Why Do Simple, Inexpensive Convergence Training Exercises Continue to Perform as Well as More Expensive Computer-Based Home Therapies? Uncoupling Your Expectations

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ABSTRACT

Convergence insufficiency is a common disorder of binocular vision affecting older children, teenagers, and adults. Patients with convergence insufficiency report symptoms of reading difficulty, eyestrain or discomfort associated with near activities, blurred vision, and headache. Affected individuals are unable to maintain fusional convergence during near activities. The diagnosis is made based on a remote near point of convergence and decreased positive fusional vergence amplitudes at near fixation. Treatment of convergence insufficiency includes orthoptic exercises designed to build convergence amplitudes, spectacles to address presbyopia, computer orthoptics that simulate the vergence demands addressed by traditional orthoptic exercises, and office and home-based vision therapy.

Researchers have sought to compare the advantages of more costly, contemporary treatments to inexpensive, simple home therapies with widely varying results. No consensus exists as to superiority of one treatment over the next in terms of reduction of symptoms, or improved objective clinical measures, regardless of cost. Simple, orthoptic convergence training exercises for use at home continue to perform well in patients with symptomatic convergence insufficiency. Three cases treated successfully with simple jump vergence exercises that preserve the fundamental neuro-sensory relationship between convergence and accommodation are presented to illustrate how compliance and adequate treatment application of inexpensive home therapies continues to improve objective measurement of convergence amplitudes and near point of convergence, and subjective symptoms. A review of the visual sciences literature reveals how asthenopic symptoms have been shown to develop in healthy volunteers in laboratory conditions after prolonged viewing of simulated 3-dimensional images on a flat-panel computer monitor like those used in popular computer vergence training programs.

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INTRODUCTION

Convergence insufficiency (CI) is a common disorder of binocular vision, characterised by inability of the vergence system to maintain prolonged ocular alignment and accurate focus during near activities, particularly with reading.[1,2] Prevalence has been reported to be 5.3% in children 6-18 years old, 6% in children 8-12 years old, 4.2% in children 9-12 years old, and 7.7% in college students.[3-5] In young and aging adults, it may be isolated and idiopathic or associated with concussion or neurologic disease,[6-12] or it can develop in early middle age, when first-time bifocal use can lead to decreased accommodative convergence.[13] The condition is defined by symptoms which include difficulty with near work, blurred near vision, asthenopia, or diplopia, and objective clinical measures of exophoria or exotropia greater at near fixation,[14] recession of the near point of convergence (NPC) and decreased fusional convergence amplitudes, also known as positive fusional vergence (PFV).[1]

Burian defined exotropic patients in whom the near deviation exceeded the distance deviation by 10 prism diopters (PD) as having CI.[15] But what is normal in terms of NPC or PFV amplitudes? In 1983 Shippman and coworkers[16] reported an average NPC breakpoint of 5 cm (range 1 to 15 cm) in a group of 46 adults with normal binocular vision. The type of target for this testing was not reported. Scheiman and colleagues[17] replicated this result two decades later, reporting 5 cm for the NPC break and 7 cm for the NPC recovery measured using standard pushup technique with a Bernell accommodative rule (Bernell Company, Mishawaka, IN, USA) placed just above the nose at the brow between the two eyes. Normal PFVs vary based on age. In 1927 Behrens and coworkers reported average fusional convergence amplitudes in 218 adult males as 14.0 PD base-out for distance breakpoint, and 38.0 PD base-out breakpoint for near.[18] Twenty years later, Mellick and coworkers[19] identified mean values and standard errors for PFV in 561 healthy volunteers across all age groups and with normal neuromuscular systems, reporting 18.0 ± 0.26 PD base-out for near fixation, and 26.0 ± 0.4 PD base-out for distance fixation. Lower values for PFV were obtained by Saladin[20] in 1978. More recently Razavi and coworkers[21] studied 111 adults with a mean age of 25.6 years, 11.0 ± 4.5 PD base-out for near fixation, and 15.5 ± 6.0PD base-out for distance fixation. Of interest, the investigators found no correlation between the amount of measured exophoria and values of PFV at distance or near.

Treatment for CI is initially non-surgical and of varying expense. These treatments include less expensive orthoptic home therapies which include smooth convergence exercises, often referred to as pencil pushups or pen convergence, jump vergence exercises such as the Brock string and near point dot cards, and computer vergence exercises. Moderately expensive treatments include spectacles with or without base-in prism to correct diplopia and relax the vergence effort, refractive error or presbyopia. Weekly office-based vision therapy programs come at a cost premium.

