body posture or *vice versa*, as a result of prismatic adaptation.

Results of this research suggest that yoked prisms have a significant effect in all these areas before any prismatic adaptation takes place. If any of these examined areas was dependent on the others, as a product of prismatic adaptation, then no correlations would be detected. Instead, body posture, spatial perception and egocentric localisation are presented as different expressions of the same effects. The ‘where am I’ and the ‘where is it’ systems seem to be affected mainly at a subconscious level, although many subjects verbally expressed being aware of ‘something changing’ without being able to provide further descriptions in most cases.

This research suggests that yoked prisms have a significant effect on body posture in terms of shifts and tilts mainly in the upper body and neck-head area. These changes in posture are not affecting weight distribution on the legs thus resulting in no significant changes in posturographic results. It seems that the body is trying to sustain homeostasis against gravity.

When yoked prisms BL were applied in healthy subjects the centre of pressure (CoP) indicated some limitation in rightward body sway highlighting the tendency of the postural shift to the left even when changes in weight distribution are not detected. Healthy subjects, like those who participated in this study, have obviously an intact muscular system and physiological neuronal activity. It could be that other body parts, which were not analyzed in this study, could be affected counterbalancing the induced effect towards a secured homeostasis. Previous research has shown that presentation of visual stimulus in the periphery has decreased the area of CoP (Berencsi, et al., 2005; Keshner & Kenyon, 2009). Prisms induce distortions in the periphery mostly oriented in the apex and base area. These distortions could have played a role in decreasing CoP in this research highlighting the importance of prism orientation.

This research showed that the body parts most affected by the application of yoked prisms were mostly oriented in the upper body. Yoked prisms BL induced a head and hips shift to the right. In addition, head and shoulders tilt to the right was recorded, resulting in a generalized rightward angular midline tilt. A noted shift of the right shoulder backwards suggests a simultaneous clock-wise rotational effect on the shoulders area. In a similar way, yoked prisms BU resulted in a head shift forward. A decreased angle, formed by the head and shoulders, was noted contemporaneously reducing the distance between chin and chest.

More tilt and shift tendencies in other parts of the body could be present in terms of muscle tonicity but not expressed thus not recorded. The reason could be attributed mainly to posture constancy. Any significant alteration in posture or body sway on the z axis could affect stability and increase the risk of falling, while on the x axis the position of the two feet side by side can create a buffer allowing changes to take place with reduced risk of stability loss.

What has been recorded on body posture is also partially related to the results recorded on space board. Pointing at fixation targets in visual open loop conditions, where eye contact with the pointing hand is prohibited, indicated that yoked prisms have mainly a rotational spatial effect. Yoked prisms BL result in a clock-wise rotation of space. Field is expanded on the z axis when viewed through the base and constricted when viewed through the apex of the prisms. Perceptual and motor systems are probably trying to synchronize and match what is visually perceived with proprioceptive and vestibular clues. As a result, the space board actually reflects not only spatial transformations induced by yoked prisms but also the upper body’s altered posture on the x and z axis.

When homeostasis and stability has been established, the person creates a new frame of reference. The integration of visual, proprioceptive and vestibular updated information change the ‘where am I’ perception. This has been reported in the final experiment, where horizontal and vertical perceptions of midline and eye level respectively were affected towards the base of the prisms. Yoked prisms BL shift midline perception to the left and yoked prisms BU shift eye level perception higher. This is partially in agreement with the shift of barycentre to the left and limitation of body sway to the right, when yoked prisms BL were applied.

Internal representation of space and body are affected simultaneously by the application of yoked prisms before any adaptation takes place. This is reflected in the altered body posture, on space board and egocentric perception in a predictive way.

8.2 Limitations

Although sophisticated high end technology is now available in research centres for evaluating body posture and spatial perception through virtual reality environments (Diniz-Filho, et al., 2015), the aim of this study was to investigate the effect of yoked prisms in body posture and egocentric localisation with low cost tools that could be easily used in a clinical setting.

One significant limitation of the current study was the single amount of prism that has been used. The amount of 8 Δ was decided after extended review of previous studies, avoiding very small or very big amounts, and based on the fact that this could be one of the highest amounts grounded in an ophthalmic lens. Using stronger prismatic lenses could induce significant aberrations and disorientation that could be problematic in providing confident results. On the other hand, using weaker prismatic lenses could be insufficient in triggering any effect.

8.3 Future research

Yoked prisms of 8 Δ were used with base left and base up orientation. We suggest that more orientations including base down and base right, or even diagonal orientations, would provide more insights and cross check results on the lateral axis. Inclusion of diagonal orientation would be an interesting factor suggesting yoked prisms base at 45°, 135°, 225° or 315°. Future researchers should experiment more with different amounts of prisms because the rule of “more is less” or “less is more” could be of significant value. In addition, prisms used in this study were of flat surfaces. Results could be different if curved or Fresnel prisms were used. This could be a topic to consider in further investigations.

As far as posturography is concerned the time frame for recording centre of pressure measurements was 20 seconds. It would be interesting to measure this postural behaviour in a prolonged time frame or in more time frames spread within a prolonged period. This would enable the evaluation of the behavioural stability in postural terms. The investigation of the performance in a prolonged period could provide also insights to whether vestibular and proprioceptive systems are enough to promote prismatic adaptation on their own, without any motor involvement.

The photographic analysis was carried out with a low cost application for smartphones and free computer software. Using more views could be beneficial and more data could be gathered. A top-down view would be ideal for recording head, shoulder and probably hips rotations. Since this research suggests that yoked prisms have a significant rotational spatial effect, it would be interesting to assure more photographic captures that would enable an enhanced analysis of potential rotational effects. In future research projects more body parts could be also analyzed. For example, knees, rib cage, elbows, etc. Video analysis could be part of a future project for the investigation of postural changes in a time frame. This approach could be useful in identifying which body parts are affected first or more providing us further insights into the physiological or neural mechanisms involved.

Space board is a clinical tool used mainly by behavioural and developmental optometrists and the version used in this study had two foamed plastic supports for resting space board on subject’s shoulders. This could potentially increase proprioceptive signals on the neck area providing the subject with a gross frame of reference about the size or edges of the space board. Adaptations on holding the space board without touching subjects’ shoulders at the appropriate height for each subject should be considered in future projects by preventing at the same time any feedback about its dimensions or location. Additionally, more fixation points could be used on the space board that would provide more data on spatial perception. Another parameter to be considered in a future experimental set up would be asking participants to hold the marker with both hands instead of the dominant hand. The reason for not selecting this condition in this study was the potential proprioceptive feedback that the subject would gain about his midline.

During the final experiment the evaluation of midline shift was conducted using the same principles as in the clinical practice. The purpose for choosing this method was to be able to transfer research findings into clinical consideration. One disadvantage is that the presence of the examiner beside the subject during the procedure could provide some kind of reference point. The velocity of the moving wolf wand is another topic to be considered because even after lot of practice nobody can assure that it’s the same in every case. A mechanical set for moving the wolf wand with a stable velocity would be better in combination with a roof camera for evaluating the final placement of the wolf wand compared to subject’s midline.

Further research on these topics would be valuable in understanding the physiological and neural mechanisms involved in posture stability and egocentric localisation. Future projects could enhance understanding the perceptual phenomena of the yoked prisms and their use in clinical application.

