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Disparity Vergence: A Proposed Name for a Dominant Component of Binocular Vergence Eye Movements

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Abstract

A proposal to name the dominant aspect of vergence "disparity vergence" is put forward. Support for this proposal is gathered by briefly reviewing the components of vergence: (1) disparity vergence, the visual feedback control system for removing binocular disparity with an appropriate binocular convergence or divergence, (2) accommodative vergence, a synkinesis with accommodative motor control, (3) proximal vergence, and (4) tonic vergence. Sensory fusion is a higher level perceptual process aided by disparity vergence, and historically the term *fusional vergence* called attention to this relationship. However, it now appears to obscure the fact that disparity is the only direct stimulus to vergence.

Key words: disparity vergence, fusional vergence, Maddox classification of convergence, tonic vergence, proximal vergence

PROPOSAL

We propose that *disparity vergence* be the term used to describe the eye movement response when the vergence system acts as a closed loop visual feedback control system to remove disparity error. Vergence eye movements have been of interest to researchers in eye movement control and physiology and to clinicians dealing with disorders of human eye movements for over a century. Indeed, it is this long period of study that has produced the variety of ancient and confusing names that in many ways incorrectly characterize the physiology and control of vergence eye movements.[1, 2]

DISPARITY VERGENCE

When a disparity, an equal and opposite binocular fixation error, is introduced, as by a target moving along the midline, or cyclopean axis, a large disjunctive vergence movement results. This vergence has in the past been termed a fusional vergence movement, although (sensory) fusion is clearly

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This paper is an outgrowth of comments made by Dr. Stark during the discussion on December 11, 1978 at the Symposium on Basic and Clinical Aspects of Vergence Eye Movements hosted by the Section on Visual Science at the Annual Meeting of the American Academy of optometry in Boston, Massachusetts.

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not a stimulus to vergence. Rather, sensory fusion is a high-order process that indirectly depends on prior removal of disparity error by the disparity vergence system. The precision with which disparity vergence removes this disparity error is impressive. The residual amount of disparity is generally less than the 6-min diam of Panum's area as established by the eye movement recordings of Riggs and Niehl,[3] by deduction from the fixation disparity studies of Martens and Ogle,[4] and by the open-loop vergence eye movement experiments of Fender and Julesz[5] on the plasticity of Panum's area. *Motor fusion* has also been used as an alternate name for our proposed term of *disparity vergence* but clearly connotes a confused relation to the sensory fusion process.

Disparity is a binocular stimulus that is quite robust to monocular differences in target blur, contrast, shape, vertical displacement and vertical disparity, and temporal synchronization.[6, 7] Julesz,[8] in his now classical random-dot-stereogram experiment, has shown that central nervous system processing of disparity is not dependent on prior appreciation of form.

ACCOMMODATIVE VERGENCE

First described in a paradigm experiment by Mueller (1826),[9] accommodative vergence is demonstrated as the large vergence response in the covered eye when a target is moved along the line of sight of the viewing eye. This classical experiment provided the emphasis on the monocular expression of accommodative vergence. This has now been shown to be a binocular response,[10-12] even under the classical conditions of the Mueller experiment. Maddox[2] early suggested that accommodative vergence was primary and disparity vergence secondary in the usual occurrence of vergence eye movements in normal binocular vision. This appears not to be true. Fincham and Walton[13] believed that disparity vergence provided the coarse setting and accommodative vergence the fine setting. Krishnan and Stark[14] suggested that with even moderate disparities the accommodation system would have no effective stimulus (and no visual feedback), that is it would be operating in open-loop mode. Evidence for this comes from Phillips,[15] who showed that the blur stimulus to accommodation[16] must fall on or very near the fovea to be effective and therefore that any sizable disparity makes blur ineffective as a stimulus to accommodation. Contrariwise, disparity is robust to blurring[6, 7] of the retinal image of the target secondary to accommodative error. Thus, the primary or initial vergence response is driven by disparity. Then as the target more closely approaches the fovea, the secondary or later blur stimulus to accommodation becomes effective. The accommodative vergence response will then be (nonlinearly) added to the disparity vergence response. It is important to note that accommodative vergence is a *synkinesis* between these two members of the triad—the accommodation, vergence, and pupillary systems. This synkinesis occurs at a fairly low neurological level in the Jacksonian sense. In the particular instance when vergence is made open loop—for example, by removing disparity by covering one eye—the vergence system reaches a level called the phoria position, the amount of vergence appropriate to the motor state of accommodation.[2, 12, 17, 18] The symmetric vergence effect on accommodation is often called vergence accommodation.[19-21] Both of these are important in clinical conditions and are also of interest to biocontrol engineers studying multi-input and multi-output systems.[22, 23]

