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

The Transient Component of Disparity Vergence maybe an Indication of Progressive Lens Acceptability

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Abstract—**Presbyopia, a degenerative condition, which decreases accommodation, sets in approximately at the age of forty. One approach to correct presbyopia is the use of bifocal or progressive lenses. Naturally, some people are more prone to adapt to wearing progressive lenses than others. The vergence system, which controls the inward and outward turning of the eyes, is a system which supports viewing objects in depth. Identifying the two components (transient and sustained components) of a pure vergence eye movement is possible with ICA (Independent Component Analysis). Preliminary results suggest a correlation with the magnitude of the transient component and whether or not a person can adapt to wearing progressive lenses or not. Furthermore, the transient component of vergence is hypothesized to be an index of how flexible the vergence system is in adapting to new environments.**

I. Introduction

Presbyopia, which occurs approximately at the age of 40, is a condition associated with the inability to accommodate and usually requires aid in the form of bifocals or progressive lenses. Unlike bifocals, progressive lenses house several implications for some presbyopes, which include but are not limited to dizziness, nausea, diplopia, etc. Such lenses require an adjustment of the amount of vergence required for a given stimulus distance (so-called prism adaptation), but they also require a change in the vergence dynamic response at different effective lens powers in order to produce vergence movements.

The vergence system involves disjunctive movements; convergence and divergence, or the inward and outward turning of the eyes, respectively. These movements are facilitated by the lateral and medial recti muscles of the eyes, which rotate the globes, until paired images project onto the foveas.

The Dual Mode Theory suggests that convergence is composed of a preprogrammed, or transient component, and a feedback, or sustaining component [1]. The transient component is responsible for the speed of the system, while the sustaining component is responsible for the accuracy of the system. This study primarily researches the transient component and is quite possibly an index of how flexible the vergence system is in adapting to new environments.

II. Methodology

Three groups of people served in this study, eight subjects in the control group ages 18 to 35; seven subjects in the presbyopic group who wearing progressive lenses daily (age 45 and older); and four subjects in the presbyopic group who have tried but could not adapt to viewing through the progressive lenses (age 45 and older). Out of these nineteen subjects five controls, four presbyopes who wear progressive lenses, and four presbyopes who have tried progressive lenses but could not adapt to them produced enough artifact free responses needed for independent component analysis. All subjects were asked to sign a consent form approved by the institution review board (IRB) at the New Jersey Institute of Technology (NJIT).

Experimental Design

Using an infrared limbus tracking eye movement monitor (Skalar IRIS Model 6500), about sixty responses were recorded from each subject to ensure adequate amount of responses for data analysis. The manufacturer reports a resolution of 2 minutes of arc for the system. All eye movements were well within the system's ± 25 degree linear range assuming proper set-up.

In order to avoid aliasing, data acquisition was performed at 200 Hz, which is above the Nyquist frequency. 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 and used to construct the eye movement response during offline data analysis.

A computer simultaneously controlled two light emitting diodes (LED) and recorded and saved the left- and right-eye movement responses separately. The subjects were properly placed on a chin rest to avoid influence from the vestibular system with both LEDs along their midline to stimulate symmetrical vergence.

Subjects were instructed to fixate binocularly on LED stimuli located at 4º and 8º vergence fixation points. Upon subject initialization (button press), the LED stimulus would change illumination after a random delay of 0.5 to 2.0 sec and change in a step manner of either 4º step convergent (towards the subject) or 4º step divergent (away from the subject). Approximately 30 samples of each response were collected. The LED targets were masked to present a thin vertical line 2 cm in length and 4 mm in width. Convergence and divergence were intermixed to decrease subject prediction and prism adaptation.

Data Analysis

Analysis began with the conversion of raw digitized left- and right-eye responses to degrees using the calibration data. Data analysis also involved utilizing data with little or no saccades due to the fact that previous studies have shown that saccades alter vergence responses. The left- and right-eye movements were inspected individually and responses that contained blinks or saccades during the transient portion of the response were omitted from analysis. Saccades were easily identified based upon their faster dynamic properties compared to vergence.

