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# The influence of age on adaptation of disparity vergence and phoria

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ABSTRACT

A paucity of research exists to investigate whether the normal aging process influences the ability to adapt disparity vergence and phoria. Vergence eye movements and dissociated phoria were recorded from 49 healthy subjects (ages 20–70 years) using an objective eye movement tracking system. Four-degree vergence responses were modified using a double-step protocol. Dynamics of vergence were quantified via peak velocity. The phoria adaptation experiment measured the magnitude (net change in phoria level) and rate (magnitude divided by the time constant) of phoria adaption during 5 min of sustained fixation on a binocular target (40 cm/8.44° from midline). The magnitude of phoria adaptation decreased as a function of age ($r = -0.33$; $p = 0.04$). The ability to adapt vergence peak velocity and the rate of phoria adaptation showed no significant age-related influence ($p > 0.05$). The data suggest that the ability to modify the disparity vergence system and the rate of phoria adaptation are not dependent on age; whereas, the magnitude of phoria adaptation decreases as part of the normal adult aging process. These results have clinical and basic science implications because one should consider age when assessing the changes in the magnitude of phoria adaptation which can be abnormal in those with oculomotor dysfunctions.

## 1. Introduction

The human brain calibrates the motor control of eye movements for optimal performance in the presence of both intrinsic (i.e. trauma, diseases, development or aging) and extrinsic (i.e. environment) changes (Leigh & Zee, 2016). One remarkable trait of the oculomotor system is adaptation, or the ability to precisely plan, coordinate, and execute eye movements to continually varying visual stimuli. The mechanism of adaptation within the oculomotor system is well-studied because the output can be easily quantified while sensory inputs (visual stimuli) are changed (Dash, Catz, Dicke, & Thier, 2010; Iwamoto & Kaku, 2010; Leigh & Zee, 2016; Ono & Mustari, 2010; Schor, 2009; Schubert & Zee, 2010; Tian, Ethier, Shadmehr, Fujita, & Zee, 2009).

In everyday life, humans use vergence eye movements – the inward (convergence) or the outward (divergence) rotation of the eyes – to perceive objects located at various distances. One of the major inputs to the vergence system is retinal disparity. Disparity is the main binocular cue describing the visual mismatch between the visual scene observed by left and right eye. The horizontal vergence system adjusts the position of the eyes to track a visual target using the lateral and medial extraocular muscles (Leigh & Zee, 2016). Dissociated heterophoria or simply phoria is the latent deviation of the visual axes to fusion in the absence of visual input to one eye (i.e., occlusion) while the other eye fixates on a target (Casillas Casillas & Rosenfield, 2006; Coffey, Reichow, Colburn, & Clark, 1991; Han, Guo, Granger-Donetti, Vicci, & Alvarez, 2010; Rosenfield, Chun, & Fischer, 1997). Most clinicians measure phoria with a target along the subject's midline. The occluded eye may maintain its position (orthophoria), rotate nasally (esophoria), rotate temporally (exophoria), rotate upward (hyperphoria) or rotate downward (hypophoria). A person's phoria level may adapt in response to a visual demand, duration of a visual task, or the amount of time that the subject is visually dissociated (Kim, Granger-Donetti, Vicci, & Alvarez, 2010; Lee, Chen, & Alvarez, 2008; Rosenfield et al., 1997; Wilmer & Buchanan, 2009). Previous research indicates that a person's phoria can be adapted or modified in order to reduce the load or amount of work expended by the vergence system (McCormack, 1985; North & Henson, 1981; Schor, 1979).

Other studies have demonstrated the malleability of the disparity vergence system (Alvarez, Bhavsar, Semmlow, Bergen, & Pedrono, 2005; Kim, Vicci, Granger-Donetti, & Alvarez, 2011; Munoz, Semmlow, Yuan, & Alvarez, 1999; Semmlow, Yuan, & Alvarez, 2002; Takagi et al., 2001). More specifically, double-step (Alvarez et al., 2005; Takagi et al., 2001) or step-ramp (Munoz

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et al., 1999) conditioning stimuli have been used to increase or decrease the gain of vergence eye movements as quantified by peak velocity. Similar to disparity vergence, the dissociated phoria level can also be adapted (Kim, Vicci, Granger-Donetti, & Alvarez, 2011). Sustained fixation of binocular targets placed at different distances (e.g. near, middle and far visual target locations), along with the use of lenses (e.g. plus or minus lenses) or prisms (e.g. base in and base out prisms), has been shown to significantly change a person's phoria level (Cheng, Schmid, & Woo, 2008; Jiang, Tea, & O'Donnell, 2007; Kim et al., 2010). While these studies clearly demonstrate the malleability of disparity-vergence and phoria, the majority of them have chosen to focus specifically on a young adult population (18 to 35 years of age) and have not considered the potential influence of aging on these visual dynamics.

Aging of the visual system has been associated with a reduction in contrast sensitivity (Owsley, 2011), visual acuity (Chou, Dana, & Bougatsos, 2009), and accommodation (Polat et al., 2012). Similarly, some investigators have reported that aging decreases vergence peak velocity (Rambold, Neumann, Sander, & Helmchen, 2006) as well as the magnitude and the time constant of phoria adaptation (Winn, Gilmartin, Sculfor, & Bamford, 1994). Conversely, Kalsi, Heron, and Charman (2001) measured static and dynamic accommodation, accommodative convergence, vergence and convergence accommodation responses and reported that there were no age-related effects in the latency and maximum velocity of vergence and accommodative vergence ($p > 0.11$) (Kalsi et al., 2001). Yang et al. also reported no aging effects on the gain (the amplitude of the output vergence response divided by the amplitude of the input stimulus target), peak velocity and acceleration of vergence responses ($p > 0.23$) (Yang & Kapoula, 2008; Yang, Le, & Kapoula, 2009b). Based upon these aforementioned studies, the influence of age-related effects on vergence dynamics quantified as peak velocity and the ability to modify the vergence and phoria systems remain unresolved in vision research.