8.4 Clinical applications

The clinical application of yoked prisms in various pathological conditions has been well documented. Postural dysfunctions are treated mainly by orthopedists and physical therapists by using additional orthotics when necessary, but the perceptual aspects of these dysfunctions are mostly overlooked. The same problem exists during the rehabilitation and therapy of neurological dysfunctions by the occupational therapists. Although therapists using sensory integration principles are aware of the sensorial aspects affecting each condition, they are not properly trained to understand visual process in depth and they are not allowed to use optical means like lenses, prisms or filters. Optometrists could enhance and support all those therapeutic and rehabilitative interventions by participating in a team which endorses a multi-disciplinary approach.

Yoked prisms may also have some clinical applications in healthy population, mainly for preventative reasons. The extended and prolonged use of computers, tablets, e-books and smart phones has been reported to have a negative impact on neck and head postures which usually shift closer to the object of sustained attention (Edmondston, et al., 2008). The ‘forward head syndrome’ could be probably prevented or limited with the use of the appropriate pair of yoked prisms by providing support to the neck muscles. Other habitual or poor ergonomic postures in various working environments could induce back or shoulder problems that could be prevented with the use of yoked prisms.

It has been also shown that fixed habitual body and head postures can influence the refractive conditions. A study among musicians in a philharmonic orchestra showed that characteristics of their refractive condition were related to their habitual posture (Harris, 1988). The application of yoked prisms in these cases could have a positive impact by counterbalancing required asymmetries according to the musical instrument they play thus reducing the development of refractive asymmetries. The concept of using yoked prisms for the management of the anisometropia has been proposed by Kraskin but has not been studied systematically (Kraskin, 2003).

Another clinical application could be related to sports performance. There are many sports which demand a certain posture for achieving maximum performance (e.g. archery). The use of yoked prisms may be beneficial for sustaining or increasing flexibility of certain body parts by also considering the combination of the induced perceptual effects.

In addition, the presence of yoked prisms in the progressive addition lenses for compensating thickness (thinning prisms) may be the etiological factor in some cases of non-tolerance. Although the amount of the incorporated yoked prisms do not exceed 2.5 Δ and are usually well tolerated (Sheedy & Parsons, 1987) it may be enough to trigger some symptoms of neuro-muscular or perceptual nature since it has been shown that increase the degree of forward head posture (Willford, et al., 1996). This means that special orders with or without the thinning prisms could be considered on an individual basis.

8.5 Conclusions

Yoked prisms can have some significant effects on body posture, spatial perception and egocentric localisation in a healthy population before any prismatic adaptation takes place. Yoked prisms BL induce a rightward shift of the head and hips, a rightward tilt of the head and shoulders and a backward shift of the right shoulder which is in agreement with the rotational spatial perception recorded on space board. An angular midline shift to the right is also noted. Egocentric localisation is shifted to the left which is also in agreement with the barycentre shifting to the left by reducing the body sway to the right. Yoked prisms BU induce a forward shift of the head and a reduced head-neck-hips angle, bringing chin closer to the chest. This is in agreement with the upward shift recorded during testing the subjective perception of eye level.

The importance of the results is focused on the fact that yoked prisms can have some profound and predicted alterations on body posture, spatial perception and egocentric localisation before any adaptation takes place. Results of this study are useful in expanding the clinical use of yoked prisms in rehabilitation and therapy of postural and perceptual dysfunctions in otherwise healthy subjects. Simple tests like the space board and the visual midline shift test can be helpful in determining the appropriate pair of yoked prisms, since results of this study showed that spatial and egocentric perception can be related to predicted postural changes.

Further research is needed in order to investigate the effects of yoked prisms of different magnitudes and base directions.

REFERENCES

Adams, G. & Hurwitz, L., 1963. Mental barriers to recovery from stroke. *Lancet*, Volume 11, pp. 533-537.

Alexander, M., Flodin, B. & Marigold, D., 2011. Prism adaptation and generalization during visually guided locomotor tasks. *J Neurophysiol*, Issue 106, pp. 860-871.

Amblard, B. & Carblanc, A., 1980. Role of foveal and peripheral visual information in maintenance of postural equilibrium in man. *Percept Motor Skill*, Issue 51, pp. 903-912.

Anand, V., Buckley, J., Scally, A. & Elliot, D., 2003. Postural stability changes in the elderly with cataract simulation and refractive blur. *Invest Ophthalmol Vis Sci*, Issue 44, pp. 4670-4675.

Backus, B., Banks, M., van Ee, R. & Crowell, J., 1999. Horizontal and vertical disparity, eye position, and stereoscopic slant perception. *Vision Res*, Issue 39, pp. 1143-1170.

Baizer, J., Kralj-Hans, I. & Glickstein, M., 1999. Cerebellar lesions and prism adaptations in macaque monkeys. *J Neurophysiol*, Volume 81, pp. 1960-1965.

Bansal, S., Han, E. & Ciuffreda, K., 2014. Use of yoked prisms in patients with acquired brain injury: A retrospective analysis. *Brain Injury*, 28(11), pp. 1441-1446.

Bardy, B., Warren, W. & Kay, B., 1999. The role of central and peripheral vision in postural control during walking. *Percept Psychophys*, Issue 61, pp. 1356-1368.

Baroni, G. et al., 1999. Long-term adaptation of postural control in microgravity. *Exp Brain Res*, Volume 128, pp. 410-416.

Barrett, A., Goedert, K. & Basso, J., 2012. Prism adaptation for spatial neglect after stroke: translational practice gaps. *Nat Rev Neurol*, 8(10), pp. 567-577.

Barrett, B., 2009. A critical evaluation of the evidence supporting the practice of behavioural vision therapy. *Ophthal Physiol Opt*, Volume 29, pp. 4-25.

Bartley, J., Plant, A. & Spurdle, A., 2014. Successful treatment of persisting neck pain after radical neck dissection using prism glasses. *Pain Med*, Volume 15, pp. 333-334.

Bedard, P., Thangavel, A. & Sanes, J., 2008. Gaze influences finger movement-related and visual-related activation across the human brain. *Exp Brain Res*, Issue 188, pp. 63-75.

Benabib, R. & Nelson, C., 1993. Efficiency in visual skills and postural control: A dynamic interaction. *Occupational therapy practice*, Issue 3, pp. 56-57.

Benda, B., Riley, P. & Krebs, D., 1994. Biomechanical relationship between center of gravity and center of pressure during standing. *IEEE Trans Rehab Eng*, 2(1), pp. 3-10.

Berencsi, A., Ishihara, M. & Imanaka, K., 2005. The functional role of central and peripheral vision in the control of posture. *Hum Movement Sci*, Issue 24, pp. 689-709.

Bisiach, E., Capitani, E. & Porta, E., 1985. Two basic properties of space representation in the brain: evidence from unilateral neglect. *J Neurol Neurosurg Psych*, Volume 48, pp. 141-144.

Black, A. et al., 1997. Mobility performance with retinitis pigmentosa. *Clin Exp Opt*, Issue 80, pp. 1-12.

Bonan, I. et al., 2004. Reliance on visual information after stroke. Part I: Balance on dynamic posturography. *Arch Phys Med Rehabil*, Issue 85, pp. 268-273.

Bosco, G. & Poppele, R., 2003. Modulation of dorsal spinocerebellar responses to limb movement: II. Effect of sensory input. *J Neurophysiol*, Volume 90, pp. 3372-3383.

Bouffard, J., Gagné, M. & Mercier, C., 2013. Effect of painful and non-painful sensorimotor manipulations on subjective body midline. *Front Hum Neurosci*, Issue 7.

Brandt, T., Dichgans, J. & Koenig, E., 1973. Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. *Exp Brain Res*, Issue 16, pp. 476-491.