Advantages and disadvantages of home-based treatment

Advantages to simple home-based therapies like pencil pushups or jump vergence exercises are simplicity, and cost. Contemplating cost, it is important to consider not just direct cost of the treatment sessions, but also indirect costs associated with frequent office visits, missed work, and missed school days. Proper technique is important, such as using a target that stimulates accommodation during pencil pushups. Non-accommodative targets, for example the featureless eraser on a pencil, may fail to stimulate accommodative convergence. Adequate time, 15-30 minutes spent per day doing the exercises and enough repetitions is also important,[22] and will contribute to successful treatment outcomes.[22,23] One important disadvantage to these simple treatments is that they can be uninteresting and fail to engage the user for extended treatment periods, especially a younger patient. Furthermore, home-based therapies which rely on simultaneous perception or diplopia recognition without suppression of the diplopic image from a dissociated exodeviation may fail by design. Stereograms and computer orthoptic programs like the popular CVS (Computerized Vergence System) program (Computer Orthoptics, Gold Canyon, AZ) rely on bifoveal fixation for correct responses and performance of the exercise.[24]

It is interesting to consider the clinical data from treatment studies comparing advantages of these simple home-based therapies to potentially more engaging and technologically driven treatments such as computer orthoptics. These studies typically analyse and compare objective measures such as NPC and PFV, or subjective data obtained from validated symptom survey instruments. Review of the literature has shown that results vary, with no consensus as to superiority of one treatment over the next, regardless of cost. Simple, inexpensive home convergence training exercises, compared to home computer vergence exercises, continue to perform well by these measures, even in comparison to office-based vision therapy.

Scheiman and coworkers[26] compared efficacy of office-based vision therapy (VT), which included treatment with computer orthoptics to pencil pushup testing (PPT), in 46 adults aged 19 to 30 years with symptomatic convergence insufficiency. The investigators concluded that intensive office-based VT was more effective than less intensive PPT for improvement of NPC and PFV amplitudes. Despite a study design flaw that introduced a treatment dosing bias favouring the more rigorous, in-office vision therapy, there was a statistically significant measured decrease in symptoms in both groups. Momeni-Moghaddam and colleagues[27] also compared PPT with weekly, office-based VT in 60 university students. In their study, VT treatments did not include computer orthoptics, including only combinations of traditional orthoptic exercises, including stereograms, a Brock string, prism bars and jump vergence exercises. The investigators found that NPC, amplitude of near phoria, and PFV amplitude results did not statistically differ between the two treatment groups. More recently, the Pediatric Eye Disease Investigator Group (PEDIG) evaluated improvement in symptoms comparing home-based computer orthoptics, with home-based PPT in children aged 9 to less than 18 years with symptomatic convergence insufficiency.[28] The study was underpowered due to insufficient recruitment. Nonetheless, the proportions of enrolled participants reaching a successful outcome, defined by predetermined composite criteria from a convergence insufficiency symptom survey, was the same for both treatment groups at the 12-week outcome visit, 23% or 16 of 69 participants in the home-based computer orthoptics group (95% CI: 14-35%) and 22% or 15 of 69 participants (95% CI: 13-33%) in the PPT group. Curiously, 5 of 31 participants (16%, 95% CI: 5-34%) in a sham computer vergence placebo group were classified as having a successful outcome. Compliance, assessed by unmasked site personnel estimates of the frequency and duration of completed therapy per session from 0 to 6 weeks and 6 to 12 weeks based on electronic data from the computer vergence programs and interviews with the participant and/or a parent at each visit, was found to be 68% for the computer vergence group, 49% for the PPT group, and 52% for the placebo group.

Several recent studies have reported home-based computer vergence training does improve objective findings and reduce symptoms.[29,30] Despite the excellent compliance with computer vergence training reported by the PEDIG trial, compliance can be an issue with computer orthoptics. For example, Cochrane Collaboration published a 2011 review of nonsurgical treatment for convergence insufficiency, reporting compliance with pencil pushups at 84.9%, and computer orthoptics at 67.3%.[31] These findings raise the research question here, why do simple home vergence therapies like pencil pushup exercises, Brock strings and stereograms, continue to perform comparably in terms of both objective clinical measures and subjective symptom surveys, to sophisticated computer vergence exercises?

