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Comparison of symmetrical prism adaptation to asymmetrical prism adaptation in those with normal binocular vision

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ABSTRACT

This study sought to determine whether symmetrical compared to asymmetrical horizontal prisms (base-out or base-in) evoked different rates of phoria adaptation. Sixteen young adults with normal binocular vision participated in a symmetrical phoria adaptation experiment using a 3Δ base-out or 3Δ base-in binocular prism flipper and an asymmetrical phoria adaptation experiment using a 6Δ base-out or 6Δ base-in monocular wedge prism. The experiments were randomized and counterbalanced to reduce the influence of the prism stimulation order. Asymmetrical base-out prism adaptation was significantly faster than symmetrical prism adaptation for subjects with normal binocular vision. Asymmetrical phoria adaptation with base-in prism was not significantly different from symmetrical phoria adaptation implying that there are directional asymmetries (convergent versus divergent eye movements) in the slow fusional component of vergence. Data suggest that a potential interaction between the version system and the slow fusional vergence system may exist. Results have clinical relevance because patients with convergence or divergence insufficiency/excess may potentially show more pronounced differences between symmetrical and asymmetrical phoria adaptation compared to binocularly normal controls. These differences might also be relevant to clinical measurements such as vergence fusional range, which can be measured symmetrically (with Risley prisms in a phoropter) or asymmetrically (with prism bar).

1. Introduction

Schor describes the disparity vergence system to be composed of “fast” and “slow” fusional vergence components (Schor, 1979). While these two components are mainly driven by retinal disparity (Horwood & Riddell, 2008; McLin, Schor, & Kruger, 1988; Schor, 1979; Semmlow & Wetzell, 1979), each component is described to have different characteristics; specifically, each has different neural time constants. For example, if an individual with normal binocular vision is presented with a visual target, the person can use the relatively quick and accurate “fast” disconjugate movements of the eyes to reduce the disparity between the current vergence angle of the eyes and that of the target of interest. The “slow” fusional vergence component has a much longer time constant compared to the “fast” fusional vergence component and is used to slowly adapt to near or far visual space. While other depth cues are present, slow fusional vergence, can be assessed by the dissociated phoria.

The dissociated phoria is the relative ocular rotation of the eyes during binocular fixation on an object in the absence of a fusible stimulus (such as when one eye is occluded). The rotation of the eye can be eso (inward), exo (outward), ortho (no movement), hyper (upward),

or hypo (downward). If a person performs sustained fixation on a target (either near or far) for 30 s or more, the phoria level controlled by the slow fusional vergence component will be shifted towards where the visual system’s gaze is located (Ying & Zee, 2006). For example, people who perform near work such as reading for a prolonged period of time will experience an esophoric shift in their phoria (Sreenivasan, Irving, & Bobier, 2012). This shift in phoria level reduces the effort it takes to maintain a given vergence angle (Schor, 1983). The interaction between the fast and slow fusional components maintain single binocular vision of targets that are at different locations in depth.

In addition to sustained fixation, the slow and fast fusional components can be altered by using a prism or a lens (Scheiman & Wick, 2014). If a prism is placed in front of one or both eyes, it shifts light and hence the image to a different point along the retina. When prisms are placed base-out, the eyes will rotate inward (convergent movement). Conversely, prisms that are placed base-in will evoke divergent eye rotation. Convergent and divergent responses of the slow fusional system have been found to have asymmetries and thus should be studied individually (Erkelens & Bobier, 2017; Erkelens, Thompson, & Bobier, 2016). When single binocular vision is allowed for one second (Larson & Faubert, 1994) to 15 s (Schor, 1979), the slow fusional

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vergence component begins to adapt to the power of the prism, and over time, the phoria returns to the level reported before the prism was first placed in front of the eye (Fogt & Toole, 2001; Henson & North, 1980; Sethi & North, 1987). This adaptive response is called phoria or prism adaptation. Plus or minus lenses have also been used to stimulate phoria adaptation (Sreenivasan, Irving, & Bobier, 2009).

Most phoria adaptation studies have been conducted asymmetrically: that is a single prism is placed over the right or the left eye so the field of view is shifted eccentrically along the retina of a single eye. This configuration is believed to stimulate both the version and vergence systems (Enright, 1992). However, phoria adaptation can also occur symmetrically along the midline (the subject's midsagittal plane) when disparity is introduced by placing two prisms with the same prismatic power in front of each eye (symmetrical phoria adaptation). It is not fully understood whether these two types of phoria adaptations (symmetrical compared to asymmetrical) produce different rates of adaptation in individuals with normal binocular vision.

Controversy exists in the literature. In the laboratory, it is possible to stimulate the saccadic or vergence systems independently by carefully presenting visual stimuli that move laterally or in depth, respectively. However, under natural conditions, both systems are usually stimulated simultaneously. There are two competing theories to describe how conditions that stimulate the integration of vergence and saccadic eye movements occur. One theory is the additivity hypothesis which supports that saccades and vergence interact nonlinearly (Coubard, 2013). On the other hand, the Ditchburn hypothesis supports independent saccadic control of each eye that is minimally influenced by the vergence system (Enright, 1996). Numerous research papers show experimental evidence that support either theory depending on the experimental conditions (Coubard, 2013). For asymmetrical target configurations, different amounts of rotation are required from each eye. Prior research supports that asymmetrical vergence movements are usually accompanied with saccadic eye movements (Enright, 1992). Symmetrical target stimuli presented along the subject's midline theoretically should stimulate symmetrical vergence eye movements. However, saccades and asymmetries between the disjunctate rotation assessed as differences between the left and right peak velocities have been reported in eye movements from symmetrical stimuli presented along midline for binocularly normal control subjects (Alkan, Biswal, Taylor, & Alvarez, 2011; Kim & Alvarez, 2012; Semmlow, Alvarez, & Pedrono, 2007; Semmlow, Chen, Granger, Donnetti, & Alvarez, 2009). Asymmetrical differences between the left and right eye are also more pronounced in patients with convergence insufficiency (Alvarez & Kim, 2013).