Bron, A., Tripathi, R. & Tripathy, B., 1997. *Wolff's anatomy of the eye and orbit.* 8th ed. London: Hodder Arnold.

Bronstein, A. & Hood, J., 1986. The cervico-ocular reflex in normal subjects and patients with absent vestibular function. *Brain Res*, Issue 373, pp. 399-408.

Brookes, R., Nicolson, R. & Fawcett, A., 2007. Prisms throw light on developmental disorders. *Neuropsychologia*, Volume 45, pp. 1921-1930.

Brook-Wavell, K., Perrett, L., Howarth, P. & Haslam, R., 2002. Influence of the visual environment on the postural stability in healthy older woman. *Gerontology*, Issue 48, pp. 293-297.

Brown, W., 1995. Optical principles of prism. In: *Clinical uses of prism. A spectrum of applications.* St. Louis: Mosby, p. 6.

Bucci, M. et al., 2009. Poor postural stability in children with vertigo and vergence abnormalities. *Invest Ophthalmol Vis Sci*, Volume 50, pp. 4678-4684.

Buchanan, J. & Horak, F., 1987. Emergence of postural patterns as a function of vision and translation frequency. *Exp Brain Res*, Volume 69, pp. 77-92.

Buckley, J., Anand, V., Scally, A. & Elliott, D., 2005. Does head extension and flexion increase postural instability in elderly subjects when visual information is kept constant?. *Gait Posture*, 21(1), pp. 59-64.

Bultitude, J. & Rafal, R., 2010. Derangement of body representation in complex regional pain syndrome: report of a case treated with mirror and prisms. *Exp Brain Res*, Issue 204, pp. 409-418.

Bultitude, J., Rafal, R. & List, A., 2009. Prism adaptation reverses the local processing bias in patients with right temporo-parietal junction lesions. *Brain*, 132(6), pp. 1669-1677.

Bultitude, J., Van Der Stigchel, S. & Nijboer, T., 2013. Prism adaptation alters spatial remapping in helathy individuals: Evidence from double-step saccades. *Cortex*, Issue 49, pp. 759-770.

Bultitude, J. & Woods, J., 2010. Adaptation to leftward-shifting prisms reduces the global processing bias of healthy individuals. *Neuropsychologia*, 48(6), pp. 1750-1756.

Buttner-Ennever, J., 1999. A review of otolith pathways to brainstem and cerebellum. *Ann NY Acad Sci*, Issue 871, pp. 51-64.

Caloroso, E. & Cotter, S., 1995. Prescribing prisms for strabismus. In: *Clinical uses of prism. A spectrum of applications.* St. Louis: Mosby, p. 213.

Carmody, D., Kaplan, M. & Gaydos, A., 2001. Spatial orientation adjustments in children with autism in Hong Kong. *Child Psychiat Hum D*, Issue 31, pp. 233-247.

Carriot, J., DiZio, P. & Nougier, V., 2008. Vertical frames of reference and control of body orientation. *Clin Neurophysiol*, Issue 38, pp. 423-437.

Catanzariti, J., Salomez, E., Bruandet, J. & Thevenon, A., 2001. Visual deficiency and scoliosis. *Spine*, Issue 26, pp. 48-52.

Chambers, B., Mai, M. & Barber, H., 1985. Bilateral vestibular loss, oscillopsia, and the cervico-ocular reflex. *Otolaryng Head Neck*, Volume 93, pp. 403-407.

Chapman, H. et al., 2010. Neural mechanisms underlying spatial realignment during adaptation to optical wedge prisms. *Neuropsychologia*, Volume 48, pp. 2595-2601.

Chen, B. & May, P., 2000. The feedback circuit connecting the superior colliculus and central mesencephalic formation: a direct morphological demonstration. *Exp Brain Res*, Volume 131, pp. 10-21.

Chokron, S. & Bartolomeo, P., 2000. Correlation between the position of the egocentric reference and right neglect signs in left-brain-damaged patients. *Brain Cog*, Volume 43, pp. 99-104.

Cho, M. & Benjamin, W., 1998. Correction with multifocal spectacle lenses. In: *Borish's clinical refraction.* 1st ed. Philadelphia: Saunders, p. 918.

Cleworth, T., Horslen, B. & Carpenter, M., 2012. Influence of real and virtual heights on standing balance. *Gait Posture*, Issue 36, pp. 172-176.

Clower, D. & Boussaoud, D., 2000. Selective use of perceptual recalibration versus visuomotor skill acquisition. *J Neurophysiol*, Volume 84, pp. 2703-2708.

Clower, D., West, R., Lynch, J. & Strick, P., 2001. The inferior parietal lobule is the target of output from the superior colliculus, hippocampus, and cerebellum. *J Neurosci*, Volume 21, pp. 6283-6291.

Cohen, L., 1961. Role of the eye and neck proprioceptive mechanisms in body orientation and motor coordination. *J Neurophysiol*, Issue 24, pp. 1-11.

Collins, J. & De Luca, C., 1993. Open-loop and closed-loop control of posture: A random-walk analysis of center-of-pressure trajectories. *Exp Brain Res*, Volume 95, pp. 308-318.

Corneil, B., Olivier, E. & Munoz, D., 2004. Visual responses of neck muscles reveal selective gating that prevents express saccades. *Neuron*, Volume 42, pp. 831-841.

Creath, R., Kiemel, T., Horak, F. & Jeka, J., 2002. Limited control strategies with the loss of vestibular function. *Exp Brain Res*, Volume 145, pp. 323-333.

Danckert, J. & Ferber, S., 2006. Revisiting unilateral neglect. *Neuropsychologia*, Volume 44, pp. 987-1006.

Danckert, J., Ferber, S. & Goodale, M., 2008. Direct effects of prismatic lenses on visuomotor control: An event-related functional MRI study. *Eur J Neurosci*, 28(8), pp. 1696-1704.

Delbaere, K., Sturnieks, D., Crombez, G. & Lord, S., 2009. Concern about falls elicits changes in gait parameters in conditions of postural threat in older people. *J Gerontol Biol Sci Med Sci*, Issue 64A, pp. 237-242.

Diniz-Filho, A. et al., 2015. Evaluation of postural control in patients with glaucoma using a vistual reality environment. *Ophthalmology*.

Dogan, S. & Erturk, N., 1990. The effect of vision on craniocervical posture and its relation to craniofacial and dentoalveolar morphology. *Quintessence Int*, Issue 21, pp. 401-406.

Dum, R. & Strick, P., 2003. An unfolded map of the cerebellar dentate nucleus and its projections to the cerebral cortex. *J Neurophysiol*, Volume 89, pp. 634-639.

Dunk, N., Lalonde, J. & Callaghan, J., 2005. Implications for the use of postural analysis as a clinical diagnostic tool: Reliability of quantifying upright standing spinal postures from photographic images. *J Manip Physiol Ther*, 28(6), pp. 386-392.

Eber, A., Strubel-Streicher, D., Guillot, M. & Collard, M., 1984. Loss of balance, vertigo and nystagmus induced by maximum excentration of gaze. The role of extra-ocular proprioception. *Rev Neurol (Paris)*, Issue 140, pp. 131-137.

Edmondston, S. et al., 2008. Reliability of isometric muscle endurance tests in subjects with postural neck pain. *J Manip Physiol Ther*, June, 31(5), pp. 348-354.

Edwards, A., 1946. Body-sway and vision. *J Exp Psychol*, Issue 36, pp. 526-535.

Errington, J. et al., 2013. The effects of vertical yoked prisms on gait. *Invest Ophthalmol Vis Sci*, 54(6), pp. 3949-3956.

