The Dynamics of Convergence Insufficiency

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Abstract – **Many people are hindered by vision dysfunctions. One of the most prominent vergence dysfunctions in society is convergence insufficiency (CI) affecting 7% of the population. This study inspects the dynamics of convergence movements in both CI and normal binocular vergence subjects. Two stimulus types, a four degree and six degree step, were presented to all subjects. The goal was to determine if the dynamics of CI subjects were different compared to subjects with normal binocular vergence. Using the main sequence analysis, data show the dynamics of CI subjects were in the normal range as those who had normal binocular vergence, but were on the lower end. This study shows the dynamics of CI subjects, whom have not had vision therapy, are slower when initiating a convergence movement.**

I. INTRODUCTION

Reading is a task that many of us take for granted. However, there is a substantial portion of the population who cannot read for prolonged periods of time or sustain near visual tasks due to accommodation (i.e. focusing) and vergence (i.e. fusing) dysfunctions or their abnormal interactions. Vergence is the oculomotor system that mediates the inward (convergence) or outward (divergence) turning of the eyes to track objects moving in depth and maintain a single and fused perception. This paper seeks to quantify objectively the most important and common vergence dysfunction, known as convergence insufficiency (CI), to gain insight into the underlying neural-oculomotor mechanisms. CI is problematic for children, because it hinders academic growth, and it is taxing for both older and younger adults because they cannot sustain near work comfortably for prolonged periods of time.

CI is diagnosed as the inability of an individual to fixate on a near target effortlessly. It is present in 7% of the general population.[1] Symptoms include blurred vision; diplopia; discomfort associated with near work; frontal headaches; sleepiness; loss of concentration; nausea; dull ocular discomfort, and general fatigue. [2] Symptoms worsen as the amount of near visual demand increases. It is defined as a reduced near point of convergence (less than 6 cm) and an increased exophoria. As our society evolves in both the work and academic environment to become more dependent on prolonged near visual tasks such as computer use and reading, there will be a continued increase in the demand and need to help those people who suffer from vergence dysfunctions, of which the most prevalent is CI.

Optometric vision therapy is the treatment of choice for patients with convergence insufficiency. Therapy typically includes in-office motor learning paradigms or "exercises" frequently reinforced with home therapy. Summarizing many large studies, Grisham reported that the average cure rate is 78%. [3] The literature clearly demonstrates that CI is prevalent in the population and that therapeutic remediation is successful. However, only a paucity of studies has quantitatively investigated the dynamics of dysfunctional vergence eye movements, and these studies were of a very small sample size. A quantitative study and analysis should provide insight as to why this dysfunction occurs, why the therapy is successful, and potentially lead to an optimization of the therapeutic procedure.

II. METHODOLOGY

This experiment consisted of a five-point calibration and two stimuli which stimulated a convergence movement through the use of computer program written in LabVIEW. The study was composed of two groups of people, those with convergence insufficiency and those with normal binocular vergence. The normal binocular vergence group was used as the control when comparing the dynamics of eye movements.

Subjects signed informed consent, which was approved by the institution's review board. After the eye movement monitor was correctly position on the subject, a five-point calibration was recorded. The five-point calibration allowed the subject's eye movements to be converted into degrees after they were digitized using a 12 bit digital acquisition board from National Instruments, model 6024e, which records signals as voltage values. A five-point calibration was performed by illuminating the light emitting diodes (LEDs) in a sequence and recording the voltage value at each position, then doing a regression analysis to determine a linear equation for the conversion.

After calibration, subjects would push a trigger button to initiate an experiment and a random time delay of 500 to 2000 msec occurred before the LEDs changed luminescence to remove anticipation by the subject. Furthermore, the four and six degree steps were randomly selected by the computer to avoid subject prediction. These responses were recorded for three seconds and experiments occured in complete darkness where the subject only observed the presence of LED targets.

Four subjects were used for this experiment. Two had convergence insufficiency and two did not. In the CI group, subjects APD and SLB had a near point convergence (NPC) of 9.5 cm and 9 cm respectively. They were both exophoric where APD was 12 to 14 diopters and SLB was 9 to 10 diopters measured at 40 cm. In

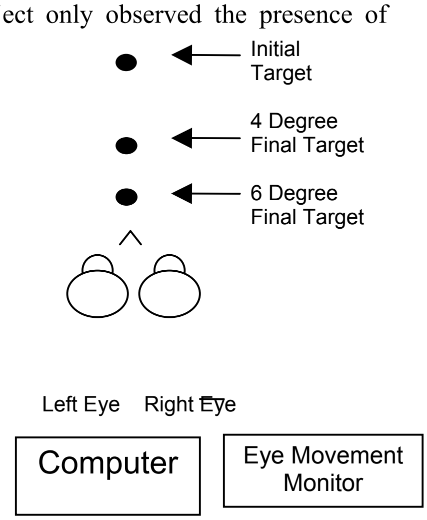

Figure 1: Experimental Set-Up

the control group, subject GSD had an NPC of 2 cm and was orthophoric where as subject FBC had an NPC of 2 cm and was 6 to 8 diopters exophoric both measured at 40 cm.

