Independent Component Analysis Reveals Transient Component of Divergence Varies with Initial Position

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***Abstract*- Vergence eye movements allow humans to view images in depth by turning the eyes inward (convergence) or outward (divergence). Four subjects were studied and tracked four degree disparity steps at different initial positions. This study shows that convergence and divergence dynamics differ depending on initial vergence position. The velocity of divergence increases for initially near targets, while convergence responses are similar irrespective of the initial position. It is speculated that the difference observed in divergence is a result of difference in magnitude of the fusion initiating component (transient component). Preliminary data using independent component analysis (ICA) shows the divergence system contains a step (sustained) component and pulse (transient) component where the amplitude of the pulse is dependent on the initial stimulus position.**

I. 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. Controversy exists in the literature related to the dynamic relationship between convergence and divergence. Several studies report that convergence is faster than divergence by as much as double [1], while other studies report pure divergence and convergence to have approximately the same velocity characteristics. [2] This investigation will show that the speed of responses 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.

The Dual Mode Theory describes convergence as a system composed of an open loop, feedforward or pulse component as well as a feedback or step component. The open loop component accounts for the system's speed while the feedback components is responsible the system's accuracy. However, the divergence system has not been studied to the extent of the convergence system. It is speculated that the divergence system is composed mainly of a step component. However, preliminary ICA results show that a pulse component is present in divergence movements and the amplitude of this pulse is dependent on the initial stimulus starting position.

II. METHODOLOGY

Four subjects participated in this study. All subjects signed informed consent forms before the experiments that were approved by the New Jersey Institute of Technology (NJIT) Institutional Review Board (IRB). Subjects were instructed to initiate an experiment by depressing a button and to maintain binocular fixation on the stimulus target.

Experimental Design

A dynamic haploscope composed of 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 ten-degree and four-degree fixation points. During an experimental session, a variety of convergent or divergent stimuli were presented. All stimuli were 4 degree step changes in disparity vergence.

Eye movements were recorded using an infrared limbus tracking system (λ = 950 nm) manufactured by Skalar Iris (model 6500).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. 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.

Data Analysis

Data analysis began by converting raw digitized left and right responses to degrees using the calibration data. Some investigations have shown that saccades alter vergence responses. [2] The left and right eye responses were subtracted to yield the net disparity vergence movement. When displayed graphically, convergence was plotted as positive, and divergence was plotted as negative. The velocity response was computed using a two-point central difference algorithm.

Data were analyzed using MATLAB (Waltham, MA) and were plotted and statistically analyzed using the software package Axum (Cambridge, MA). Principle component analysis (PCA) has also confirmed that two components constitute the vergence eye movement. [3] In this study, the result of PCA was used by ICA to dissect the behavioral eye movement responses into the pulse and step subcomponents.

The ICA model is a generative model: it attempts to explain how the sources, in this case the underlying neural subcomponents, are mixed to generate the observed signals based on the linear mixing model: [4]

$$\mathbf{X} = \mathbf{As}$$

where **X** and **s** are vectors representing the signals and sources, respectively .This analysis used the "Fast ICA" program developed by the ICA group at Helsinki University.

Figure 1 shows ensemble vergence data on the left and two components generated by the ICA algorithm.

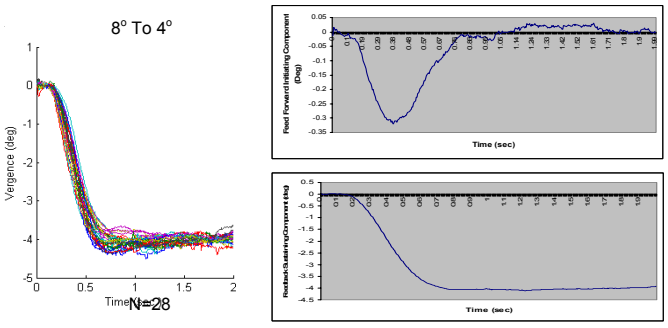

Figure 1: Raw divergence eye movements (left) and the two components found by the ICA algorithm (right)

III. RESULTS

Typical individual divergence eye movements are shown for each subject in Figure 2. Qualitatively, the divergence responses to stimuli near to the subject occurred earlier and with a greater peak velocity compared to responses to stimuli far from the subject depicted in the solid red line.