Falla, D., Rainoldi, A., Merletti, R. & Jull, G., 2004. Spatio-temporal evaluation of neck muscle activation during postural perturbations in healthy subjects. *J Neurophysiol*, Volume 92, pp. 2368-2379.

Farne, A., Ponti, F. & Ladavas, E., 1998. In search for biased egocentric reference frames in neglect. *Neuropsychology*, Volume 36, pp. 611-623.

Farne, A., Rossetti, Y., Toniolo, S. & Ladavas, E., 2002. Ameliorating neglect with prism adaptation: Visuo-manual and visuo-verbal measures. *Neuropsychologia*, 40(7), pp. 718-729.

Ferber, S. & Murray, L., 2005. Are perceptual judgments dissociated from motor processes? A prism adaptation study. *Cogn Brain Res*, Issue 23, pp. 453-456.

Fernandez-Ruiz, J. & Diaz, R., 1999. Prism adaptation and aftereffect: Specifying the properties of a procedural memory system. *Learn Mem*, Volume 6, pp. 47-53.

Fischer, V. & Mahaphon, T., 2006. Use of yoked prism in the management of nystagmus on spina bifida. *Optometry*, 77(6), pp. 275-276.

Flach, F. et al., 1992. Visual perception dysfunction: schizophrenic and affective disorders vs controls. *J Neuropsych Clin N*, Issue 4, pp. 422-427.

Fogt, N. & Henry, J., 1999. The extend to which compensation for the prismatic effects of spectacle lenses is maintained. *Optom Vis Sci*, Issue 76, pp. 170-176.

Fogt, N. & Jones, R., 1996. The effect of refractive lenses on perceived direction. *Vision Res*, 36(22), pp. 3735-3741.

Forkiotis, C., 1995. Characteristics of spectacle lenses. How patients respond to lenses. *J Optom Vis Dev*, Volume 26, pp. 224-231.

Fortis, P., Goedert, K. & Barrett, A., 2011. Prism adaptation differently affects motor-intentional and perceptual-attentional biases in healthy individuals. *Neuropsychologia*, Volume 49, pp. 2718-2727.

Fox, C., 1990. Some visual influences on human postural equilibrium: binocular versus monocular fixation. *Percept Psychophys*, Issue 47, pp. 409-422.

Frassinetti, F., Angeli, V., Meneghello, F. & al., e., 2002. Long-lasting amelioration of visuospatial neglect by prism adaptation. *Brain*, Volume 125, pp. 608-623.

Friedrich, M. et al., 2008. Influence of pathologic and simulated visual dysfunctions on the postural system. *Exp Brain Res*, Issue 186, pp. 305-314.

Friston, K. et al., 1992. Motor practice and neurophysiological adaptation in the cerebellum: a positron tomography study. *Proc R Soc Lond B Biol Sci*, Issue 248, pp. 223-228.

Gaertner, C. et al., 2013a. Postural control in nonamblyopic children with early-onset strabismus. *Invest Ophthalmol Vis Sci*, 54(1), pp. 529-536.

Gaertner, C. et al., 2013b. Benefit of bi-ocular visual stimulation for postural control in children with strabismus. *PLoS ONE*, 8(4).

Galbrecht, D., Marks, L. & Franzel, A., 2007. Successful prism treatment in two cases of isolated oculomotor nerve palsy. *Optometry*, 78(6), p. 271.

Garriott, R. & Rouse, M., 1994. A unique management tool for double elevator palsy. Poster # 48 (BV-113). *Optom Vis Sci*, 71(12), p. 49.

Gentaz, R., 1988. L' oeil postural. *Agressologie*, Issue 29, pp. 685-686.

Gentle, A. & Ruskell, G., 1997. Pathway of primary afferent nerve fibers serving proprioception in monkey extra-ocular muscles. *Ophthal Physiol Opt*, Volume 17, pp. 225-231.

Geruschat, D. & Turano, K., 2007. Estimating the amount of mental effort required for independent mobility: persons with glaucoma. *Invest Ophthalmol Vis Sci*, Issue 48, pp. 3988-3994.

Gibson, J., 1933. Adaptation after-effects , and contrast in the perception of curved lines. *J Exp Psych*, Volume 16, pp. 1-31.

Gibson, J., 1979. *The ecological approach to visual perception.* Boston: Houghton Mifflin, Co..

Gilbert, P. & Thach, W., 1977. Purkinje cell activity during motor learning. *Brain Res*, Issue 128, pp. 309-328.

Gizzi, M., Khattar, V. & Eckert, A., 1997. A quantitative study of postural shifts induced by yoked prisms. *J Optom Vis Dev*, Volume 28, pp. 200-203.

Goldberg, M. & Hudspeth, A., 2000. The vestibular system. In: *Principles of neural science.* 4th ed. s.l.:McGraw-Hill.

Goodale, M. & Milner, A., 1992. Seperate visual pathways for perception and action. *Trends Neurosci*, 15(1), pp. 20-25.

Gottshall, K., Hoffer, M., Cohen, H. & Moore, R., 2006. Active head movements facilitate compensation for effects of prism displacement on dynamic gait. *J Vestibul Res*, Issue 16, pp. 29-33.

Graci, V., Elliott, D. & Buckley, J., 2010. Utility of peripheral visual cues in planning and controlling adaptive gait. *Optom Vis Sci*, 87(1), pp. 21-27.

Grossman, G., Leigh, R., Bruce, E. & al., e., 1989. Performance of the human vestibuloocular reflex during locomotion. *J Neurophysiol*, Issue 62, pp. 264-272.

Guerraz, M., Sakellari, V., Burchill, P. & Bronstein, A., 2000. Influence of motion parallax in the control of spontaneous body-sway. *Exp Brain Res*, Issue 131, pp. 244-252.

Habak, C., Casanova, C. & Faubert, J., 2002. Central and peripheral interactions in the perception of optic flow. *Vision Res*, Issue 42, pp. 2843-2852.

Hallett, M. et al., 1991. Physiological analysisof simple rapid movements in patients with cerebellar deficits. *J Neurol Neurosur Ps*, Issue 53, pp. 124-133.

Harris, C., 1974. Beware the straight-ahead shift: A non perceptual change in experiments on adaptation to displaced vision. *Perception*, Volume 3, pp. 461-476.

Harrison, D. et al., 2007. Validation of a computer analysis to determine 3-D rotations and translations of the rib cage in upright posture from three 2-D digital images. *Eur Spine J*, Issue 16, pp. 213-218.

Harrison, D. et al., 2008. Upright static pelvic posture as rotations and translations in 3-dimansional from three 2-dimansional digital images: Validation of a computerized analysis. *J Manip Physiol Ther*, 31(2), pp. 137-145.

Harris, P., 1988. Visual conditions of symphony musicians. *J Am Optom Assoc*, December, 59(12), pp. 952-959.

Harris, P., 2011. The use of lenses to improve quality of life following brain injury. In: *Vision rehabilitation. Multidisciplinary care of the patient following brain injury.* s.l.:CRC Press, p. 278.

Harris, P., 2011. The use of lenses to improve quality of life following brain injury. In: *Vision rehabilitation. Multidisciplinary care of the patient following brain injury.* Boca Raton: CRC Press, p. 223.

Hatada, Y., Rossetti, Y. & Miall, R., 2006. Long-lasting aftereffect of a single prism adaptation: shifts in vision and proprioception are independent. *Exp Brain Res*, 173(3), pp. 415-424.

Heilman, K., 2004. Intentional neglect. *Front Biosci*, Issue 9, pp. 694-705.