The visual sciences literature

In free space viewing conditions, the human brain generates a 3-D picture essentially by having two eyes spaced a short distance apart. Each eye captures a slightly different perspective of what is in front of it. In the eleventh century, Ibn al-Haytham first described a special set of points in free space where single vision occurs.[32] Franciscus Aguilonius coined the term horopter 500 years later to describe the locus of all points lying on a horizontal line passing through the point of fixation that resulted in a single perceived image, while objects in free space slightly in front of or slightly behind this line resulted in double images.[33] Panum further described this area of fixation in the visual space just proximal to what was subsequently referred to as the empirical horopter, where images seen by each eye fall on slightly disparate retinal points, as the narrow area where stereopsis exits,[33] now known by his name. By fusing these two disparate images, the human brain perceives a single image with real depth, or stereopsis, the highest form of binocular vision. Retinal blur and the accommodation required to clear the image varies continuously with changes in scene depth.[34] Vergence distance, driven by disjunctive, binocular eye movements and focal distance to the target, driven by fixation with a monocular change in accommodation, are the same. Under these circumstances, vergence distance and focal distance are coupled (Figure 1).[35] Accommodative changes evoke vergence changes, and vergence changes evoke accommodation changes, which is the near reflex as described by Fincham seven decades ago.[36] Advantages of coupled vergence distance and focal distance are increased speed of accommodation and vergence, as well as reduced fusion times required to discern the cyclopean stimulus in a random-dot stereogram.[35] Coupling enhances human high-grade sensorimotor fusion in all fixation ranges.

Three-dimensional displays work by generating two separate versions of the same depicted image, in several different ways. These include anaglyphic images (one red image and one green or blue image, perceived separately by each eye using glasses, similar to those used with the Worth 4-dot test), polarised images (each perceived separately using polarised glasses, such as those used with the Titmus or Randot stereo tests), and active shutter glasses that work by opening and closing the left and right lenses in an alternating manner and at very high speed.[37] In each method, one image is seen by the left eye, and one by the right eye. To create the proper illusion of real depth, the left eye's image must not be seen by the right eye, nor must the right eye's image be seen by the left eye. Lastly, lenticular displays work without additional special glasses, using a plastic screen overlay that sends slightly different pictures to each eye so that a single fused three-dimensional image is perceived, but only when seated in a specified location in front of the screen. But in viewing a 3-D display, unlike viewing a real object in free space, vergence distance (to the simulated virtual image behind or in front of the screen) is no longer equivalent to focal distance

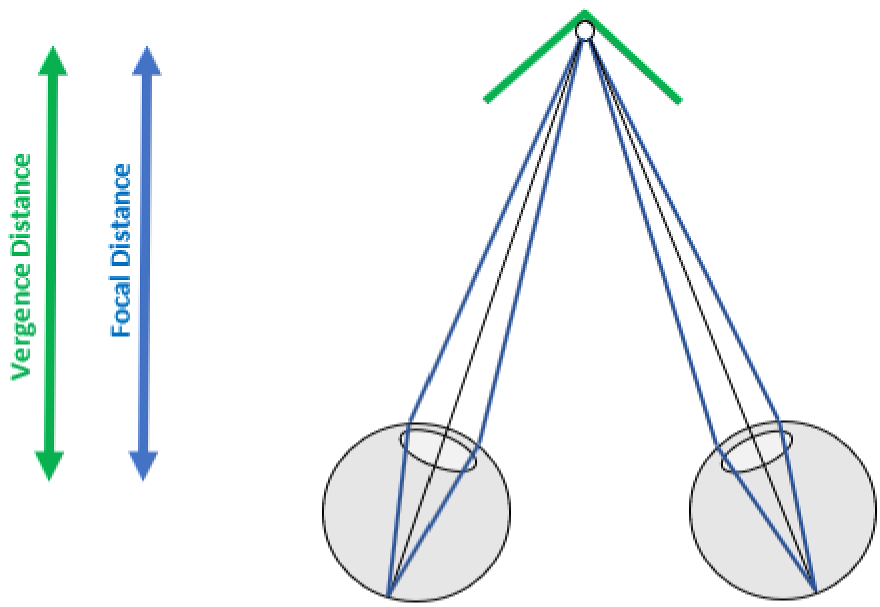

Figure 1. Neural coupling: In real-world viewing, vergence distance (driven by disjunctive, binocular eye movements) and focal distance to the target (driven by fixation with a monocular change in accommodation) are the same (Redrawn by the author, adapted from Hoffman et al.[35]).

