Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Divergence Dynamic Modification as a Function of Initial Position

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Abstract- **The ability to change or adapt is critical in the survival of a species. Research has shown that the dynamics of disparity vergence eye movements, the inward (convergence) or outward (divergence) turning of the eyes, are malleable and depend to some extent on the amplitude of preceding stimuli. Divergence eye movements are dependent on initial stimulus position where responses that occur closer to the subject are faster compared to responses that occur farther from the subject. The purpose of this study was to investigate if the modification of divergence eye movements was also a function of initial stimulus position. An experimental trial consisted of three phases: baseline, modification, and recovery. The baseline and recovery phases used only 4° test stimuli. The modification phase consisted of a 4° test randomly intermixed with an 8° step presented in a 1:5 ratio. Two experiments were conducted, one with an initial vergence angle of 8° (far) and the other with an initial position of 20° or 18° (near). Two subjects participated. The dynamic characteristics of the responses to test stimuli were quantified by measuring the magnitude of the peak velocity. Preliminary results suggest the amount of change in peak velocity was greater when the stimuli were closer to the subject. Data suggest that the peak velocity of divergence observed during baseline conditions maybe correlated to the ability to change the dynamics of the disparity vergence system.**

I. INTRODUCTION

Divergence dynamics have been shown to be dependent on initial stimulus position [1]. Further investigation of divergence data using independent component analysis, a blind source separation technique revealed that the transient component varies systematically with the initial stimulus position and are responsible for the position dependent behavior [2]. The purpose of this study is to explore the influence of initial position on dynamic modification or motor learning observed in divergence. Previously, researchers have shown that divergence can be manipulated. During a decreasing gain protocol, divergence visual stimuli are presented in a 5:1 ratio of a modification to test stimulus. For a decreasing gain experiment, the modification stimulus amplitude would be less compared to the test stimulus. Researchers have shown that during a decreasing gain protocol, the dynamics of divergence could be reduced [3]. Will the modification of divergence be different if the visual stimuli are close to the subject compared to further away?

Independent component analysis of divergence without any influence from the environment (modification experiments) revealed that the transient component varies as a function of initial position. Munoz and colleagues in 1999, showed that with an increasing gain protocol that is similar to the one we are using, subjects who had the greatest peak velocity observed during the baseline phase of the experiment also exhibited the greatest change in response dynamics during the modification phase [4]. Following on this study, Semmlow & Yuan in 2002, performed an independent component analysis on results concluding that the magnitude of the transient component was correlated to the ability of a subject to modify his / her response dynamics [5;6]. This study hypothesizes that the transient component of a vergence eye movement is correlated to a person's oculomotor learning ability in vergence; that is, the ability to mechanically learn different visual environments.

To test this hypothesis, an experiment was performed that utilized an increasing gain protocol under near and far initial conditions. Since researchers have shown that the transient component is larger for near initial conditions, it is hypothesized that the dynamic increase in divergence responses will be larger when the stimulus is near as compared to far, for the same modification stimulus.

II. METHODS

Subjects:

Two subjects have participated in these preliminary experiments and further data collection is ongoing. The subjects signed informed consent approved by the New Jersey Institute of Technology Institutional Review Board. One subject is a presbyopic male and an experienced subject. The other is an inexperienced nonpresbyopic female.

Experimental Protocol:

The experiment was designed to generate two types of stimuli -- a test stimulus and a modification stimulus. This study investigated how the modification stimulus influenced the dynamic properties of the response to the test stimuli located close to the subject (an initial position of 20° or 18°) and further from the subject (an initial position of 8°). The male subject (Subj:01) was able to fixate a target of 20°; however, the female subject's closest comfortable viewing fixation target was 18° (Subj:02). The modification stimulus was a larger step change in disparity vergence of 8°. The test stimulus was a smaller 4° movement. Experiments were performed for divergent stimuli (eliciting an outward turning of the eyes). The goals of this study were to determine if 1) the larger step modification stimuli influenced the dynamics of smaller 4° degree divergence step responses and 2) if the modification was different when the visual stimuli were closer compared to further from the subject. In other words, would the presence of repeated larger 8° step stimuli 1) increase the gain of responses to smaller 4° step stimuli and 2) was this modification greater when the stimuli were close to the subject compared to further away?