Heimbrand, S., Bronstein, A., Gresty, M. & Faldon, M., 1996. Optically induced plasticity of the cervico-ocular reflex in patients with bilateral absence of vestibular function. *Exp Brain Res*, Issue 112, pp. 372-380.

Held, R., 1965. Plasticity in sensory-motor systems. *Sci Am*, Issue 213, pp. 84-94.

Held, R. & Schlank, M., 1959. Adaptation to disarranged eye-hand coordination in the distance-dimension. *Am J Psychol*, Issue 72, pp. 603-605.

Helmholtz, H., 1925. Treatise on physiological optics. *Opt Soc Am*, Volume 3.

Hills-Willford, C., Kisner, C., Glenn, T. & Sachs, L., 1996. The interaction of wearing multifocal lenses with head posture and pain. *J Orthop Sport Phys*, Issue 23, pp. 194-199.

Hock, D. & Coffey, B., 2000. Effects of yoked prism on spatial localization and stereolocalization. *J Behav Optom*, 11(6), pp. 143-148.

Houston, K., 2010. Measuring visual midline shift syndrome & disorders of spatial localization: A literature review & report of a new clinical protocol. *J Behav Optom*, 21(4), pp. 87-93.

Huang, M. & Ciuffreda, K., 2006. Short-term adaptation to vertical yoked prisms. *Optom Vis Sci*, 83(4), pp. 242-248.

Imamizu, H. et al., 2000. Human cerebellar activity reflecting an acquired internal model of a new tool. *Nature*, Issue 403, pp. 192-195.

Inglis, J., Kennedy, P., Wells, C. & Chua, R., 2002. The role of cutaneous receptors in the foot. In: *Sensorimotor control of movement and posture.* s.l.:Kluwer Academic / Plenum Publishers.

Iosa, M., Fusco, A., Morone, G. & Paolucci, S., 2012. Effects of visual deprivation on gait dynamic stability. *Sci World J*, pp. 1-7.

Isableu, B. et al., 2010. Individual differences in the ability to identify, select and use appropriate frames of reference for perceptuo-motor control. *Neuroscience*, Issue 169, pp. 1199-1215.

Isolato, E. et al., 2004. Monocualr versus binocular vision in postural control. *Auris Nasus Larynx*, Issue 31, pp. 11-17.

Ivanenko, Y., Grasso, R. & Lacquaniti, F., 1999. Effect of gaze on postural responses to neck proprioceptive and vestibular stimulation in humans. *J Physiol*, Issue 519, pp. 803-814.

Jacquin-Courtois, S. et al., 2010. Effect of prism adaptation on left dichotic listening deficit in neglect patients: Glasses to hear better?. *Brain*, 133(3), pp. 895-908.

Jacquin-Courtois, S. et al., 2007. Wheel-chair driving improvement following visuo-manual prism adaptation. *Cortex*, Issue 44, pp. 90-96.

Jakobson, L. & Goodale, M., 1989. Trajectories of reaches to prismatically-displaced targets: Evidence for "automatic" visuomotor recalibration. *Exp Brain Res*, Issue 78, pp. 575-587.

Janik, T. et al., 2007. Validity of a computer postural analysis to estimate 3-dimensional rotations and translations of the head from three 2-dimensional digital images. *J Manip Physiol Ther*, 30(2), pp. 124-129.

Jarchow, T. et al., 2003. Perceived horizontal body position in healthy and paraplegic subjects: effect of centrifugation. *J Neurophysiol*, Volume 90, pp. 2973-2977.

Jennings, J., 2000. Behavioural optometry - a critical review. *Optom Pract*, Issue 1, pp. 67-78.

Johannsen, L., Broetz, D. & Karnath, H., 2006. Leg orientation as a clinical sign for pusher syndrome. *BMC Neurol*, Issue 6.

Kane, S. & Thach, W., 1989. Palatal myoclonus and function of the inferior olive: are they related?. *Exp Brain Res*, Volume 17, pp. 427-460.

Kaplan, M., 1978-1979. *Vertical yoked prisms.* Duncan, Oklahoma: Optometric Extension Program.

Kaplan, M. & Carmody, D., 1997. Extent of use of prisms by optometric practitioners. *J Optom Vis Dev*, Volume 28, pp. 86-90.

Kaplan, M., Carmody, D. & Gaydos, A., 1996. Postural orientation modifications in autism in response to ambient lenses. *Child Psychiat Hum D*, Issue 27, pp. 81-91.

Kaplan, M., Edelson, S. & Seip, J., 1998. Behavioral changes in autistic individuals as a result of wearing ambient transitional prism lenses. *Child Psychiat Hum D*, Issue 29, pp. 65-76.

Kapoor, N. et al., 2001. A new portable clinical device for measuring egocentric localization. *J Behav Optom*, 12(5), pp. 115-119.

Kapoor, N., Ciuffreda, K. & Suchoff, I., 2001. Egocentric localisation in patients with spatial neglect. In: *Visual and vestibular consequences of acquired brain injury.* Santa Ana: Optometric Extension Program Foundation, pp. 131-144.

Kapoor, N., Ciuffreda, K. & Suchoff, I., 2001. Egocentric localization in patients with visual neglect. In: *Visual and vestibular consequences of acquired brain injury.* Santa Ana: Optometric Extension Program, pp. 131-144.

Kapoula, Z. & Le, T., 2006. Effects of distance and gaze position on postural stability in young and old subjects. *Exp Brain Res*, Issue 173, pp. 438-445.

Kaufman, L., 1974. In: *Sight and mind. An introduction to visual perception.* New York: Oxford University Press, p. 414.

Kelly, J., Loomis, J. & Beall, A., 2005. The importance of perceived relative motion in the control of posture. *Exp Brain Res*, Issue 161, pp. 285-292.

Kelly, J., Riecke, B., Loomis, J. & Beall, A., 2008. Visual control of posture in real and virtual envionments. *Percept Psychophys*, 70(1), pp. 158-165.

Kennedy, P., Cressman, E., Carlsen, A. & Chua, R., 2005. Assessing vestibular contributions during changes in gait trajectory. *Neuro-report*, Issue 16, pp. 1097-1100.

Keshner, E. & Kenyon, R., 2009. Postural and spatial orientation driven by virtual reality. *St Heal T*, Issue 145, pp. 209-228.

Kitazawa, S., Kohno, T. & Uka, T., 1995. Effects of delayed visual information on the rate and amount of prism adaptation in the human. *J Neurosci*, Volume 11, pp. 7644-7652.

Klier, E., Wang, H. & Crawford, J., 2003. Three-dimensional eye-head coordination is implemented downstream from the superior colliculus. *J Neurophysiol*, Volume 89, pp. 2839-2853.

Koenderink, J. & van Doorn, A., 1981. Exterospecific component of the motion parallax field. *J Opt Soc Am A*, Issue 71, pp. 953-957.

Kraskin, R., 1982. *Lens power in action.* Santa Ana: Optometric Extension Program.

Kraskin, R., 2003. Compensatory lenses and postural alterations. In: K. G. Harris P, ed. *Lens power in action.* Santa Ana: Optometric Extension Program, pp. 154-160.

Lazarus, S., 1996. The use of yoked base-up and base-in prism for reducing eye strain at the computer. *J Am Optom Assoc*, Volume 67, pp. 204-208.

Lee, D. & Lishman, J., 1975. Visual proprioceptive control of stance. *J Hum Movement Stud*, Issue 18, pp. 87-95.

Legrand, A. et al., 2011. Postural control in children with strabismus: Effect of eye surgery. *Neurosci Lett*, Issue 501, pp. 96-101.