to the target (the surface of the screen). Vergence distance and focal distance are then said to be uncoupled (Figure 2).[35]

In 2002, several years after 3-D monitors and televisions became commercially available, researchers began looking into public concern about potential adverse effects associated with extended viewing of screen-generated stereo imagery, with specific reports of increased viewer fatigue and discomfort with prolonged use of computer displays simulating a 3-D viewing experience.[35,38-41] Hoffman and coworkers[35] developed a novel volumetric 3-D display capable of presenting coupled or uncoupled focusing cues to test subjects at only one base viewing distance of 39 cm or 2.5 dioptres in the laboratory. The researchers found that when focusing cues were coupled as in any real-world viewing experience, the time required for healthy volunteers to identify a stereoscopic image was reduced, stereoacuity accuracy in a time-limited task improved, distortions in depth perception were reduced, and test subjects reported less viewer fatigue and discomfort. The authors showed that under laboratory conditions, asthenopia developed due to the uncoupling of vergence and accommodation required with viewing computer-simulated 3D displays.[35] The normal correlation between focal (accommodative) distance and vergence distance were disrupted, with focal distance fixed on one static display surface as vergence distance continued to vary depending on where on the computer or TV screen the subject was looking. In other words, a conflict between vergence demand and accommodation demand per se causes discomfort and fatigue. Shibata and colleagues[42] expanded on this work, developing a 3-D display that could manipulate vergence distance and focal distance independently. They presented masked test subjects with visual tasks at multiple viewing distances in different sessions in order to determine which distances caused the greatest symptoms, evaluated with a 5-point Likert symptom survey tool. In three experiments, the authors examined i) the effect of viewing distance on discomfort and fatigue, ii) the effect of vergence-accommodation conflict on discomfort and fatigue, and iii) the predictive qualities of measured phoria and zone of clear single binocular vision. They found that vergence-accommodation conflicts are a cause of visual discomfort associated with viewing stereo displays. In the first experiment, their data predicted that at a given range of disparities in the displayed image, subjects became more comfortable as they moved farther from the display screen. In the second experiment, data predicted that minifying content and viewing at close distance, for example viewing simulated 3-D content on a smart phone or electronic tablet device, yielded slightly less visual discomfort, while magnifying content and viewing it on the large surface of a cinema screen at a far distance should yield slightly more discomfort, largely due to a subject's inability to diverge his or her eyes comfortably for distance. In the third experiment, measured phoria and fluctuation of vision outside of an established zone of comfort were found to be predictive of development of asthenopia. As subjects attempt to resolve these conflicts, symptoms of eye strain, headache, and visual fatigue were reported. The authors assumed that visual discomfort associated with viewing 3-D displays is caused by motor and not sensory aspects of the vergence. Accommodation conflict was not directly tested and remains a topic for future research.

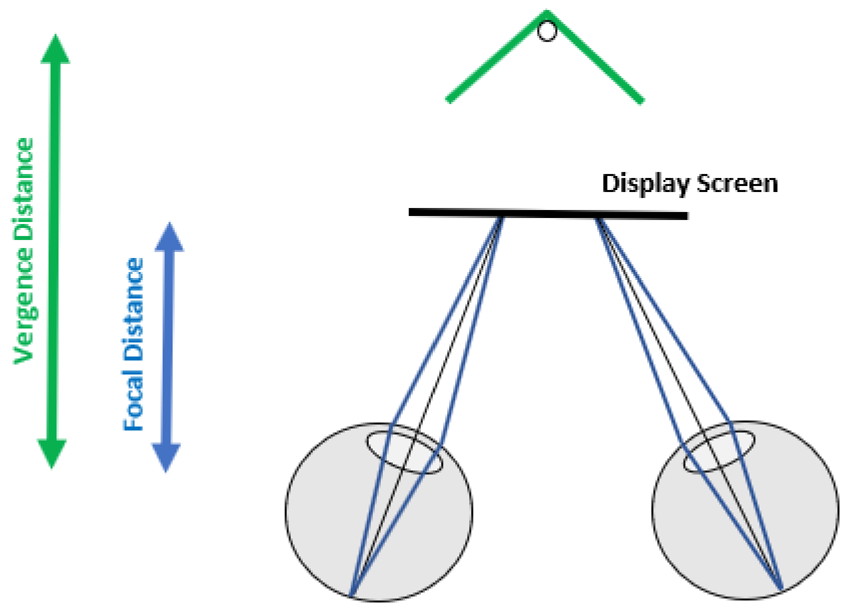

Figure 2. Neural uncoupling: Vergence distance, which varies depending on the distance being simulated by the content on the display screen, is no longer the same as focal distance to the target (the screen surface) (Redrawn by the author, adapted from Hoffman et al.[35]).

