A Review of Convergence Insufficiency: What Are We Really Accomplishing with Exercises?

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ABSTRACT

Introduction: Orthoptic exercises have been the primary treatment for convergence insufficiency since this condition’s first description in 1855. It is presumed that exercises work by improving fusional convergence. In recent years, research from eye movement laboratories has challenged our theories on the nature and dynamics of convergence, the effect of convergence exercises, and the etiology of primary convergence insufficiency.

Methods: A review of the ophthalmological, optometric, and basic science literature was done to retrieve the most recent research on vergence eye movements and convergence insufficiency.

Results: Convergence appears to be a bi-phasic response to a change in stimulus position in depth. The first phase, which may represent the contribution of proximal convergence, is not under visual feedback, is fast with a short latency, and is triggered by stimuli moving rapidly in depth or by large, sudden changes in fixation. This phase is followed by a slow vergence movement with a slightly longer latency, triggered by small disparity vergence errors. The second phase is under the control of visual feedback, and represents the contributions of fusional and accommodative convergence. Eye movement recordings indicate that the velocity and amplitude of the first phase of convergence are temporarily adaptable with exercises. The second phase does not appear to be amenable to training. Tonic convergence is also trainable.

Conclusion: Convergence exercises are effective in temporarily improving the dynamics of proximal and tonic convergence, but have little effect on fusional or accommodative convergence.

CONVERGENCE INSUFFICIENCY: DEFINITION AND ETIOLOGY

Convergence insufficiency (CI) is an uncommon disorder of ocular motility characterized by an inadequate amount of ocular convergence needed to achieve and maintain comfortable, clear, single binocular vision at near fixation. Exodeviations are found in 1% of the general population.¹
and CI accounts for 11% to 19% of children with an exodeviation. Based on these figures, the prevalence of CI in the general population can be estimated at approximately 0.1% to 0.2%. Govindan and co-workers found an incidence of 64 new cases per year, per 100,000 patients aged 19 years and younger.

CI may be caused by or associated with head trauma, neurodegenerative diseases, ischemia, thyroid ophthalmopathy, myasthenia gravis, toxic agents or medications, infection or inflammation, or decompression sickness. CI is most commonly a primary condition, typically presenting in the young adult population, and presumably caused by an inborn deficiency or acquired imbalance of vergence eye movements that has yet to be identified.

**DIAGNOSTIC CRITERIA**

The most common clinical signs of CI as reported in the literature are a remote near point of convergence (typically beyond 10 cm from the bridge of the nose), and poor convergence amplitudes (a break point ≤ 15Δ, with recovery more than 4Δ from the break point). Other signs reported to be associated with CI include an exodeviation at near fixation ≥10Δ, a low AC/A ratio (≤ 2:1), and poor vergence “facility” (ease with which vergence is generated and the movement completed). Some authors claim that decreased accommodative amplitudes for age and poor accommodative “facility” are also associated with the condition.

Symptoms associated with convergence insufficiency include fatigue, blurred vision at near, intermittent diplopia at near, “eye strain,” tension in and around the eyes, and the sensation of the print moving while reading. Convergence insufficiency is an uncommon cause of headaches, accounting for less than 1% of all headaches presenting to the ophthalmologist. Among published clinical studies, the presence of symptoms is the single most common criterion used to diagnose CI, to monitor progress of the condition, or to determine the success of its treatment.

**TREATMENT OPTIONS**

CI was first described by von Graefe in 1855, who recommended exercises to improve convergence amplitudes. Such exercises continue to be the mainstay of treatment to this day. A wide variety of office-based and home-based orthoptic exercises have been designed to reduce symptoms of CI. It has been hypothesized that exercises work because they improve fusional convergence and/or modify accommodative convergence to allow comfortable near binocular vision. Many patients have found temporary relief with these methods, whether or not the clinical signs or measurements have significantly improved.