An experimental session consisted of three phases: baseline, modification, and recovery. The baseline phase consisted of only 4° diverging steps and served as the control. The next phase, modification, consisted of the modification (8° divergence steps) stimulus with an occasional, randomly occurring, test stimulus (smaller 4° diverging step). The stimulus presentation was randomized so that on average the subject was five times more likely to view the modification stimulus (the larger 8° step) compared to the test stimulus (the smaller 4° step.) The recovery phase was also 4° steps and used to determine is excessive fatigue was observed that may influence results.

Instrumentation:

Eye movements were recorded using an infrared limbus tracking system (wavelength = 950 nm) manufactured by Skalar Iris (model 6500). All eye movements were well within the system's ± 25 degree linear range assuming proper set-up. The left- and right-eye movements were recorded and saved separately. The presentation of stimuli, signal digitization, and data storage were controlled by a custom LabVIEW™ program. Data acquisition were done at a sampling rate of 200 Hz, which is well above the Nyquist frequency for vergence eye movements.

Due to the haploscopic viewing conditions, stimuli appeared at the same distance from the subject and accommodation as well as proximal cues associated with depth information were held constant. However, since pinhole viewing was not used, the accommodation system was not open-loop. The stimulus displays were placed 56 cm away from the subject. The targets were a vertical line 3 cm by 2 mm and remained constant throughout the experiment.

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 movement were stored with the response movement and used to construct the eye movement response during offline data analysis. Using the same instrumentation, a study comparing two versus three calibration points showed that the average working nonlinearity was 3% of the total movement amplitude with a maximum nonlinearity of 5% [1]. Since the nonlinearities of the system were small, two calibration points were used to convert the data to degrees.

Data Analysis:

Data analysis began by converting raw digitized left- and right-eye responses to degrees using the calibration data. These eye movements were inspected individually and responses that contained blinks or saccades were omitted from analysis. Saccades were easily identified based upon their fast dynamic properties. 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 [2].

This behavior was analyzed by measuring the magnitude of the peak velocity of all 4° step responses during four phases: baseline responses when the initial position was near and far as well as modification responses when the initial position was near and far from the subject. Data observed during the recovery phase were used to determine if extreme fatigue occurred. Since dynamics observed during the recovery phase where similar to those observed during the baseline phase, recovery data are not presented in the interest of brevity.

Data were quantified using a custom MATLAB program (Waltham, MA), statistical calculations were performed using NCS2000 (Kaysville, UT), and results were plotted using the software package Axum (Cambridge, MA).

III. RESULTS

Figure 1 left shows the average divergence response for the baseline (blue) and the modification phase (red) when the initial position of the visual stimulus was "near" to the subject, an initial vergence position of 20° or 18° for subjects one and two respectively. Figure 1 right shows average divergence responses to 4° steps during the baseline (green) and modification phase (turquoise) when the initial vergence stimulus was "far" from the subject, the vergence fixation position was 8°. Note for all responses the stimulus was a 4° step change in disparity where different dynamic behaviors were observed depending on the external visual environment.

The position (in units of degrees) is shown on the lower traces (solid lines) and the velocity (in units of degrees per second) is shown in the upper traces (dashed lines). For responses closer to the subject, the velocity is greater in magnitude and the width of the velocity trace is smaller compared to the average velocity traces when the stimulus was more distant.

Recovery responses are not plotted in the interest of clarity but were used to determine if excessive fatigue was experienced by the subject. The responses to 4° step stimuli were slightly less compared to baseline but were not substantially different.

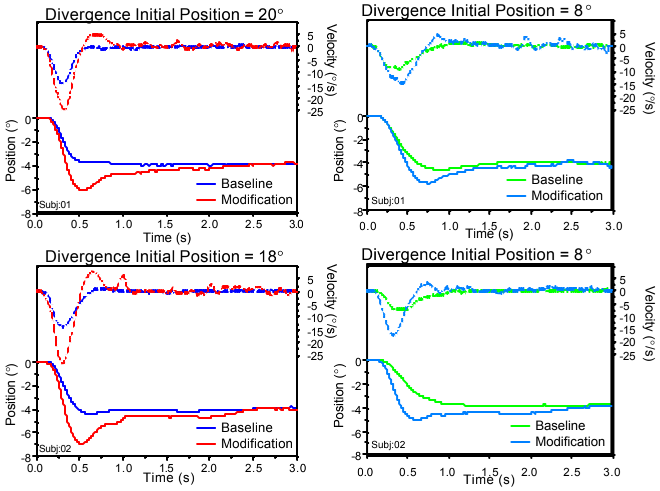

Figure 1: Average responses all to 4° step stimuli presented near (left side) and far (right side) from the subject during baseline and modification phases.