To date, a systematic study on the ability to adapt the disparity-vergence and phoria systems as a function of age using objective eye movement tracking has not been published. Thus, the purpose of this examination is to investigate whether the adaptability of the disparity-vergence and the phoria systems is maintained throughout adult life. It is well established that accommodation decreases with age (Leigh & Zee, 2016). Prior research supports that accommodation is an input to the vergence system (Maxwell, Tong, & Schor, 2010; Semmlow & Hung, 1980; Yuan, Semmlow, Alvarez, & Munoz, 1999). Since accommodation decreases with age and it does interact with the vergence system then it is possible that vergence performance may also decrease with age. This study will test the hypothesis that with the advancement of age, the ability to modify vergence peak velocity during a short-term modification experiment, as well as the magnitude and the rate of phoria adaptation, may decline with age. This knowledge is important because decreased phoria adaptation is common in some binocular dysfunctions such as convergence insufficiency (Brautaset & Jennings, 2005; Erkelens, Thompson, & Bobier, 2016; Sreenivasan & Bobier, 2015; Sreenivasan, Irving, & Bobier, 2008). If vergence and phoria adaptation are reduced with age, then it is important that clinicians and researchers take into account potential aging effects when studying the reduced ability to adapt vergence and phoria commonly observed in binocular dysfunctions.

## 2. Methods

### 2.1. Subjects

A total of forty-nine subjects participated in the study. All subjects signed a written informed consent form approved by the NJIT Institution Review Board in accordance with the Declaration of Helsinki. All subjects were instructed to look at the visual targets when presented and were naïve to the hypotheses of the study. The subjects were divided into three groups based upon age: 20 to 35 years (n = 10; "younger" group), 36 to 50 years (n = 28; "mid-aged" group), and 51 to 70 (n = 11; "older" group). All subjects had no prior experience with other oculomotor experiments and were naïve to the goals of the study. None of the subjects had neurological dysfunction or injury; ocular; oculomotor; or binocular abnormalities. Binocular function was assessed using a Randot Stereopsis Test (Bernell Corp., South Bend, IN, USA) and near point of convergence (NPC) using methods described in detail in a previous research (Alvarez, 2015; Alvarez et al., 2010; Jaswal, Gohel, Biswal, & Alvarez, 2014; Lee et al., 2008; Scheiman, Talasan, Mitchell, & Alvarez, 2016; Semmlow, Alvarez, & Pedrono, 2007; Talasan, Scheiman, Li, & Alvarez, 2016). An optometrist objectively measured refraction using static retinoscopy. Monocular amplitude of accommodation was assessed for the right eye with the Astron Accommodative Ruler with the printed Gulden fixation target of a column of 20/30 letters. The subject was instructed to keep the letters clear and tell the examiner when the letters first blur. The target was moved towards the subjects at a rate of about 1 cm/s until it appeared to blur. Subjects had normal or corrected-to-normal vision during the experiment. For incipient presbyopes and presbyopes, the vision parameters were measured through the near add of their spectacles. The mean and standard deviation of each group attributes are described in Table 1.

### 2.2. Short-term vergence modification experiment

Eye movements were recorded using an infrared ($\lambda = 950$ nm) video-based ISCAN eye movement monitor which tracks both eyes simultaneously and independently. The manufacturer's specification for accuracy was 0.3° over a ±20° horizontal range (ISCAN Inc., Burlington, MA, USA). The horizontal eye movements were analyzed by tracking the centroid of the pupil. Eye movements were sampled at 500 Hz using a custom LabVIEW™ program, VisualEyes, with the same 12-bit digital acquisition hardware card (Guo, Kim, & Alvarez, 2011).

Before the experiment, all subjects were situated in a head and chin rest assembly to reduce the influence of the vestibular system (Khojasteh & Galiana, 2007). The stimuli were 40 cm away or 2.5D in a darkened room using a haploscopic experimental set-up, see Fig. 1. The haploscope kept the accommodative demand constant while changing the disparity visual cue to different vergence angles. Two computer monitors projected independent visual

**Table 1**
Mean and standard deviation of the three age group attributes.

| Group | Age (yrs) | Gender F = Female M = Male | Stereopsis (sec arc) | Amplitude of accommodation (D = Diopters) | Near point of Convergence (cm) | Mean right eye sphere (D = Diopters) | Mean left eye sphere (D = Diopters) |
|---|---|---|---|---|---|---|---|
| Young | 23.5 ± 2.50 | 4 F and 6 M | 21.8 ± 3.5 | 11.1 ± 1.8 | 5.0 ± 2.0 | −0.05 ± 0.98 | −0.13 ± 0.94 |
| Mid-Aged | 46.1 ± 2.60 | 16 F and 12 M | 35.2 ± 15.7 | 3.2 ± 1.9 | 5.9 ± 2.2 | −1.45 ± 2.22 | −1.02 ± 1.93 |
| Older | 61.0 ± 6.13 | 5 F and 6 M | 46 ± 21.9 | 1.4 + 0.8 | 6.4 ± 3.2 | 0.30 ± 2.60 | 0.28 ± 2.63 |