Reports

Accommodative and fusional components of fixation disparity. John L. Semmlow and George Hung.

Traditional measurements of fixation disparity, like other binocular measurements, confound influences from both blur-driven and disparity-driven components. Measuring fixation disparity with accommodation open-loop eliminates accommodative interactions, and results show fixation disparity is reduced to about half the value observed normally for high levels of forced vergence. Thus fixation disparity curves are shaped by both accommodative and fusional vergence processes.

Background. Maddox1 was the first to formalize the structure of convergence eye movements and proposed that convergence is performed in three hierarchical steps. First, underlyng all vergence responses is a tonic component. As the eyes focus on a near target, the increase in accommodation produces an accommodative convergence component. Finally, a “fusional supplement” is added when necessary to bring the eyes into alignment for single vision. This component hierarchy has been incorporated into a number of theoretical structures describing vergence eye movements.2, 3

Recent experimental evidence has shown that during binocular fixation some vergence components do not have the values predicted by Maddox. Ogle et al.4 noted little correlation between traditional disassociated phoria and associated phoria (the vergence stimulus required for zero fixation disparity) measurements. This led them to conclude that monocular phoria measurements “cannot be presumed to be a measure of the oculomotor imbalance when fusion is maintained”.4 In addition, Semmlow and Heerema5 showed that a sudden interposing of a cover over one eye, while both eyes were viewing a target strategically positioned on the phoria line, produced a transient divergent movement in the covered eye. This movement indicates the presence of a binocular fusional vergence component when the Maddox hierarchy predicts the “fusional supplement” will be zero. Hence, monocular and binocular accommodative vergence components must be different even though the accommodative stimulus remains the same.

Such experiments clearly demonstrate the synkinetic interaction between the accommodation and vergence systems. Thus measurements on isolated systems may not directly reflect their binocular behavior. Conversely, binocular measurements will in general confound the contributions of individual components.

One such binocular measurement used in both experimental research and clinical practice is that of fixation disparity.6 This is a measure of the fixation error under binocular viewing conditions usually plotted as a function of either vergence or accommodative stimulation. While fixation disparity measurements are used to provide information on fusional vergence, they may also include the effects of other vergence components. For example, the influence of accommodative stimulation and the related changes in accommodative convergence on fixation disparity are well known.7 Further, the effect of forced convergence (or divergence) on the accommodative response is equally well established, although its existence as a mechanism independent of accommodative vergence is controversial.8, 9 Irrespective of the mechanism involved, any interaction of fusional vergence with the accommodative response will produce a change in blur stimulation due to accommodative feedback. This change in blur will in turn modify accommodative convergence and the measured fixation disparity. Thus the state of the lens and indeed the entire accommodative system could influence fixation disparity as traditionally measured.8

The functional relationship between fixation disparity and forced convergence or divergence shows considerable intersubject variation.4 Some of this variation may be attributable to processes outside the fusional vergence system such as interactions between accommodation and vergence. Clearly, it would be useful to determine how much fixation disparity is directly related to fusional vergence as opposed to interactive or other processes. Here we propose to measure fixation disparity as a function of forced convergence and divergence under stimulus conditions which should eliminate accommodation/vergence interactions. Comparing these results with fixation disparity curves obtained in the usual manner will isolate the contribution of interactive mechanisms.

To obtain measurements of fixation disparity which reflect only the operation of the fusional vergence system, it is necessary to ensure that changes in accommodative response do not influence the vergence system. As mentioned previously, such changes normally alter the blur
Fig. 1A. Fixation disparity measuring apparatus. Overall arrangement of the optical system. L1 and L2 are achromatic double convex lenses. M1 and M2 are fixed front-surface mirrors, whereas M3 and M4 are movable front-surface mirrors. B is a beam splitter and D is a dove prism. P is an iris diaphragm which can be reduced to a 1 mm pinhole to provide open-loop accommodative stimulation. PL1 and PL2 are Polaroid screens. The position of the target, T, was varied to adjust closed-loop accommodation.

stimulus which will then modify accommodative convergence. We propose to eliminate these accommodative interactions by measuring fixation disparity with the accommodative system open-loop. An optical pinhole will be used to eliminate blur irrespective of accommodative response; thus there will be no stimulus to inhibit or modify accommodative convergence. The resulting fixation disparity must be related only to fusional vergence. By comparing fixation disparity measured under both open- and closed-loop accommodation, that portion attributed to accommodative interaction can be clearly and quantitatively defined.

Methods. A schematic representation of the experimental apparatus is shown in Fig. 1A. This device is a modification of a general binocular stimulator described elsewhere and permits continuous adjustment of fusional demand without the distortion associated with rotary (Risley) prisms. An optical relay system permits easy placement of a pinhole (P, Fig. 1A) in a plane optically conjugate to the subject's entrance pupil, producing open-loop accommodative stimulation (blur free regardless of the refractive power of the subject's lens).

The subject, positioned in a bite bar, viewed a backlit target with binocular peripheral detail and two monocular central reference lines (Fig. 1B). Except for the stimulus target the visual field was completely dark. Through the use of appropriately positioned Polaroid screens (Fig. 1A), the upper fixed reference line was seen only by one eye, whereas the lower movable line was seen only by the other. The relative displacement of two lines could be determined from a vernier indicator to an estimated visual angle of 0.2 min of arc. Fixation disparity was measured subjectively by briefly illuminating the lower line and applying the methods of limits described by Ogle.

Closed-loop accommodative stimulation was adjusted to be close to the subject's tonic accommodative response (around 0.5 diopter). Fusional
Measurements requiring high stimulus demand were intermixed with those of low stimulus demand to reduce the adaptation known to occur with sustained forced vergence. Additionally, a "recovery" period of at least 5 min was allowed between each measurement. After completing a series of measurements with closed-loop accommodation, the procedure was repeated with accommodation open-loop. Both experimental sequences were repeated in reverse order on another day to ensure generality of the results.