CASE REPORTS

Symptoms of patients with CI do not always correlate well with objective measures.[29,43] For the purposes of this report, the reader should assume normal values for positive fusional vergence amplitudes to be breakpoint of 20 PD base-out prism at distance fixation, and breakpoint 40 PD base-out prism at near fixation, approximating an average of the values discussed earlier in this report from Behrens,[18] in 1927 and Mellick[19] in 1929, which reflect the author's clinical practice. Measured values for underlying heterophoria were added to breakpoint and recovery values obtained with the base-out prism bar to obtain the final values for PFV amplitudes reported for each case. NPC was measured using a Royal Air Force (RAF) Rule (Sussex Vision, UK), and the vertical line with a central dot for convergence fixation target (Figure 3). The rule is placed on the cheeks of the face, over the nose. The fixation cube is then advanced along the 50 cm rail of the RAF rule in the primary reading position, from a remote position greater than 20 cm toward the patient until horizontal diplopia of the fine vertical fixation line and central dot is reported. The author has found this vertically oriented target line allows precise and accurate detection of diplopia from the small-angle horizontal strabismus the moment fixation is lost. For patients without CI or any other abnormalities of vergence, normal NPC is assumed to be 2-4 cm, the point on the RAF rule where the 50 cm rule meets the cheek rest (Figure 4). This is closer than previously published normative values described earlier in this report, and admittedly the fixation target will be blurred for most patients, but in the author's experience, normal patients can easily converge to this distance. Distance fixation is fixation on an accommodative target at the end of a 6-metre exam lane. Near fixation is fixation on an accommodative target at 33 cm. Results of the Worth 4-dot are described as i) sensory fusion (4 dots), ii) diplopic response (5 dots simultaneously), or iii) suppression (2 green dots or 3 red dots at either distance or near fixation). Table 1 summarises the relevant clinical data and measurements obtained at the initial orthoptic evaluation for each patient. Table 2 summarises the relevant clinical data, measurements, and treatment compliance obtained at the final orthoptic evaluation. There was no masking of the examiner.

Case 1

A 58 year-old right-handed Caucasian female was referred by her general ophthalmologist for symptoms of reading difficulty. For almost a year, she reported having to close one eye while reading to avoid 'confusing' text images. She denied diplopia. Her past ocular history was significant for early-childhood amblyopia for which she did some patching between the ages of 5 and 10 years, and essential blepharospasm for which she had received Botox injections every 4 to 5 months for over a decade, but no injections in the days or weeks prior to the initial orthoptic examination. She had worn spectacles to address her myopic astigmatism since grade school, and in recent years multifocal spectacles were used to address her presbyopia. Her past medical history was significant for schizophrenia, gastroesophageal reflux disease and migraine without auras, all treated with medication.

Best-corrected Snellen distance visual acuity was 6/6 in each eye and she read Jaeger 1 font at 36 cm in each eye. There was sensory fusion with the Worth 4-dot test at distance and near fixation, and 140 arc-seconds (4/9 circles) of Titmus near stereo

Figure 3. RAF (Royal Air Force) Rule and inset detail of near target block with vertical line and central dot for convergence fixation used by the author to accurately quantify near point of convergence (Modified image from Sussex International, UK, used with permission).

Figure 4. Retouched detail of RAF rule extending the centimetre rule scale toward the cheek guard placed over the patient's nose to demonstrate the 2 cm 'normal' value for NPC used by the author.

(Stereo Optical Company, Chicago, USA). She was orthophoric in all positions of gaze in the distance, with a 6 PD exophoria measured at near. NPC was 2 cm with effort, but PFV testing revealed a breakpoint of 6 PD base-out for distance and 12 PD base-out for near (Table 1). The diagnosis of convergence insufficiency was made based on the reduced PFV amplitude and reported symptoms.