Taking into account the differences in eye movements elicited by asymmetrical and symmetrical target configurations, one plausible outcome of this study is that the rate of adaptation induced by the asymmetrical condition is faster than that of the symmetrical condition. This may potentially occur because the asymmetrical condition is a combination of vergence and version (saccadic) eye movements, which may utilize some nonlinear interaction as described by the additivity hypothesis. There is evidence showing that there are interactions and dependencies between version and vergence eye movements (Alvarez, Jaswal, Gohel, & Biswal, 2014; Erkelens, Steinman, & Collewijn, 1989; Kim, Vicci, Granger-Donnetti, & Alvarez, 2011). Specifically, these studies suggest that saccades facilitate the peak velocity of disparity vergence. There is also recent research showing that the phoria level of an individual influences vergence peak velocity (Alvarez, 2015; Alvarez et al., 2010; Kim, Vicci, Han, & Alvarez, 2011; Lee, Granger-Donnetti, Chang, & Alvarez, 2009; Talasan, Scheiman, Li, & Alvarez, 2016). It may be that the asymmetrical phoria adaptation stimulation recruits the version system in addition to the vergence systems. This may lead to an increase in the rate of phoria adaptation potentially because version (saccades) facilitate vergence peak velocity. However, there is also contradicting evidence suggesting that vergence and version are independent (Alvarez et al., 2009; Alvarez, Semmlow, Ciuffreda, Gayed,

& Granger-Donnetti, 2007; Kim et al., 2011; King & Zhou, 1995; Rashbass & Westheimer, 1961; Semmlow et al., 2009; Semmlow, Yuan, & Alvarez, 1998). Therefore, a second plausible outcome is that the symmetrical condition could produce a faster adaptation rate since it mostly evokes pure vergence movements. Activating one system might be less complicated and time consuming than pooling resources from two systems. Thus, the symmetrical condition might produce a faster phoria adaptation. Third, there may be no difference in the results between symmetrical or asymmetrical phoria adaptation. One of the main goals of this experiment is to determine whether symmetrical and asymmetrical phoria adaptation have similar or different adaptation rates, and if one is different which one is faster. Such knowledge has potential clinical implications, which will be described within the discussion.

2. Methods

2.1. Subjects

All sixteen subjects were young adults (6 males and 10 females) and were not aware of the purpose of the experiment. Their age ranged between 18 and 22 years (*Mean (M)* = 19.1, *Standard Deviation (SD)* = 1.5). The study was approved by the New Jersey Institute of Technology Institutional Review Board, and it is in accordance with the Declaration of Helsinki where subjects signed written informed consent.

2.2. Typical vision parameters to assess normal binocular vision

Typical vision parameters to assess binocular vision are summarized in Table 1 as a mean with one standard deviation. These measurements were recorded before subjects started the experiment to determine whether they had normal binocular vision, and could participate in the study. Only subjects with normal binocular vision who did not report being diagnosed by a clinician to have a disorder or disease that may affect vergence, accommodation or ocular motility participated in this study. All subjects had normal or corrected to normal (20/20) visual acuity. The near (40 cm) dissociated phoria was tested using the flashed Maddox rod procedure. Normal stereo vision was assessed with a Randot Stereo Test (Bernell Corp., South Bend, IN), which indicated that subjects had normal local and global binocular vision. The near point of convergence (NPC) was measured using an Accommodation Convergence Ruler (Bernell Corp., South Bend, IN) placed at the bridge of the nose using the same protocol described by the Convergence Insufficiency Treatment Trial (Convergence Insufficiency Treatment Trial Study Group, 2008). NPC break was measured in cm along midline when a target was perceived diplopic or deviation of ocular alignment to the midline target was observed. NPC recovery was also measured in cm along the midline when the subject was able to regain fusion after the NPC break. Fusional vergence range was measured using a base-in and base-out prism bar which contained 1 Δ , 2 Δ to 20 Δ in increments of 2 Δ , and 20 Δ to 45 Δ in increments of 5 Δ . The values for the vergence range for blur, break and recovery are reported in Table 1. Table 1 also reports the range of the subject's measurements, and the values that clinicians recommend to be assessed as having normal binocular vision (Scheiman & Wick, 2014).

2.3. Experimental conditions: phoria prism adaptation measured with flashed Maddox rod procedure

This experiment used the flashed Maddox method to measure horizontal near dissociated phoria. Subjects sat 40 cm away from a near dissociated phoria Muscle Imbalance Measure (MIM) Card placed symmetrically along the subject's midline (Bernell Corp., South Bend, IN). The phoria card was positioned at eye level for each subject by adjusting the card vertically dependent on each subject's height. Baseline phoria was measured twice before the beginning of each of the

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