Four subjects between the ages of 18 and 35 were tested. All subjects had normal refraction (after correction) and good binocular vision.

Results. Fixation disparities measured in four subjects with accommodation open-loop (dashed lines) and closed-loop (dotted lines) are shown plotted as functions of vergence stimulation in Fig. 2. The results of Fig. 2 showed that fixation disparity associated with strong fusional effort was significantly reduced when accommodation is open-loop. In particular, the increase in fixation disparity with increased vergence stimulation was reduced for all subjects when accommodative interactions were eliminated. Also, in most subjects the functional relationship between fixation disparity and fusional demand was more nearly linear when accommodation was open-loop.

Discussion The results of Fig. 2 show that a substantial percentage of fixation disparity is due to accommodative interactions, particularly at higher fusional demands. Specifically, at least half the fixation disparity measured at forced convergences of 30 prism diopters or more is eliminated when accommodation is open-loop. Although the strong influence of the accommodation system on vergence is clearly demonstrated, the mechanism mediating this interaction is speculative. It is likely that accommodative convergence is modified, just as the accommodative response itself is different, when the accommodation system is open-loop. The influence of accommodative convergence on fixation disparity under closed-loop accommodation is well established; thus the difference in fixation disparity with accommodation open- and closed-loop is probably due to modification of accommodative convergence.

Regardless of the specific mechanism involved, an important implication of our results is that fixation disparity features are influenced by both accommodative and fusional vergence components. Thus an unusual fixation disparity curve could be due to anomalies in either system. Further, by including accommodative influences, fixation disparity measurements are subject to modification by a variety of accommodative processes. For
Fig. 2. Fixation disparity as a function of fusional vergence stimulus for four subjects. The dashed lines were obtained with accommodation open-loop, whereas the dotted lines were obtained in the traditional manner. The brackets indicate the range of values obtained at each vergence position; hence they represent the maximum uncertainty of each measurement.

example, the size of the accommodative dead space (or depth of focus) should modify, if only slightly, the fixation disparity manifested during overconvergence. Similarly we expect lens responsiveness to influence fixation disparity curves. Hence, a severe presbyope should show less fixation disparity increase with forced vergence than a nonpresbyope, other factors being the same.

Analyzing the functional relationship between fixation disparity and forced vergence, Ogle et al. categorized the variation found between different subjects. The extensive intersubject variation found is consistent with the fact that fixation disparity is influenced by both accommodative and fusional vergence systems. By similar reasoning we would expect fixation disparity curves obtained with open-loop accommodation to show less intersubject variation. Comparing the four open-loop accommodation curves in Fig. 2 (dashed lines), the basic similarity is evident. However, these subjects also show similar traditional fixation disparity curves, and the data set is too small for generalization. Current experiments are directed at associating various features of fixation disparity curves with specific accommodative or fusional vergence mechanisms.

Summary. Motor control of the visual near response is achieved through the mutual interaction of blur-driven and disparity-driven components. This "synkinesis" implies that measurements made
on isolated accommodative or vergence systems will not fully describe their behavior when combined. Similarly, binocular measurements made on one motor response such as fixation disparity may be affected by processes in both systems. However, it is possible to eliminate accommodative influence during binocular fixation by opening the accommodative feedback loop and obtaining a measure of fixation disparity related to fusional vergence mechanisms alone.

Results on four subjects show that at high levels of overconvergence at least half the fixation disparity is attributable to accommodative interaction, since this disparity is eliminated when the accommodation system is open-loop. Thus, in analyzing fixation disparity measurements, particularly their relationship to the vergence stimulus, both accommodative and fusional vergence processes must be considered. Similarly, the extensive intersubject variation seen in fixation disparity measurements is consistent with the fact that fixation disparity response curves are shaped by the combined influences of the two systems.

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Key words: fixation disparity, fusional vergence, accommodative interactions, open-loop accommodation.

REFERENCES

Response of the vestibulo-ocular reflex to differing programs of acceleration. SIDNEY BLAIR AND MARY GAVIN.

The vestibulo-ocular reflex of normal monkeys was tested by a modified Bärényi spinning test (B-test) and by sinusoidal rotation. The two tests gave concordant estimates of the time constant and corner frequency. Deviation from concordance was caused largely by modification of the reflex during the testing procedures. As a means of estimating both time constant and corner frequency in the vestibulo-ocular reflex, the B-test is to be preferred to sinusoidal rotation because although both tests provide similar information, the B-test is the more rapidly performed and analyzed and the B-test modifies the reflex less.

One approach to understanding normal and pathological function in the vestibulo-ocular reflex (VOR) is by eliciting eye movement with a program of acceleration of the head: comparison of the acceleration stimulus with the eye movement response defines the signal-processing characteristics of the reflex. Different programs of acceleration may highlight different features of the VOR, but in the last analysis the results obtained by all programs should be concordant. The choice of program of acceleration used for medical diagnosis or in an experiment may be determined by constraints of available instrumentation, convenience, or the professional background of the investigator. To determine whether one may make immediate comparison between sets of data obtained by different methods, we have matched the results obtained by testing the VOR with low-frequency sinusoidal rotation (s-test) with the results obtained by using a velocity step (B-test, a modified Bärényi test).

Methods. Data were obtained from two monkeys, one Macaca speciosa and one Macaca fascicularis. Each monkey had stainless steel screws implanted in its calvarium to permit immobilization of the head during testing. Horizontal D.C. electro-oculograms were recorded via nonpolarizing electrodes and were calibrated by repeatedly...