Treatment was initiated with near point dot card simple jump-vergence home exercises, essentially a paper version of the Brock string (Figure 5), the goal being to fuse the most proximal dot on the card, located approximately 2 cm away from her eyes with the end of the card placed at the tip of her nose, while maintaining perception of the desired, V-patterned physiological diplopia of the line of beads regressing away from her nose. The author uses a custom 12-dot version of this card with an upper case letter A labelling the furthest dot from the patient, an upper case letter X labelling the 7th, middle dot on the line approaching the patient, and an upper case V labelling the most proximal dot to the patient, to serve as reminders as to what pattern of physiological diplopia the patient should perceive as they converge correctly and accurately on the labelled points along the line connecting the dots on the card. This activity was to be performed two or three times a day for 10 minutes per session, with a scheduled return visit in 8 weeks to re-evaluate signs and symptoms.

The patient returned 6 weeks later reporting excellent compliance having done the exercises five or six times per day for 10 minutes each session. There was sensory fusion with the Worth 4-dot at distance and near fixation, and 100 arc-seconds (5/9 circles) of Titmus near stereo. She was orthophoric in all positions of gaze in the distance, and this time she was orthophoric at near fixation as well, fixating through the near add segments. NPC was still 2 cm with effort, but PFV testing had increased to breakpoint 18 PD base-out, recovery point 14 PD base-out for distance and no breakpoint with up to 40 PD base-out at near fixation (Table 2). No spectacle prism was required or recommended.

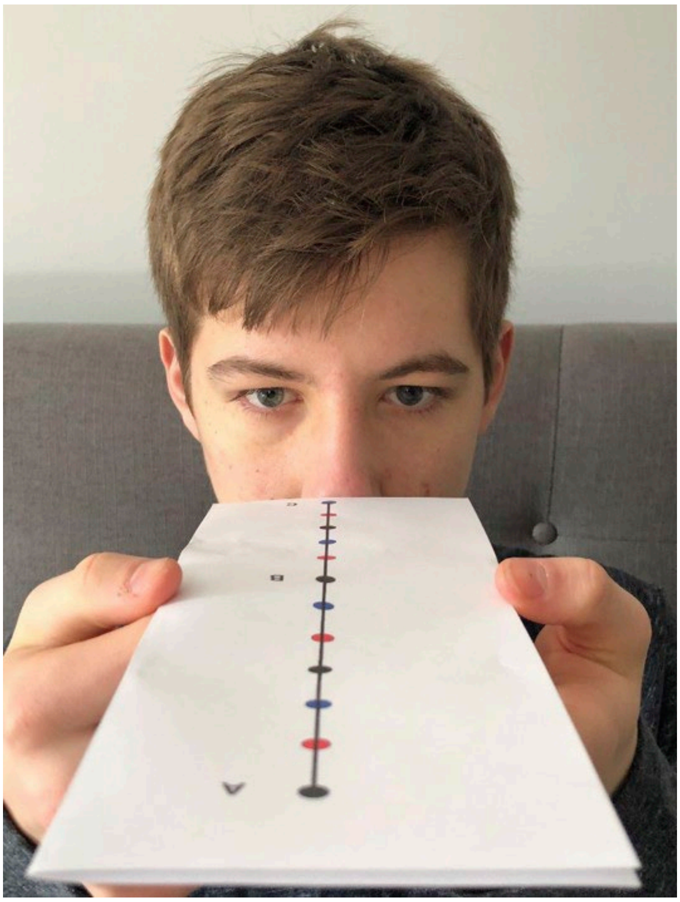

Figure 5. Teen male demonstrating an example of simple home jump convergence exercises with a near point dot card.

Case 2

An emmetropic 11 year-old girl was seen with symptomatic CI. Her symptoms sometimes developed in the mornings on school days, initially consisting of blurred vision followed by a low-grade headache. Her mother denied any maternal family history of migraine headache and there was no reported diplopia. There were no other reported neurological signs or symptoms.

Uncorrected Snellen visual acuity was 6/6 in each eye. Near acuity was not recorded. There was sensory fusion of the Worth 4-dot at distance and near fixation, and 25 arc-seconds of Titmus near stereo acuity. She was orthophoric in all positions of gaze in the distance, with a 2 PD exophoria measured at near. NPC was 6 cm with effort. PFV testing revealed a breakpoint of 6 PD base-out at distance fixation and 12 PD base-out at near fixation. Recovery points for both fixation ranges were not recorded (Table 1). The diagnosis of convergence insufficiency was made based on the reduced PFV amplitudes, slightly remote NPC and reported symptoms.