However, spontaneous improvement in symptoms has also been reported and one can not ignore the potential for a placebo effect, particularly if the main outcome criterion is improvement in symptoms, as is often the case.

Convergence has been studied in several eye movement laboratories in recent years, in order to more accurately quantify normal and abnormal vergence and accommodation. These studies have discovered new intricacies to normal convergence, and revealed the vergence characteristics that are susceptible to adaptation with exercises.

**DYNAMICS OF NORMAL CONVERGENCE**

As with all types of eye movements, convergence is described and defined in terms of latency, velocity, amplitude, and the stimulus needed to generate the response. Latency is the length of time between the
presentation of the stimulus and the onset of the response. Latency is a function of central nervous system processing time, and is a measure of the efficiency of initiation of the eye movement (reaction time). The mean latency of the vergence response in adults is approximately 160 to 180 msec, compared to approximately 316 msec for children. Though significantly longer in children, latencies approach adult levels by age ten years. Yang and co-workers reported that the improvement with age is the result of attention factors and the visuomotor process alone. Latency is similar under monocular and binocular conditions.

Vergence is considered one of the “slow” eye movements, with pure vergence peak velocity measured at 30–80° per second. Velocity is faster for sudden, large changes in fixation distance, and under binocular conditions. Both velocity and latency are important components of vergence facility.

The amplitude of an eye movement is often described in terms of gain. Gain is a measure of how closely the response matches the change in stimulus. Vergence gain is higher under binocular conditions than under monocular conditions, due to the input of disparity-driven convergence. The maximum degree of disparity that will evoke a vergence response is approximately 4° of arc.

Convergence movements can be divided into two general categories based on function: those that serve to grossly align the eyes in the awake state (tonic vergence), and those that serve to keep the object of regard imaged onto both foveas with changes in object position in depth (proximal, fusional, and accommodative convergence). Tonic vergence represents the baseline, resting level of vergence tone. Tonic vergence can be observed by comparing eye position while asleep with eye position while awake but in the absence of other visual cues.

The latter group of convergence movements can be further subdivided based on the stimulus required to generate a response. Awareness of a near object triggers proximal convergence, binocular image disparity triggers fusional convergence, and retinal image blur triggers accommodative convergence. Each of these subtypes of convergence differs slightly in latency, velocity, and amplitude as well.

Under normal conditions, proximal, fusional, and accommodative convergences rarely function in isolation. Laboratory studies have shown how they coordinate to achieve the normal convergence response to a change in stimulus position in depth. Convergence appears to be a bi-phasic response consisting of a “pulse” followed by a “step”. The vergence pulse initiates the movement and is open-looped, meaning that it is not under the control of visual feedback. This phase is triggered by targets moving rapidly in depth, or by large, sudden changes in fixation distance. The pulse has a shorter latency, and a faster velocity than the step part of the response. In their work on proximal convergence, Wick and Bedell and Schor and co-workers concluded that proximal vergence most likely initiates the vergence response to changes in fixation from distant to near targets. Proximal convergence has been found to account for 70–80% of the vergence response, with its contribution increasing with the onset of presbyopia. In addition, the dynamics of proximal convergence (velocity, latency) mimic those found in the initial phase of the convergence response. It is possible then that the initial, open-loop phase of the convergence response is the role of proximal convergence.

The step is closed-loop, modulated by visual feedback, and is designed to complete and refine the vergence response. It is triggered by targets moving slowly in depth, or by small errors in image disparity, and likely represents the contributions
of fusional convergence (primarily), and accommodative convergence (minimally).\textsuperscript{40} The step latency is longer by approximately 60 msec (for fusional convergence) or more (for accommodative convergence),\textsuperscript{46} and the velocity is slower than for the vergence pulse.\textsuperscript{41} Figure 1 illustrates how the types of convergence may interact to achieve a normal convergence response.