The stimulus always began at the same initial position using an illuminated LED. The computer initiated the shutting off of the initial LED and the lighting of the next LED where subjects were asked to track or fuse the new target. These LEDs were positioned along the midline of the subject as shown in Figure 1. Lastly, the convergence movements made by the eyes were measured using the Skalar Iris model 6500, an infrared limbus-tracking device. These movements were recorded at a rate of 200 Hz. The resolution of the eye movement monitor is 2 minute arc with a linearity of ± 25 degrees. Throughout the experiment, the data was collected from each eye independently.

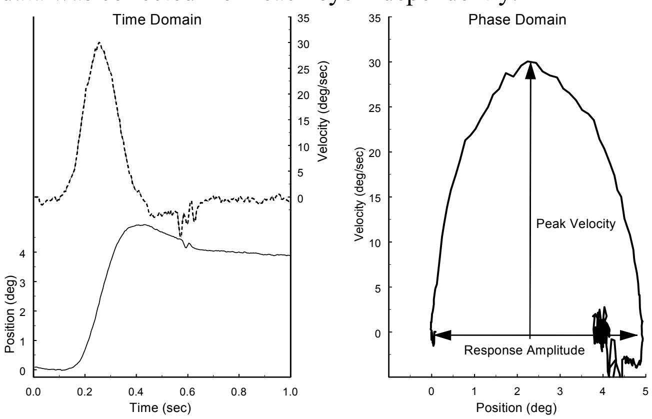

Figure 2: Main Sequence Analysis

Figure 2 shows a typical response on the left where the left and right eye movements were subtracted and the position (solid line) and velocity (dashed line) are plotted as a function of time. The main sequence was calculated to quantify eye movement dynamics. The main sequence is calculated in the phase domain, plot of velocity vs. position, and is the ratio of the peak velocity to the response amplitude as shown on the right side of Figure 2.

III. RESULTS

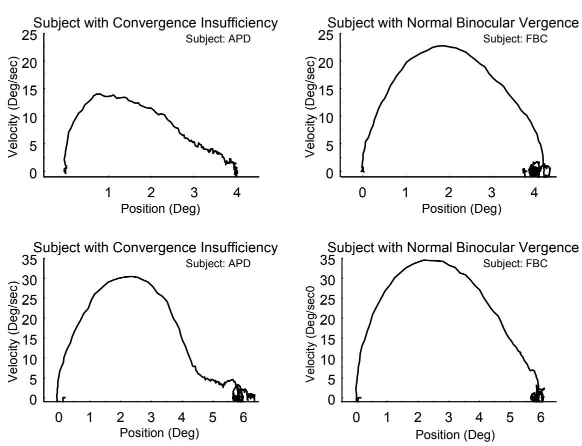

Figure 3: Phase Plane Analysis of a CI and a Control Subject

The recording of a typical eye movement for a four degree and six degree response can be seen in the phase plane plot, for two subjects, as shown in Figure 3. The subject APD, who has convergence insufficiency, is shown on the left with the top graph displaying a four degree movement and the bottom displaying a six degree movement. The subject FBC, who has normal binocular vergence, is shown on the right with the top graph displaying a four degree movement and the bottom a six degree movement. A comparison between the CI subject and the normal subject in both the four and six degree movements show that the CI subject's peak velocity was slower compared to the normal subject.

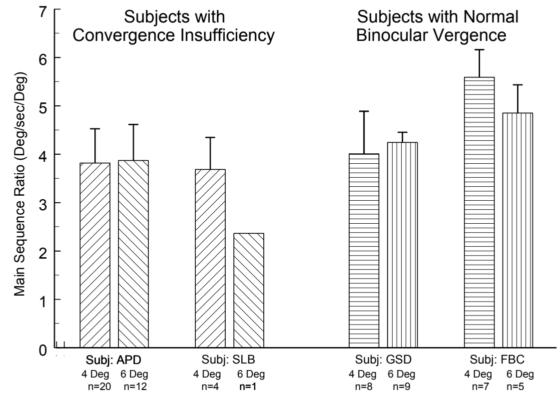

Figure 4: Main Sequence Analysis

Next, a main sequence analysis was completed on the four subjects for both four and six degree movements. Figure 4 displays the mean and the standard deviation for the main sequence ratios. The two subjects on the left have CI and the two on the right have normal binocular vergence. The main sequence shows the CI subjects have a ratio that is slightly lower compared to subjects with normal vergence.

IV. DISCUSSION

Data collected suggest a slight upward trend in the main sequence of subjects with normal binocular vergence. This suggests the dynamics of those without binocular dysfunctions are faster compared to the people who have CI.

It is hypothesized that CI subjects can improve their dynamics to a point, which resembles the dynamics of a person with normal binocular vergence. Currently, vision therapy is given to CI subjects, which is believed to improve their vergence dynamics. A potential change in dynamics may account for an average cure rate of 78% for patients participating in vision therapy as stated by Grisham.

To conclude, more subjects and data need to be collected to ascertain if the dynamics between CI and normal binocular vergence subjects are different. In addition, the dynamics of subjects with CI should be tested before and after vision therapy. This will give a better understanding if the therapy is helpful by improving the vergence system dynamics.

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