The application of ICA used here requires a number of repetitive responses to the same stimulus. Simulations indicated that 10-20 individual responses were sufficient to determine accurate estimates of two components [2;3].

ICA is a form of "blind source separation" that can isolate individual components from a mixture provided the components are nongaussian and sufficiently independent [4;5;6]. The basic principles behind ICA are well described in number of references and will be only briefly mentioned here. The ICA model is a generative model: it attempts to explain how the components are mixed to generate the observed signals assuming a linear mixing model [6]:

$$x = As + noise$$

where x is a vector of size m (the number of mixtures, or individual responses in our application), and s is a vector of size n (the number of underlying sources, or components in our application). The noise vector represents the disturbances in the form of additive noise independent of the source vector s. The goal of ICA is to identify the linear mixing matrix A. Inverting the mixing matrix produces an "unmixing" matrix, $U = A^{-1}$, that can be used to estimate the unobservable source vector s ($s = Ux$). This is accomplished by linear transformations of the data set (i.e., rotations and scalings) with the goal of optimizing some objective function related to statistical independence, such as a measure of nongaussianity. There are a number of different approaches for estimating A, differing primarily in the objective function that is optimized and the optimization method [6]. Since both the mixing process A and the sources s are unknown, these techniques are part of a larger family known as blind source separation (BSS) [4].

In this application, the signals produced by the neural control components of vergence eye movements constitute the latent variables, s, and the mixing matrix, A, accounts for their movement-to-movement variability. The critical assumptions in ICA are that the variables are statistically independent and have nongaussian distributions. This latter is essential since it is the nongaussianity of the data set that is often optimized. While vergence responses are certainly nongaussian, the initial portions of these responses will not be completely independent due to stimulus induced synchronization of the driving neural sources. In other words, even if the underlying neural sources are independent, their activation by a common stimulus could induce a temporary correlation between their responses. As these responses continue this 'stimulus effect' diminishes so that the components become independent during the latter portion of the response. To avoid this stimulus induced synchronization, the evaluation of the mixing matrix, A, was performed only on the latter portion of the responses. The time period following maximum ensemble variance (close to the time of peak velocity) was found to provide sufficient component independence to permit accurate determination of the mixing matrix. The mixing matrix, A, obtained from the truncated responses was inverted to give the unmixing matrix, U, which was then applied to the whole response (including the initial portion) to estimate the underlying motor components, s.

Another important assumption in the ICA model is that the independent sources not only exist, but undergo instantaneous linear mixing to produce the sensor signal. While no biological process is likely to be linear, extensive eye movement data indicate that separate neural signals, such as those from version and vergence neural centers do combine in an approximately linear manner. Moreover, most models of the oculomotor plant are linear [7].

Several popular ICA algorithms can be downloaded from the internet as MATLAB script files. In this study, we used the "FastICA" algorithm developed by the ICA Group at the Helsinki University (available at: http://www.cis.hut.fi/projects/ica/fastica/fp.html). In our analysis, data dimensionality was reduced to two. This is the number of components predicted by the Dual-Mode Theory and also indicted by principle component analysis (PCA) analysis. To apply ICA to ensemble vergence response data, each response is treated as an observed signal.

Simulations showed that the algorithms produced a better match between isolated and simulated components if the data sets were symmetrical [8]; that is, responses were modified by adding the inverted response to the end of the actual response to make the ensemble data symmetric along the time axis. This is because the PCA algorithm requires symmetrical data in order to accurately reduce the dimensionality of the data set. While this operation does not add any new information to the data set, it does change its statistical properties. Specifically, a modified, symmetrical data set showed more than one order of magnitude greater difference in the ratios between the first three eigenvalues as compared to the original data set. This improvement influenced the construction of principal components during the pre-processing operation and resulted in much better component decompositions of simulated data. After analysis, the inverted responses were discarded.