**ANATOMY OF THE VERGENCE SIGNAL**

Anatomical evidence of a two-step convergence response has been found in animal studies. It has long been known that the midbrain reticular formation contains convergence cells that fire just before and during fusional or accommodative convergence.\textsuperscript{48–51} Their firing activity correlates with vergence velocity and amplitude. More recently, the role of specific areas in the pons has been clarified with respect to vergence. Omnipause neurons located in the nucleus raphe interpositus in the pons slow firing activity just before a fast vergence movement (vergence pulse),\textsuperscript{52–53} while cells in the nucleus reticularis tegmenti pontis are active during slow vergence (vergence step).\textsuperscript{54} These two groups of pontine nuclei project to different areas of the cerebellum.\textsuperscript{53–54} There is also evidence of an internal representation of viewing distance, independent of cues from accommodation caused by retinal image blur, that may be the anatomic substrate of the proximal component of the vergence response.\textsuperscript{53}

**CHARACTERISTICS OF CONVERGENCE SUSCEPTIBLE TO ADAPTATION**

Using a scleral search coil technique, Van Leeuwen and co-authors proved that orthoptic training improved overall vergence amplitude, accuracy, and velocity in patients with convergence insufficiency.\textsuperscript{57} The question is: which part(s) of the convergence response improved with orthoptics? It has often been presumed that orthoptic therapy is effective in treating convergence insufficiency because it improves fusional convergence ampli-
However, this assumption does not hold up in the face of results of recent laboratory studies.

Several laboratories have reported that the velocity and amplitude of the initial, open-loop response is trainable with repetition, though the effect is not lasting.\textsuperscript{38,43,46} Latency appears to be consistent and not trainable in normal subjects.\textsuperscript{43} In contrast, the velocity and amplitude of the second phase of the convergence response does not appear to adapt with training.\textsuperscript{46,58} This suggests that it is not disparity or accommodative convergence that improves with orthoptic exercises, as these types of convergence run on a closed-loop feedback system. Figure 2 illustrates the effect of training on the convergence response to a change in stimulus location in depth that would require a convergence response of 8° to maintain the image on both foveae. The fusional convergence response is unchanged in latency, velocity, or amplitude. The proximal response, however, increases in amplitude and velocity such that the training effect observed is an overshoot of the target position.

Tonic vergence also appears to be amenable to training. Several researchers have shown that sustained convergence effort over a period of only minutes will temporarily shift tonic vergence inward. This effect has been observed with sustained near work\textsuperscript{46,58} and with prism adaptation using base-out prism.\textsuperscript{40,59} Tonic vergence adaptation is demonstrable in any age group, though the magnitude of the response declines with age at a rate of 0.6% per year.\textsuperscript{60}

WHAT DOES THIS MEAN FOR THE MANAGEMENT OF CONVERGENCE INSUFFICIENCY?

Interpretation of the data suggests that the most effective exercises for convergence insufficiency would use either sustained convergence effort to improve tonic con-
vergence, or repetitive, rapid, and large amplitude changes in stimulus position in depth to improve proximal convergence. Fortunately, many of the exercises already in common use and shown to be effective already employ such techniques. Examples might include reading with base-out prism, “jump vergence” exercises using base-out prism, or vergence facility exercises requiring rapid switches in fixation from distance to near. Our current understanding of CI suggests that it cannot be cured with exercises. Because the training effect is temporary, lasting relief of symptoms would only be achieved with daily exercises over an indefinite period of time.

The results of these recent laboratory studies have also raised some interesting questions regarding the etiology, diagnosis, and management of convergence insufficiency. Is it possible that a defect in a specific subtype of convergence is responsible for primary CI? Is there more than one type of primary CI? And, if so, can we devise clinical tests to distinguish between the types, as well as create effective treatments targeting the specific deficiency? Finally, a well-designed, prospective study is needed to determine the long-term efficacy of orthoptic exercises on tonic and proximal convergence.

REFERENCES


Key words: convergence insufficiency, convergence amplitudes, proximal convergence, fusional convergence, accommodative convergence