The treatment plan was to start with the near point dot card jump-vergence exercise described above, three 10-minute sessions per day, with the short-term goal being to appreciate the desired physiological diplopia responses described in Case 1, with the card held at the end of her nose.

The patient returned 10 months later for re-evaluation for recurrent symptoms associated with near activities, which developed after having stopped the orthoptic exercises because she lost the card. Compliance with the prescribed paper Brock string exercises was good initially after the first exam and her headache symptoms disappeared completely.

On return evaluation there was sensory fusion of the Worth 4-dot at distance and near fixation, with 40 arc-seconds (9/9 circles) of Titmus near stereo. She remained orthophoric at distance fixation and there was 2 PD of exophoria measured at near fixation. NPC had improved to 4 cm, and most impressively PFV had improved to 16 PD base-out breakpoint, 10 PD base-out recovery point at distance fixation and 25 PD base-out breakpoint, 10 PD base-out recovery point at near fixation. In summary, this patient experienced a reduction of symptoms, a two-fold improvement in PFV amplitudes at both distance at near and a 50% improvement in measured NPC since she began doing the simple jump-vergence home therapies, even after having discontinued the treatment for a number of weeks prior to re-evaluation (Table 2).

Case 3

A 71 year-old adult female was evaluated for an 8-month history of symptomatic strabismus and vertigo following a brainstem stroke causing a left hemiparesis. Her chief complaint was asthenopia with diplopia at near fixation, with a suspicion for convergence insufficiency trending toward spontaneous improvement over time up until a few months before the initial orthoptic examination. She had been doing smooth vergence pencil pushups to improve tracking, recommended by her neurologist. The patient denied a childhood history of strabismus or amblyopia.

Best-corrected Snellen linear visual acuity was 6/6 in the right eye and 6/15 in the left, improved to 6/6 with manifest refraction. Near acuity was Jaeger 4 on the right at 33 cm, improved to Jaeger 1 at the same test distance with manifest refraction, and Jaeger 1 on the left at 33 cm. There was central sensory fusion of the Worth 4-dot at near fixation, a diplopic response at distance fixation, and 40 arc-seconds (9/9 circles) of Titmus near stereo. She was orthophoric in all positions of gaze at distance fixation, but there was an intermittent exotropia (IXT) of 10 PD at near. NPC was very remote at 18 cm. PFV testing revealed a breakpoint of 16 PD base-out, recovery point 14 PD base-out at distance fixation, and breakpoint of 20 PD base-out, recovery point 15 PD base-out at near fixation. Diagnosis was symptomatic CI, with remote NPC and decreased fusional

Table 1. Initial orthoptic examination data

Case	Sex	Age (years)	NPC	Proximal fusion vergence Break/recovery	Near stereo	Motility at distance	Motility at near	Treatment prescribed	Acuity RE	Acuity LE
1	F	58	2 cm	6Δ base-out (F) 12Δ base-out (N)	140 arc-secs 4/9 circles	Orthophoria	X 6Δ	Near point dot card	6/6	6/6
2	F	11	6 cm	6Δ base-out (F) 12Δ base-out (N)	25 arc-secs 9/9 circles	Orthophoria	X 2Δ	Near point dot card	6/6	6/6
3	F	71	18 cm	16/14Δ base-out (F) 20/14Δ base-out (N)	40 arc-secs 9/9 circles	Orthophoria	X(T) 10Δ	Near point dot card	6/6	6/15

convergence amplitudes at distance and near (Table 1), but in the context of anisometropic refractive error, -1.25 dioptre spherical equivalent in the left eye. With best-corrected near acuity in trial frames, the near diplopia all but resolved, she could read at a normal range, so the recommendation was to update the spectacle correction and return for orthoptic re-evaluation.

The patient returned 6 weeks later, still complaining of diplopia associated with reading despite the updated spectacles. Best-corrected Snellen linear visual acuity was 6/6 in both eyes. Near acuity Jaeger 1 at 33 cm in both eyes. Once again there was central sensory fusion of the Worth 4-dot at near fixation, but a vertical diplopia response at distance fixation. Titmus near stereo had decreased to 80 arc-seconds (6/9 circles). There was a 2 PD symptomatic but non-localising right hypertropia, comitant in all gaze positions at distance fixation, and an 8 PD symptomatic exophoria at near fixation. NPC had improved to 8 cm. PFV was not tested in lieu of addressing the symptomatic vertical tropia first. Accordingly, her spectacle correction was updated to include 2 PD base-down prism in the left lens, which resolved her diplopia in free space in the clinic, and the patient was asked to return with the updated glasses for re-evaluation of the CI.