The ability of ensemble ICA to isolate components was evaluated using simulated responses from a quantitative model of the disparity vergence system [2]. The underlying simulated components are shown in Figure 1 (solid lines) along with the components estimated by ICA (dashed lines). A very close match is observed between the simulated components and those calculated by ICA algorithm.

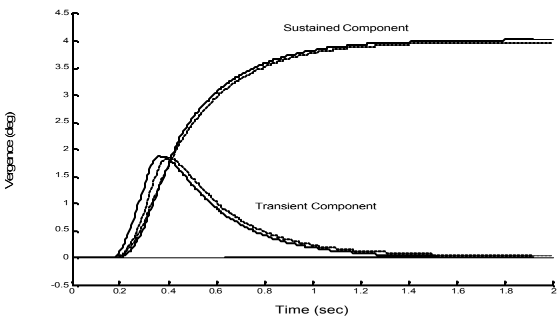

Figure 1: Comparison of isolated components found by ICA (dashed lines) and the actual model generated components (solid lines). A very close match is found between the simulated component averages and the components isolated by ICA.

III. RESULTS

Figures 2 through 4 illustrate typical convergent response from twelve different subjects. The green line represents the average convergence response for 10-30 experimental responses. The red line indicates the sustaining component and the blue line represents the transient component. Figures 2 through 4 are the results from three populations sets; controls (age 18-35), presbyopes who have adapted to wearing progressive lenses (age 45 or older) and presbyopes who have tried but could not adapt to wearing progressive lenses (age 45 or older). The control data, Figure 2 shows the largest variability in the transient component magnitude.

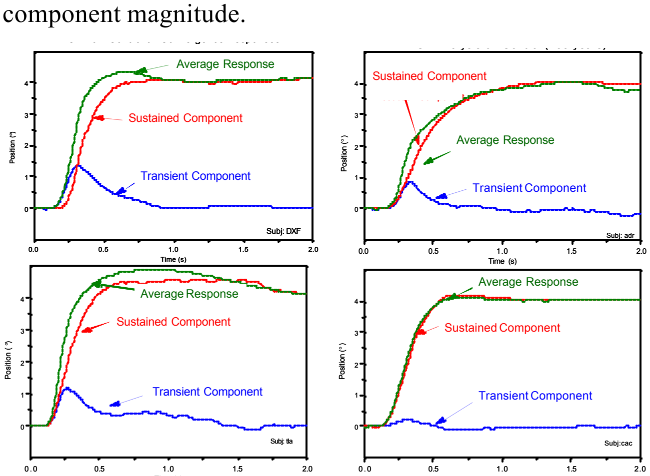

Figure 2: ICA Analysis of Convergence 4 Degree Steps Responses on Controls (Ages 18 – 35)

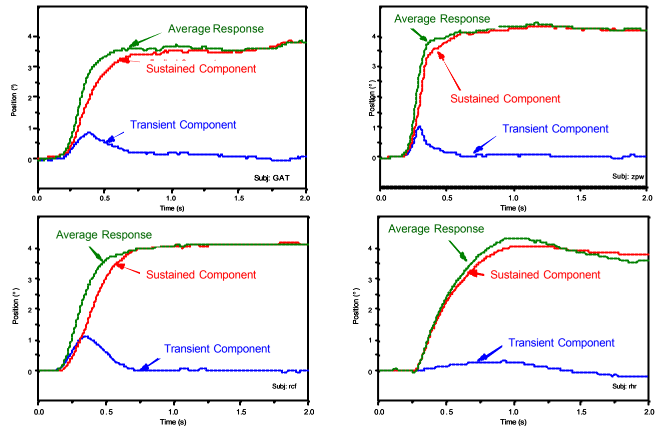

Figure 3: ICA Analysis of Convergence 4 Degree Steps Responses on Presbyopes (Ages 45+) who wear Progressive Lenses

