Abstract- Vergence eye movements are essential to daily life. When driving down a highway a person typically looks between the speedometer and the road signs. This form of eye movement initiates a vergence response. Vergence is composed of convergence (inward) and divergence (outward) eye movements. Convergence movements are a combination of burst cells, described as feedforward and feedback components. The feedback component is a pulse of energy released by burst cells in the initial stage of the eye movement. Feedback is a series of steady periodic pulses released by tonic cells to fixate the eyes onto the target. However, divergence eye movements have not been studied extensively in the past. This study will examine the neuro-control strategy used to mediate divergence eye movements (looking from near to far), when given different initial positions for the eyes to begin moving from. Preliminary data using independent component analysis (ICA) shows the divergence system contains an initial pulse, similar to the burst cells found to initiate convergence movements, when the movement began with a large initial bias (target very close to the subject). In responses beginning at a target located further away from the subject and continuing to move farther away, there is no noticeable pulse based on ICA. Demonstrated in this study is the dynamics of divergence movements at different initial conditions.

I. INTRODUCTION

Daily life involves many eye movements. These eye movements are composed of conjunctive (parallel) and disjunctive (opposite) movements. Disjunctive or vergence is the oculomotor system, which initiates the movement of the eyes in opposite directions in the horizontal plane. Through this, binocular vision is maintained as depth perception changes. [1] Two forms of vergence movements can be made. The first is convergence, which involves the inward motion of the eyes, and the second is divergence which is the outward motion. These two mechanisms allow the eyes to track objects moving in depth and maintain fusion of that object. [2]

The convergence system has been well studied in the past several years. Convergence is composed of a dual mode system, feedforward and feedback. Burst cells are modeled as feedforward, an initial, instantaneous firing that occurs right before and at the beginning of the eye movement. An initial velocity is given in feedforward component though the spikes generated by the burst cells. The number of spikes corresponds to the total initial convergence movement. [1] The feedback mechanism, a tonic cell response, then takes over for precision and accuracy, by aligning the eyes onto the target with the firing of repetitive and steady pulses. The burst and tonic cells for convergence movements have been found in the mesencephalic reticular formation, which is located dorsal and lateral to the oculomotor nucleus. [1]

However, the divergence system is yet a mystery. The oculomotor vergence component is responsible for many aspects of daily life. When a driver looks at the dashboard for what speed he is going at to when he looks up and sees a police car in front moving further away, the divergence system is activated. The eyes have just moved apart and are tracking an object in the distance. It is not completely understood how divergence operates. This study will investigate the divergence system further to determine how the initial conditions affect the neural control strategy to mediate the response.

II. METHODOLOGY

This experiment used a computer program written in Labview to introduce a six degree change in stimulus at two different initial positions. In turn, this initiated the vergence system to conduct a divergence eye movement. This study is composed of only those who have normal binocular vision.

This experiment consisted of one subject, JLS. Before conducting the experiment, the subject was asked to sign the informed consent which the institution’s review board had approved. Next, the eye movement monitor was properly placed on the individual and a stimulus with an 8 degree bias was given. This stimulus allowed for a 6 degree movement from the 8 degree mark to the 2 degree, as point A on figure 1 represents. The second part of the experiment induced the same stimulus, but with a 14 degree bias. This stimulus began at 14 degrees and went to 8 degrees, making a 6 degree movement, which is point B in figure 1.

The stimulus sent out by Labview was displayed on two oscilloscopes. These oscilloscopes sent the signal to two mirrors which were positioned at 45 degrees to the line of sight, thus forming a stereoscopic pair. Before the experiments began, the oscilloscopes were calibrated using two points positioned at exactly 5 and 2 degrees from each eye. To record the divergence eye movements, the Skalar Iris model 6500, an infrared limbus-tracking system, was adjusted to the subject’s eyes. The eye movement monitor had a resolution of 2 minute arcs with a linearity of ±25 degrees. The data were sampled at a rate of 200 Hz and sent to the National Instruments, model 6024e, digital acquisition board to be digitized. Data for each eye were collected independently.

The eye movement dynamics were then quantified using a main sequence analysis and independent component analysis (ICA). A plot of the velocity vs. position in the phase plane allows for the main sequence to be calculated. The main sequence is the ratio of the peak velocity to the response amplitude. ICA is a method of taking the signal
and finding its independent components. Such as having a person speak English and another person speak Spanish into the same microphone and then having two signals separated into its unique languages after the analysis. The ICA model 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 [3].

\[ X = As \]

where \( X \) and \( s \) are vectors representing the signals and sources respectively. In this application, the signals, \( X \), are the recorded eye movements, the sources, \( s \) are the underlying feedforward and feedback components generated by presumed divergence burst and tonic cells respectively. The mixing matrix, \( A \), consists of the component mixture and movement-to-movement variability. This analysis used the “Fast ICA” program developed by the ICA group at Helsinki University.

III. RESULTS

The phase plane in figure 2 shows two typical 6 degree eye movement readings. The slower of the two readings has a bias of 8 deg and the faster phase plane has a bias of 14 deg. The peak velocity of the 8 degrees initial starting point is smaller than the response beginning at 14 degrees.

![Phase Plane Analysis](image)

**Figure 2: Phase Plane Analysis Subject JLS**

A main sequence analysis was completed, in which the average dynamics and standard deviation are displayed in figure 3. The left bar is the main sequence ratio for a 8 to 2 degree movement, and the right side is the 14 to 8 degree movement. The data show that when an object moved from an initial point far from the face, the average main sequence ratio was lower in comparison to when the object moved from very close to the face to afar.

![Main Sequence Analysis](image)

**Figure 3: Main Sequence Analysis Subject JLS**

The raw data of a typical eye movement in figure 4 shows slow movements (initial position equals 8 deg) on the left side and fast movements (initial position equals 14 deg) on the right side. This raw data is used for the ICA analysis which finds the independent components of a signal. The data in this figure depict the repeatability of the experiment and the consistency in the velocity, given the initial starting conditions of the divergent movement.

![ICA Analysis Raw Data Subject JLS](image)

**Figure 4: ICA Analysis Raw Data Subject JLS**

IV. DISCUSSION

An ICA analysis of the divergent eye movements indicates the firing of burst and tonic cells depend on the initial position of the eyes from where the movement began. Figure 5 establishes on the left, a slow 8 to 2 degree movement, in which the feedback component makes a steady movement of 6 degrees and the feedforward component does not appear to have any magnitude. The graph on the right displays a much faster response, (movement from 14 to 8 degree) due to an initial pulse generated by the feedforward component at the beginning of the movement. Also note the feedback component has a faster initial slope.

![ICA Analysis Neural Subcomponent Data Subject JLS](image)

**Figure 5: ICA Analysis Neural Subcomponent Data Subject JLS**

The ICA analysis indicates that a dual behavior could exist in the divergent system, dependent on the initial condition. If an object is tracked from very close to the face to far, burst cells could be triggered to give a quicker movement rather than a gradual movement generated primarily by the tonic cells. Another possibility is the divergence system could be a passive system resulting from the absence of a convergence stimulus. Additional data needs to be collected from several individuals to further understand the neural control of divergence eye movements.

REFERENCES