Leslie, S., 2001. Optometric management of persistent Streff Syndrome with vertical yoked prisms. *Behav Aspects Vision Care*, 42(1), pp. 33-42.

Le, T. & Kapoula, Z., 2006. Distance impairs postural stability only under binocular viewing. *Vis Res*, Volume 46, pp. 3586-3593.

Leukel, C., Gollhofer, A. & Taube, W., 2015. In experts, underlying processes that drive visuomotor adaptation are different than in novices. *Front Hum Neurosci*, Volume 9.

Lewit, K., 1985. Muscular and articular factors in movement restriction. *Manual Med*, Issue 1, pp. 83-85.

Lord, S. & Menz, H., 2000. Visual contributions to postural stability in older adults. *Gerontology*, Issue 46, pp. 306-310.

Luaute, J. et al., 2006. Functional anatomy of the therapeutic effects of prism adaptation on left neglect. *Neurology*, Volume 66, pp. 1859-1867.

Luaute, J. et al., 2009. Dynamic changes in brain activity during prism adaptation. *J Neurosci*, 29(1), pp. 169-178.

Magnani, B., Pavani, F. & Frassinetti, F., 2012. Changing auditory time with prismatic goggles. *Cognition*, 125(2), pp. 233-243.

Magrun, W., 2012. The interaction of neural systems: How the visual, vestibular, and somatosensory systems collaborate for efficient function. In: *Neuro-visual preocessing rehabilitation: An interdisciplinary approach.* Santa Ana: Optometric Extension Program Foundation, pp. 24-48.

Maravita, A. et al., 2003. Prism adaptation can improve contralesional tactile perception in neglect. *Neurology*, Volume 60, pp. 1829-1831.

Margolis, N. & Suter, P., 2006. Visual field defects & unilateral spatial inattention: Diagnosis and treatment. *J Behav Optom*, 17(2), pp. 31-37.

Martin, T. et al., 1996a. Throwing while looking through prisms. 1. Focal olivocerebellar lesions impair adaptation. *Brain*, Volume 119, pp. 1183-1198.

Martin, T. et al., 1996b. Throwing while looking through prisms. 2. Specificity and storage of multiple gaze-throw calibrations. *Brain*, Volume 119, pp. 1199-1211.

Masterton, B. & Biederman, G., 1983. Proprioceptive versus visual control in autistic children. *J Autism Dev Disord*, Issue 13, pp. 141-152.

Matheron, E., Le, T.-T., Yang, Q. & Kapoula, Z., 2007. Effects of a two-diopter vertical prism on posture. *Neurosci Lett*, Issue 423, pp. 236-240.

Matsuo, T. et al., 2006. Body sway increases immediately after strabismus surgery. *Acta Med Okayama*, Volume 60, pp. 13-24.

Matsuo, T. et al., 2010. Postural stability changes during the prism adaptation test in patients with intermittent and constant exotropia. *Invest Ophthalmol Vis Sci*, 51(12), pp. 6341-6347.

McIntrye, D., Ring, C. & Carroll, D., 2004. Effects of arousal and natural baroreceptor activation on the human muscle stretch reflex. *Psychophysiology*, 41(6), pp. 954-960.

Menezes, M., 2013. Acquired brain injury - Part 3: Managing the patient with ABI. *Optometry Today*, 3 May, pp. 49-52.

Metzger, E., 1950. Correction of congenital nystagmus. *Am J Ophthalmol*, Volume 33, pp. 1796-1797.

Miall, R., Imamizu, H. & Miyauchi, S., 2000. Activation of the cerebellum in co-ordinated eye and hand tracking movements: an fMRI study. *Exp Brain Res*, Issue 135, pp. 22-33.

Michel, C. et al., 2003. Simulating unilateral neglect in normals using prism adaptation: Implications for theory. *Neuropsychologia*, Issue 41, pp. 25-39.

Michel, C. et al., 2007. Enhancing visuomotor adaptation by reducing error signals: Single-step (aware) versus multiple-step (unaware) exposure to wedge prisms. *J Cogn Neurosci*, 19(2), pp. 341-350.

Michel, C., Rossetti, Y., Rode, G. & Tilikete, C., 2003. After-effects of visuo-manual adaptation to prisms on body posture in normal subjects. *Exp Brain Res*, Issue 148, pp. 219-226.

Mitra, S., 2004. Adaptive utilization of optical variables during postural and suprapostural dual-task performance: Comments on Stoffregen, Smart, Bardy, and Pagulayan (1999). *J Exp Psychol Human*, Issue 30, pp. 28-38.

Mittelstaedt, H., 1999. Evidence of somatic graviception from new and classical investigations. *Percept Psychophys*, Issue 61, pp. 615-624.

Moore, J., 2001. *The neuroanatomy of the visual system (DVD),* Las Cruces, NM: Clinician's View.

Morningstar, M. et al., 2005. Reflex control of the spine and posture: a review of the literature from a chiropractic perspective. *Chiropr Osteop*, 13(16), pp. 1-17.

Morton, S. & Bastian, A., 2004. Prism adaptation during walking generalizes to reaching and requires the cerebellum. *J Neurophysiol*, 92(4), pp. 2497-2509.

Moseley, G. et al., 2013. Limb-specific autonomic dysfunction in complex regional pain syndrome modulated by wearing prism glasses. *Pain*, Issue 154, pp. 2463-2468.

Nijboer, T. et al., 2011. Repetitive long-term prism adaptation permanently improves the detection of contralesional visual stimuli in a patient with chronic neglect. *Cortex*, 47(6), pp. 734-740.

Nijboer, T., Olthoff, L., Van der Stigchel, S. & Visser-Meily, J., 2014. Prism adaptation improves postural imbalance in neglect patients. *Neuroreport*, 25(5), pp. 307-311.

Normand, M. et al., 2007. Three dimensional evaluation of posture in standing with the PosturePrint: an intra- and inter-examiner reliability study. *Chiropr Osteop*, 15(15).

Nougier, V., Bard, C., Fleury, M. & Teasdale, N., 1998. Contribution of central and peripheral vision to the regulation of stance: Developmental aspects. *J Exp Child Psychol*, Issue 68, pp. 202-215.

Odenrick, P., Sandstedt, P. & Lennerstrand, G., 1984. Postural sway and gait of children with convergent strabismus. *Dev Med Child Neurol*, Issue 26, pp. 495-499.

Ogle, K., 1951. Distortion of the image by prisms. *J Opt Soc Am*, 41(12), pp. 1023-1028.

Padula, W., 2012. The bimodal relationship between focal and ambient vision. In: *Neuro-visual processing rehabilitation: An interdisciplinary approach.* Santa Ana: Optometric Extension Program Foundation, pp. 1-11.

Padula, W. & Argyris, S., 1996. Post trauma vision syndrome and visual midline shift syndrome. *Neurorehabilitation*, Volume 6, pp. 165-172.

Padula, W., Argyris, S. & Ray, J., 1994. Visual evoked potentials evaluating treatment for post-trauma vision syndrome in patients with traumatic brain injuries. *Brain Injury*, Volume 8, pp. 125-133.

Padula, W. et al., 2009. Modifying postural adaptation following a CVA through prismatic shift of visuo-spatial egocenter. *Brain Injury*, 23(6), pp. 566-576.

Padula, W. et al., 2007. Evaluatig and treating visual dysfunction. In: *Brain injury medicine.* New York: Demos Medical Publishing, pp. 511-528.

Paulus, W., Straube, A. & Brandt, T., 1984. Visual stabilization of posture. Physiological stimulus characteristics and clinical aspects. *Brain*, Issue 107, pp. 1143-1163.