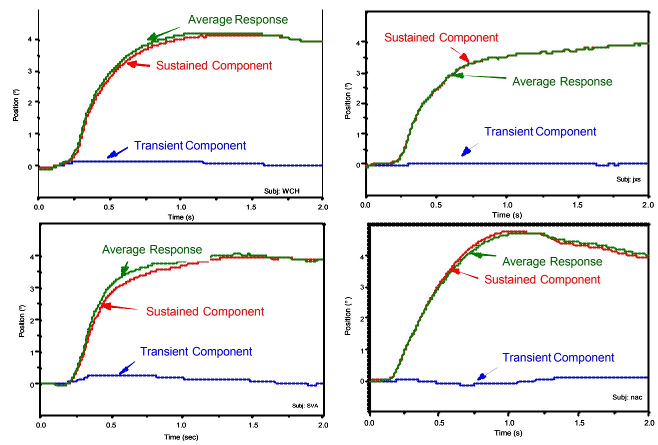

Figure 4: ICA Analysis of Convergence 4 Degree Steps Responses on Presbyopes (Ages 45+) who tried but CANNOT wear Progressive Lenses

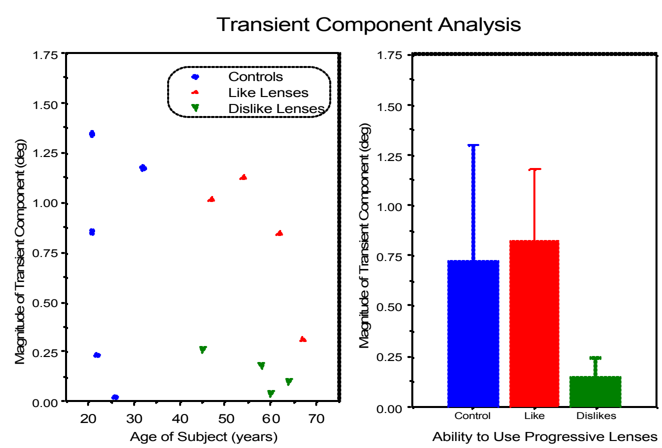

Figure 5: Magnitude of transient component (º) as a function of age (left plot) and average magnitude with standard deviation of the transient component for each group (right plot). Controls are denoted in blue, presbyopes who adapted to progressive lenses are denoted in red, and presbyopes who did not adapt to progressive lenses are denoted in green.

Figure 5 left is a summary plot of the previous ICA graphs in Figures 2 through 4. Clearly, the most variability exists among the five subjects in the control group. In addition, the presbyopic subjects who adapted to wearing progressive lenses have a larger transient component magnitude compared to presbyopes who could not adapt to wearing progressive lenses.

IV. Discussion

Results show that the magnitude of the transient component is correlated to the ability to use progressive lenses. When comparing the presbyopes who could adapt to progressive lenses to those who could not, the difference in the magnitude of the transient component was statistically significant (p=0.0017). Figure 5 clearly illustrates a greater variability present among the control subjects. These preliminary results suggest that the transient component does not appear to decrease with age as with many other visual systems (ie. prism adaptation and accommodation leading to presbyopia). However, there is an apparent decrease in magnitude among the presbyopes who could not wear progressive compared to presbyopes who could learn to wear progressive lenses suggesting a correlation. This decreased magnitude of the transient component may potentially be a decrease in a person's ability to adapt to new visual environments such as wearing progressive lenses.

V. Conclusion

Acceptance of progressive lenses may be correlated with ability to modify vergence which itself is dependent on the transient component. However, the magnitude of transient component does not appear to be correlated to age. Ultimate goals of the research are to identify possible optometric vision eye therapy, eye muscle exercises, to train the eyes to adapt to progressive lenses. Future work is needed to identify a clinical tool to assess if a person would easily adapt to progressive lenses or perhaps need specialized training such as optometric vision therapy.

VI. ACKNOWLEDGEMENT

This work was funded in part by Essilor International, a Career Award from the National Science Foundation (BES-0537072 and BES-0447713) and by the Ronald E. McNair Postbaccalaureate Achievement Program in accordance with the United States Department of Education.

VII. REFERENCES

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