PROXIMAL AND TONIC VERGENCE

Other inputs to the vergence system are proximal and tonic vergence, as discussed by many authors, including Maddox.[2] Proximal vergence follows perceived target position and is especially effective when disparity vergence is disabled by making it open loop. For example, while looking with one eye through a microscope, residual vergence may well be strongly influenced by the proximal perception of the microscope slide, even though it may be at optical infinity. Tonic vergence is more or less defined by exclusion—if disparity is not active and the accommodative vergence synkinesis can be accounted for and thus discounted, and proximal vergence minimized—then the remaining bias from other central nervous system structures and subsystems have an influence called tonic vergence. Tonic vergence is known to be influenced by anesthetics and states of consciousness of the central nervous system.

DYNAMICS

The motor or behavioral aspects of vergence are also of interest.[24, 25] Vergence is apparently driven by a quasilinear, almost step change in neural firing that produces movements along the main sequence[26] which are quite similar to glissades, another type of step-envelope-driven eye movement. A number of biocontrol engineers have studied the dynamic aspects of vergence, and interesting phenomena in the system have been defined. The leaky integrator, first shown by Zuber and Stark[27] and then carefully defined by Krishnan and Stark,[28] allows for the return to the phoria position upon application of the cover test. The differential degree of overshoot in convergence vs divergence represents an important asymmetry that has been modeled by Krishnan and Stark.[28] Because of this asymmetry, the main sequence results on vergence have relied on the divergence movement with less preemphasis and overshoot. Long-term adaptation has been studied and may be of importance in clinical conditions.[29, 30] It is of interest to note that the dynamics of vergence are limited only by the central nervous system control signals, since the much faster saccades use the same final common pathway neurons and muscular apparatus.

CLINICAL ASPECTS

Defects of binocular vision such as strabismus and amblyopia are of clinical importance. In these conditions, the absence of disparity vergence is a striking new motor phenomenon, recently demonstrated by Kenyon[31] and Kenyon et al.[32-34] When disparity vergence is absent, much of the eye movement response to targets moving in depth is produced by accommodative vergence which is normally concealed by disparity vergence.[33] Other phenomena occur, such as nonlinear interactions between saccadic eye movements and the ongoing accommodative vergence.[34, 35]

COMMENT

We intend this brief paper to provide an appropriate perspective from which the reader may view and judge our proposal. Disparity vergence is a complete example of a closed loop visual feedback control system with a well-defined binocular stimulus and a carefully studied binocular motor response, be it convergence or divergence. Added to this disparity vergence is the acommodative vergence synkinesis, related to the final aspects of accommodative control. Although disparity vergence is the primary and prominent component of ordinary vergence, accommodative vergence is also coacting and may dominate the response in clinical conditions such as strabismus and amblyopia, when disparity vergence may be absent, or in laboratory conditions such as monocular viewing. Proximal and tonic vergence are rather minor phenomena. Sensory fusion is a higher level perceptual process aided in part by disparity vergence. Perhaps *fusional vergence* has served its role by calling attention to this relation, but it now seems preferable to call disparity vergence "disparity vergence."

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