Perennou, D., Amblard, B., Laassel, E. & Pelissier, J., 1997. Hemispheric asymmetry in the visual contribution to postural control in healthy adults. *Neuroreport*, Volume 8, pp. 3137-3141.

Peterka, R., 2002. Sensorimotor integration in human postural control. *J Neurophysiol*, Issue 88, pp. 1097-1118.

Peterson, B. et al., 2001. Dynamic and kinematicstrategies for head movement control. *Ann NY Acad Sci*, Issue 942, pp. 381-393.

Piponnier, J., Hanssens, J. & Faubert, J., 2009. Effect of visual field locus and oscillation frequencies on posture control in an ecological environment. *J Vision*, 9(13), pp. 1-10.

Pisella, L. et al., 2004. Preserved prism adaptation in bilateral optic ataxia: strategic versus adaptive reaction to prisms. *Exp Brain Res*, Issue 156, pp. 399-408.

Pisella, L. et al., 2005. Ipsidirectional impairment of prism adaptation after unilateral lesion of anterior cerebellum. *Neurology*, 65(1), pp. 150-152.

Poulain, I. & Giraudet, G., 2007. Age related changes of visual contribution in posture control. *Gait Posture*, 16(4).

Przekoracka-Krawczyk, A., Nawrot, P., Czainska, M. & Michalak, K., 2014. Impaired body balance control in adults with strabismus. *Vis Res*, Issue 98, pp. 35-45.

Pyykko, I. et al., 1991. Postural control in blinds and in usher's syndrome. *Acta Oto-Laryngol*, pp. 603-606.

Ramachandran, V. & Altschuler, E., 2009. The use of visual feedback, in particular mirror visual feedback, in restoring brain fnction. *Brain*, Volume 132, pp. 1693-1710.

Rapcsak, S., Verfaellie, M., Fleet, W. & Heilman, K., 1989. Selective attention in hemispatial neglect. *Arch Neurol*, Volume 46, pp. 178-182.

Raphan, T. & Cohen, B., 2002. The vestibulo-ocular reflex in three dimensions. *Exp Brain Res*, Volume 145, pp. 1-27.

Reading, R., 1985. Prism-induced horopter distortions. *Ophthal Physiol Opt*, 5(4), pp. 403-409.

Redding, G., Rossetti, Y. & Wallace, B., 2005. Applications of prism adaptation: A tutorial in theory and method. *Neurosci Biobehav R*, 29(3), pp. 431-444.

Redding, G. & Wallace, B., 1993. Adaptative coordination and alignment of eye and hand. *J Motor Behav*, Volume 25, pp. 75-88.

Redding, G. & Wallace, B., 1997. Prism adaptation during target pointing from visible and nonvisible starting locations. *J Motor Behav*, Issue 29, pp. 119-130.

Redding, G. & Wallace, B., 2000. Prism exposure after-effects and direct effects for different movement and feedback times. *J Motor Behav*, 32(1), pp. 83-99.

Redding, G. & Wallace, B., 2004. First trial "adaptation" to prism exposure: Artifact of visual capture. *J Motor Behav*, 36(3), pp. 291-304.

Redding, G. & Wallace, B., 2006. Prism adaptation and unilateral neglect: Review and analysis. *Neuropsychologia*, Volume 44, pp. 1-20.

Riach, C. & Starkes, J., 1989. Visual fixation and postural sway in children. *J Motor Behav*, Issue 21, pp. 265-276.

Riccio, G. & Stoffregen, T., 1991. An ecological theory of motion sickness and postural instability. *Ecol Psychol*, Issue 3, pp. 195-240.

Richardson, J., 2000. The use of randomized control trials in complimentary therapies: exploring the issues. *J Adv Nurs*, Volume 32, pp. 398-406.

Richer, S., 1986. Mobility spectacles for a patient with ankylosing spondylitis. *Am J Optom & Physiol Optics*, 63(11), pp. 927-930.

Ringman, J. et al., 2004. Frequency, risk factors, anatomy, and course of unilateral neglect in an acute stroke cohort. *Neurology*, Volume 63, pp. 468-474.

Robey, J. & Boyle, K., 2013. The role of prism glass and postural restoration in managing a collegiate baseball player with bilateral sacroiliac joint dysfunction: A case report. *Int J Sports Phys Ther*, 8(5), pp. 716-728.

Rock, I., 1975. In: *An introduction to perception.* New York: Macmillan Publishing, p. 320.

Rode, G. et al., 2006. Neglect and prism adaptation: A new therapeutic tool for spatial cognition disorders. *Restor Neurol Neuros*, Issue 24, p. 347–356.

Rode, G. et al., 2006. Prism adaptation improves spatial dysgraphia following right brain damage. *Neuropsychologia*, Volume 44, pp. 2487-2493.

Rode, G., Rossetti, Y. & Boisson, D., 2001. Prism adaptation improves representational neglect. *Neuropsychologia*, 39(11), pp. 1250-1254.

Rode, G., Tiliket, C. & Boisson, D., 1997. Predominance of postural imbalance in left hemiparetic patients. *Scand J Rehabil Med*, Issue 29, pp. 11-16.

Roll, J. & Roll, R., 1988. From eye to foot: A proprioceptive chain involved in postural control. In: *Posture and gait: Development, adaptation and modulation. Proceedings of the 9th International Symposium on postural and gait research, Marseille, France, May 29 - June 1.* Amsterdam: Elsevier, pp. 155-164.

Roll, R., Velay, J. & Roll, J., 1991. Eye and neck proprioceptive messages contribute to the spatial coding of retinal input in visually oriented activities. *Exp Brain Res*, Volume 85, pp. 423-431.

Romayananda, N., Wong, S., Elzeneiny, I. & Chan, G., 1982. Prismatic scanning method for improving visual acuity in patients with low vision. *Am Acad Ophthalmol*, Issue 89, pp. 937-945.

Rossetti, Y. et al., 1998. Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature*, Issue 395, pp. 166-169.

Saj, A. et al., 2013. Prism adaptation enhances activity of intact fronto-parietal areas in both hemispheres in neglect patients. *Cortex*, 49(1), pp. 107-119.

Sarri, M. et al., 2008. Prism adaptation aftereffects in stroke patients with spatial neglect: Pathological effects on subjective straight ahead but not visual open-loop pointing. *Neuropsychology*, Volume 46, pp. 1069-1080.

Sarri, M., Greenwood, R., Kalra, R. & Driver, J., 2010. Prism adaptation does not change the rigtward spatial preference bias found with ambiguous stimuli in unilateral neglect. *Cortex*, 47(3), pp. 353-366.

Savin, D. & Morton, S., 2008. Asymmetric generalization between the arm and leg following prism-induced visuomotor adaptation. *Exp Brain Res*, Issue 186, pp. 175-182.

Scheiman, M. & Wick, B., 1994. Nystagmus. In: *Clinical management of binocular vision. heterophoric, accommodative, and eye movement disorders.* Philadelphia: Lippincot-Raven Publishers, p. 531.

Schintu, S. et al., 2014. Prism adaptation in the healthy brain: The shift in line bisection judgments is long lasting and fluctuates. *Neuropsychologia*, Volume 53, pp. 165-170.

Schoner, G., 1991. Dynamic theory of action-perception systems: The moving room paradigm. *Biol Cybern*, Volume 64, pp. 455-462.

Schubert, M., Das, V., Tusa, R. & Herdman, S., 2004. Cervico-ocular reflex in normal subjects and patients with unilateral vestibular hypofunction. *Otol Neurotol*, Issue 25, pp. 65-71.