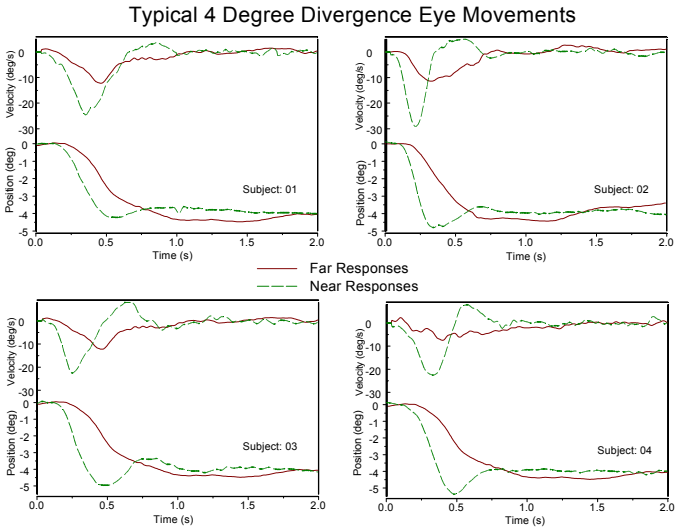

Figure 2: Divergence Responses for Stimuli near (dashed green line) and far (solid red line) from subject

IV. DISCUSSION

When reviewing the dynamics of convergence and divergence, the relationship was dependent on the initial positional conditions. Based on primate neurophysiologic studies, it has been shown that different cells exist for convergence and divergence movements. [5] These studies show that convergence cells are more prevalent compared to divergence cells in the midbrain specifically within the mesencephalic reticular formation. [5] Thus, divergence is not simply a negative convergence movement but a separate neurophysiological system. The neuro-control strategy of the two systems may be different. Evidence of burst and burst-tonic cells show that combinations of a transient and a sustained neural signal are used for both convergence and divergence movements. The divergence cells may fire with more synchronization for near stimuli creating a pulse with a greater magnitude and stronger kinematics compared to divergence responses to stimuli further from the subject. It is also possible that the divergence cell pool may be dependent on the initial position and thus different cells are responsible for stimuli at different distances from the subject.

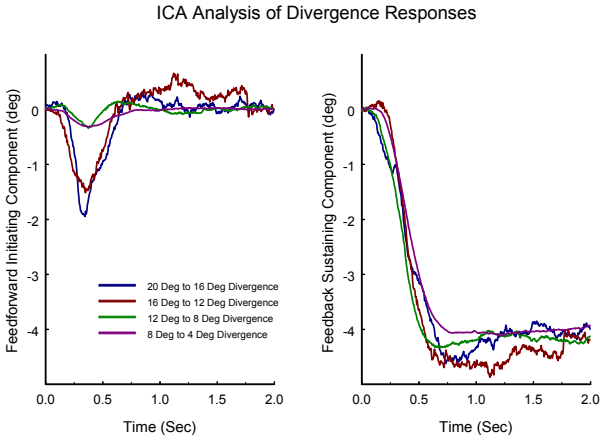

Figure 3: ICA of Subj 004 divergence responses

Our laboratory has begun an independent component analysis of the divergence and convergence data. These preliminary results, Figure 3 suggest that a pulse is present during divergence movements that are stimulated by near targets but the amplitude of this pulse decreases as the stimulus is moved further from the subject.

IV. CONCLUSION

The dynamics of divergence eye movements are dependent on the initial stimulus position. The closer the stimulus is to the subject, the faster the responses as quantified by the maximum velocity. Convergence is not dependent on the initial stimulus position. An independent component analysis revealed that the preprogrammed pulse of divergence maybe responsible for difference in divergence dynamics where the magnitude of the pulse or the fusion initiating component is dependent on the initial stimulus position.

V. ACKNOWLEDGMENT

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VI. REFERENCES

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