

Divergence eye movements are dependent on initial stimulus position

Tara L. Alvarez^{a,*}, John L. Semmlow^{b,c}, Claude Pedrono^d

^a Department of Biomedical Engineering, New Jersey Institute of Technology, University Heights, Newark, NJ 07102, United States

^b Department of Biomedical Engineering, Rutgers University, Piscataway, NJ, United States

^c Department of Surgery, Bioengineering, Robert Wood Johnson Medical School, UMDNJ Piscataway, NJ, United States

^d Essilor International S.A. Saint Maur, France

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Abstract

Previous studies on the speed and latency of convergence and divergence eye movements have produced varied, sometimes contradictory, results. Four subjects were studied and tracked 4° disparity step changes for convergence and divergence at different initial target positions. Here we report that the dynamics of divergence movements not only differ from convergence movement, but depend on the initial vergence position. Velocities of divergence eye movements in response to targets that were initially near to the subject were approximately twice that of responses to initially distant targets and also exhibited shorter temporal properties. Hence, while convergence responses are fairly similar irrespective of the initial position, divergence dynamic and temporal properties are dependent on the initial stimulus position. It is speculated that the differences observed in divergence may be the result of nonlinear properties of the extraocular muscles or a difference in the underlying neural controller potentially a difference in the magnitude of the fusion initiating component of divergence.

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1. Introduction

The vergence system is responsible for the convergence and divergence movement of the eyes allowing the visual system to fuse stimuli moving in depth. This disjunctive movement of the eyes is facilitated by the medial and lateral recti muscles which rotate the globes, until paired images project onto the foveas.

Controversy exists in the literature related to the dynamic and temporal relationship between convergence and divergence. Several studies report that convergence is faster than divergence (Hung, Ciuffreda, Semmlow, & Horng, 1994; Hung, Semmlow, & Ciuffreda, 1986; Hung, Zhu, & Ciuffreda, 1997; Zee, Fitzgibbon, &

Optican, 1992) by as much as double (Hung et al., 1994), while other studies report pure divergence and convergence to have approximately the same velocity characteristics (Collewyn, Erkelens, & Steinman, 1995). Specifically, while analyzing the main sequence (an indicator of the first order dynamics), one study showed convergence to have a main sequence double that of divergence where the initial stimulus position was 8° (Hung et al., 1994). This investigation will show that the speed of responses and related dynamic properties of divergence vary as a function of initial position. Depending on the initial location of the stimulus, the relationship between convergence and divergence dynamic properties can vary dramatically.

Several studies also report inconsistencies in the temporal relationship between convergence and divergence. Rashbass and Westheimer (1961) state that divergence and convergence have similar latencies (i.e. reaction

* Corresponding author. Tel.: +1 973 596 5272; fax: +1 973 596 5222.
E-mail address: tara.l.alvarez@njit.edu (T.L. Alvarez).

Table 1
Summary of previous findings for convergence and divergence latency \pm standard deviation when information was available

Latency (ms)		Study
Convergence	Divergence	
180	190	Semmlow and Wetzel (1979)
161	182	Hung et al. (1997)
250	210	Krishnan et al. (1973)
150 \pm 30	130 \pm 20	Alvarez et al. (2002)
219 \pm 7	198 \pm 8	Yang et al. (2002)

times) of 160–170 m. Other reports state that convergence latency is less than divergence latency (Hung et al., 1997; Semmlow & Wetzel, 1979). Conversely, researchers have published convergence to have a longer latency than divergence (Alvarez, Semmlow, Yuan, & Munoz, 2002; Krishnan, Farazia, & Stark, 1973). Previous findings regarding convergence and divergence are summarized in Table 1. All of these studies had a limited set of subjects. A recent study by Yang, Bucci, and Kapoula (2002) reports that the latency for convergence is greater than divergence for the 15 adult subjects studied, documenting differences that were statistically significant, $P < 0.01$.

Latency does vary between individuals, which may account for some of the controversy in the literature; however, the present study shows that for a given subject, convergence does not demonstrate a strong dependency on initial position; whereas, divergence eye movements are dependent on the initial stimulus position. Depending on where the initial targets are located in space influences the latency of divergence; thus, initial target positioning will determine whether the convergence latency is greater or less than divergence latency.

2. Methods

2.1. Subjects

Four subjects (18–60 years old) participated in this study. Two subjects were male, and two were female. All subjects signed informed consent forms before the experiments that were approved by the New Jersey Institute of Technology (NJIT) Institutional Review Board (IRB). During the experiment, the subjects' head were immobilized using a custom chin rest to avoid any influence from the vestibular system. They were instructed to initiate an experiment by depressing a button and to maintain binocular fixation on the stimulus target. All were able to perform the task easily. One subject (Subject 004 who is 60 years old) was aware of the goals of this study and has been participating in eye movement experiments for many years. The other three subjects were naïve to the goals of the study and were inexperienced subjects.

2.2. Experimental design

Disparity vergence stimuli were presented using a dynamic haploscope. Two computer monitors were used to produce a symmetrical disparity vergence stimulus of paired vertical lines. Two partially reflective mirrors were placed in front of the subject's midline and projected the two stereoscopically paired vertical lines from the stimulus displays into the subject's line of sight. The stimulus displays were calibrated with real targets corresponding to 10° and 4° fixation points. Using the same instrumentation design, a study comparing two versus three calibration points showed that the average nonlinearity was 3% of the total movement with a maximum nonlinearity of 5% (Horng, Semmlow, Hung, & Ciuffreda, 1998a, 1998b). Since the nonlinearities of our system were small, we used two calibration points to convert the data to degrees. Only the targets produced by the stimulus displays were seen by the subject during the experiment, and no proximal cues associated with depth information related to the target distance were present (Rosenfield & Ciuffreda, 1991).

During an experimental session, a variety of convergent or divergent stimuli were presented. All stimuli were 4° step changes in disparity vergence. For the divergence experiments, stimuli began at initial vergence positions of 20°, 16°, 12°, and 8°. One subject, subj001, could not fuse a 20° stimulus, so her initial vergence positions were limited to 18°, 16°, 12°, and 8°. The four stimuli were randomly presented after a random delay of 0.5–2.0 s to avoid subject prediction which can alter vergence dynamics (Yuan, Semmlow, & Munoz, 2000; Alvarez et al., 2002). The convergence experiments also had four initial positions: 16°, 12°, 8° and 4°. The 16° initial position was not included for the one subject (subj001) who could not fuse a 20° near target. Hence the range of all convergent stimuli overlapped the range of divergent stimuli.

Eye movements were recorded using an infrared limbus tracking system ($\lambda = 950$ nm) manufactured by Skalar Iris (model 6500). The manufacturer reports a resolution of 2 min of arc. All eye movements were well within the system's $\pm 25^\circ$ linear range assuming proper set-up. The left and right eye movements were recorded and saved separately. The presentation of stimuli and the digitization of signals that were saved to disk were controlled by a custom LabVIEW program. Data acquisition was done at a sampling rate of 200 Hz, which is well above the Nyquist frequency for vergence eye movements. Calibration of left and right eye movement responses was performed by recording the output of the eye movement monitor at two known positions before and after each response. Calibration data for each eye were stored with the response and used to construct the eye movement response during offline data analysis.

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