Schwartz, S. et al., 2005. The effect of cataract surgery on postural control. *Invest Ophthalmol Vis Sci*, Issue 46, pp. 920-924.

Serino, A., Angeli, V., Frassinetti, F. & Ladavas, E., 2006. Mechanisms underlying neglect recovery after prism adaptation. *Neuropsychologia*, 44(7), pp. 1068-1078.

Serino, A., Barbiani, M., Rinaldesi, M. & Ladavas, E., 2009. Effectiveness of prism adaptation in neglect rehabilitation: A controlled trial study. *Stroke*, Issue 40, pp. 1392-1398.

Serino, A., Bonifazi, S., Pierfederici, L. & Ladavas, E., 2007. Neglect treatment by prism adaptation: What recovers and for how long.. *Neuropsychol Rehabil*, 17(6), pp. 657-687.

Sheedy, J. & Parsons, S., 1987. Vertical yoked prism - Patient acceptance and postural adjustment. *Ophthalmic Physiol Opt*, 7(3), pp. 255-257.

Silva, A., 1992. Scoliotic attitude and skeletal muscles hypertony: a new method of treatment. In: *Proceedings of the international symposium on 3-D scoliotic deformities.* Montreal: s.n., pp. 226-229.

Sokhadze, G. et al., 2012. *Effects of ambient prism lenses on autonomic reactivity to emotional stimuli in autism.* Toronto, Annual International Meeting for Autism Research (INSAR).

Stoffregen, T., 1985. Flow structure versus retinal location in the optical control of stance. *J Exp Psychol*, Issue 11, pp. 554-565.

Stoffregen, T., Pagulayan, R., Bardy, B. & Hettinger, L., 2000. Modulating postural control to facilitate visual performance. *Hum Movement Sci*, Volume 19, pp. 203-220.

Stoffregen, T. & Riccio, G., 1990. Responses to optical looming in the retinal center and periphery. *Ecol Psychol*, Issue 2, pp. 251-274.

Stoffregen, T., Schmuckler, M. & Gibson, E., 1987. Use of central and peripheral optical flow in stance and locomotion in young walkers. *Perception*, Volume 16, pp. 113-119.

Streff, J., 1973. Optical effects of "plano" prisms with curved surfaces. *J Am Optom Assoc*, 44(7), pp. 717-721.

Striemer, C. & Danckert, J., 2010. Dissociating perceptual and motor effects of prism adaptation in neglect. *Neuroreport*, 21(6), pp. 436-441.

Suchoff, I. & Ciuffreda, K., 2004. A primer for the optometric management of unilateral spatial inattention. *Optometry*, Volume 75, pp. 305-318.

Sugio, T. et al., 1999. The role of the posterior parietal cortex in human object recognition: a functional magnetic resonance imaging study. *Neurosci Lett*, Issue 276, pp. 45-48.

Sumitani, M. et al., 2007b. Prism adaptation to optical deviation alleviates pathologic pain. *Neurology*, Volume 68, pp. 128-133.

Sumitani, M. et al., 2007a. Pathologic pain distorts visuospatial perception. *Neurology*, Volume 68, pp. 152-154.

Super, S., 1995. Prism use in vision therapy. In: *Clinical uses of prism. A spectrum of applications.* St. Louis: Mosby-Year Book, Inc., pp. 271-272.

Suttle, C. et al., 2011. A lack of posture effect with 5-dioptre vertical yoked prism in normally sighted adults. *Optom Vis Sci*, Volume 88, pp. E-abstract 115786.

Sutton, A., 1985. *Spatial characteristics of lenses and prisms.* s.l.:OEP Curriculum II.

Tea, Y., 2008. Back to the basics Part 1: Prime yourself to prescribe prism. *Rev Optom*, Issue 145.

Tilikete, C. et al., 2001. Prism adaptation to rightward optical deviation improves postural imbalance in left hemiparetic patients. *Curr Biol*, Volume 11, pp. 1-20.

Trevarthen, C. & Sperry, R., 1973. Perceptual unity of the ambient visual field in human commissurotomy patients. *Brain*, Issue 96, pp. 547-570.

Turano, K., Rubin, G. & Quigley, H., 1999. Mobility performance in glaucoma. *Invest Ophthalmol Vis Sci*, Issue 40, pp. 2803-2809.

Ushio, N., Hinoki, M., Nakanishi, K. & Baron, J., 1980. Role of ocular muscle proprioception in the maintenance of body equilibrium with particular reference to the cervical reflex. *Agressologie*, Issue 21, pp. 143-152.

Ustinova, K. & Perkins, J., 2011. Gaze and viewing angle influence visual stabilization of upright posture. *Brain Behav*, 1(1), pp. 19-25.

Valenti, C., 1996. Exploring a new technique to assess spatial localization. In: *OEP vision therapy.* s.l.:Optometric Extension Program, pp. 52-71.

Van Hedel, H. & Dietz, V., 2004. The influence of age on learning a locomotor task. *Clin Neurophysiol*, Issue 115, pp. 2134-2143.

Vuillerme, N. & Rougier, P., 2005. Effects of head extension on undisturbed upright stance control in humans. *Gait Posture*, Issue 21, pp. 318-325.

Wade, M. & Jones, G., 1997. The role of vision and spatial orientation in the maintenance of posture. *Phys Ther*, 77(6), pp. 619-628.

Wallace, B., 1977. Stability of Wilkinson's linear model of prism adaptation over time for various targets. *Perception*, Issue 6, pp. 145-151.

Wallace, B. & Garrett, J., 1975. Perceptual adaptation with selective reduction of felt sensation. *Perception*, Issue 4, pp. 437-445.

Warren, W. & Kurtz, K., 1992. The role of central and peripheral vision in perceiving the direction of self-motion. *Percept Psychophys*, Issue 51, pp. 443-454.

Weiner, M., Hallet, M. & Funkenstein, H., 1983. Adaptation to lateral displacement of vision in patients with lesions of the central nervous system. *Neurology*, Volume 33, pp. 766-772.

Weissberg, E., Lyons, S. & Richman, J., 2000. Fixation dysfunction with intermittent saccadic intrusions managed by yoked prisms: A case report. *Optometry*, 71(3), pp. 183-188.

Weiss, N. & Brown, W., 1995. Use of prism in low vision. In: *Clinical uses of prism.* St. Louis: Mosby - Year Book, Inc., p. 289.

Welch, R., 1978. *Perceptual modification: Adapting to altered sensory environments.* New York: Academic Press.

Wilkinson, D., 1971. Visual-motor control loop: A linear system?. *J Exp Psychol*, Issue 89, pp. 250-257.

Willford, C., Kisner, C., Glenn, T. & Sachs, L., 1996. The interaction of wearing multifocal lenses with head posture and pain. *J Orthop Sport Phys*, 23(3), pp. 194-199.

Winter, D., 1995. Human balance and posture control during standing and walking. *Gait Posture*, Issue 3, pp. 193-214.

Wong, M. et al., 2002. Effect of using prismatic eye lenses on the posture of patients with adolescent idiopathic scoliosis measured by 3-D motion analysis. *Prosthet Orthot Int*, Issue 26, pp. 139-153.

Yoonessi, A. & Yoonessi, A., 2011. Functional assessment of magno, parvo and konio-cellular pathways; Current state and future clinical applications. *J Ophthalmic Vis Res*, 6(2), pp. 119-126.

Young, M., 2004. A review on postural realignment and its muscular and neural components. *Exp Brain Res*, Issue 159, pp. 33-46.