Data were quantified by measuring peak velocity, Figure 2 and Table 1. Comparing peak velocities during the baseline, the divergence responses that were closer to the subject had greater peak velocities compared to those further from the subject. The key new finding from this experiment is the change in velocity during the modification phase was greater when the stimuli were close to the subject (peak velocity change = 8.31°/s and 12.75°/s for subjects one and two respectively) compared to further away (peak velocity change = 4.89°/s and 8.48°/s for subjects one and two respectively). When comparing the baseline with modification phases, the changes were statistically significant for both near ($p<0.0001$) and far ($p<0.01$).

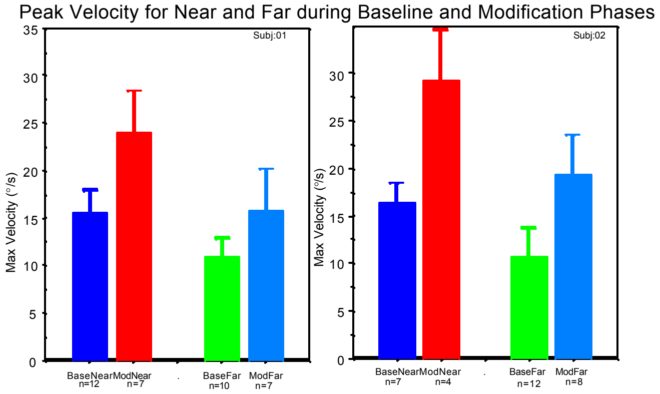

Figure 2: Summary of peak velocity (°/s) ± standard deviation for two subjects during the baseline (blue) and the modification phase (red) when the initial position of the visual stimulus was "near" to the subject, an initial position of 20° or 18° for subjects one and two respectively as well as divergence responses to 4° steps during the baseline (green) and modification phase (turquoise) with an initial stimulus position of 8° or "far" from the subject.

Table 1: Maximum velocity with standard deviation from divergence modification experiments

Initial Vergence Angle	Phase	Subj: 01	Subj:02
		Peak Velocity (°/s)	Peak Velocity (°/s)
Near	Base	15.59 ± 2.29 n=12	16.47 ± 2.02 n=7
Near	Modification	23.90 ± 4.48 n=7	29.22 ± 5.40 n=4
Far	Base	10.88 ± 2.01 n=10	10.77 ± 3.01 n=12
Far	Modification	15.77 ± 4.44 n=7	19.35 ± 4.18 n=8

IV. DISCUSSION

Motor learning utilizing an increasing gain protocol does occur with divergence when the stimuli are presented close as well as far from the subject. There was a greater increase at near compared to far, although the percent increase was approximately the same. The percentage change was 53% during the near experiments and 45% during the far experiments for subject one and 77% during the near experiments and 80% during the far experiments for subject two). Thus, the response with the higher baseline velocity (the higher transient component as revealed by independent component analysis) showed a proportionately larger increase in velocity with motor learning. This suggests that the transient component of the baseline response is an indicator of the amount of change the person is capable of for a given initial position. For instance at near, the average peak velocity was 15.59 deg/sec and the peak velocity during modification was 23.90 deg/ sec or approximately one and a half times the baseline. Similarly at far, the average peak velocity was 10.88 deg/sec and the peak velocity during modification was 15.77 deg/ sec or again approximately one and a half times the baseline.

We speculate that the dynamics of the transient component are related to the velocity encoded neurons described by Mays and colleagues [9;10]. The transient component varies per person but we speculate that it is responsible for the person's ability to adapt or change to his/ her visual environment. A larger transient component at near with divergence leads to a greater ability to change compared to a smaller transient component at far.

V. CONCLUSION

Preliminary data suggests that divergence modification is dependent on initial stimulus position. The larger the baseline dynamics, the greater the overall change in dynamics during the modification phase. The changes observed between the baseline and modification phases were statistically significant. It is hypothesized that dynamic modification observed is correlated to the magnitude of the transient component where the larger the initial transient component, the greater the ability of the person to change his / her dynamics.

VI. ACKNOWLEDGEMENT

This research was supported by a Career Award from the National Science Foundation (BES-0537072 and BES-0447713).

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