She returned five months later, her vertical diplopia having resolved with the vertical prism spectacles. But she was still symptomatic at near fixation, with headache, some of which was now being called post-stroke chronic headache by her neurologist, asthenopia and intermittent diplopia causing her to lose her place while reading. Best-corrected Snellen linear visual acuity was 6/7.5 in the right eye and 6/6 in the left eye. Near acuity was Jaeger 1 at 33 cm in both eyes. There was central sensory fusion of the Worth 4-dot at both distance and near fixation, and 60 arc-seconds (7/9 circles) of Titmus near stereo. NPC was still 8 cm and PFV amplitudes were reduced (breakpoint of 14 PD base-out, recovery point 12 PD base-out at distance fixation, and breakpoint of 18 PD base-out, recovery point 16 PD base-out at near fixation[26]). Diagnosis was now symptomatic CI, with remote NPC and reduced PFV amplitudes, remaining symptomatic over time despite good acuity at distance and near in both eyes, and vertical prism in the distance glasses that was working well, with no reported vertical diplopia. Treatment was to add home jump-convergence exercises, again the near point dot card to be used two to three times every day for 10 minutes each time and to return in 6-8 weeks to repeat the sensorimotor exam.

Five months later she returned having compliantly performed the home convergence exercises with the near point dot card for at least 10 minutes per day, 6 days per week. Her headaches persisted, and this was being treated with medication by her neurologist. Subjectively, she reported improvement in her reading symptoms, not losing her place as much as before she started the convergence exercises. Best-corrected Snellen linear visual acuity was 6/7.5 in the right eye and 6/6 in the left. There was central sensory fusion of the Worth 4-dot test at distance and near fixation. Titmus near stereo was 60 arc-seconds (7/9 circles). She was orthophoric in all positions of gaze in the distance, with a 10 PD exophoria near fixation. NPC showed improvement to 6 cm. PFV had improved, with breakpoint of 25 PD base-out, recovery point 20 PD base-out at distance fixation, and breakpoint of 35 PD base-out, recovery point 25 PD base-out prism at near fixation (Table 2).

DISCUSSION

Cases 2 and 3 met the entry criteria for near point of convergence (>6 cm), but all three met entry criteria for positive fusional vergence at near (<15 PD base-out) used by the CITT investigator group[25] and Serna et al[26] in their evaluations of children with symptomatic CI. All three patients improved in both reported symptoms and objective clinical measures of NPC, and PFV amplitudes, using simple, inexpensive jump-vergence exercises, and did not require the addition of more

Table 2. Final orthoptic examination data

Case	Sex	Age (years)	NPC	Proximal fusion vergence Break/recovery	Near stereo	Motility at distance	Motility at near	Treatment compliance	Treatment duration	Acuity RE	Acuity LE
1	F	58	2 cm	18/14Δ base-out (F) >40Δ base-out (N)	100 arc-secs 5/9 circles	Orthophoria	X' 2Δ	50 minutes daily for 6 weeks	6 weeks	6/6	6/6
2	F	11	4 cm	16/10Δ base-out (F) 25/10Δ base-out (N)	40 arc-secs 9/9 circles	Orthophoria	X' 2Δ	20 minutes daily for 9 of 10 months	10 months	6/4.8	6/4.8
3	F	72	6 cm	25/20Δ base-out (F) 35/25Δ base-out (N)	60 arc-secs 7/9 circles	Orthotropia	X' 10Δ	10 minutes daily	11 months	6/7.5	6/6

expensive treatments such as computer vergence training, or formal vision therapy. The goal for treatment dosing was 20-30 minutes of the jump-vergence training per day, 6 days per week using the near point dot card (Table 2). Jump-vergence near point dot card exercises were performed compliantly in two of the three cases, yet all three eventually reported improvement in symptoms.

These patients might have shown short-term improvement by using a concentrated program of base-out computer vergence exercises designed only to improve their convergence, as reported by Huston.[30] However in that study, data regarding reported improvement of either subjective symptoms, objective clinical measures, or both were obtained after only 6 weeks of treatment and then at some 'later' time, not specified by the authors. To this author's knowledge, no long-term data exist from any treatment comparison study reporting compliance, improvement in objective clinical measures, or reported adverse events of computer-based vergence training exercises. For example, in the CITT from 2005, comparing office-based vison therapy to smooth vergence pencil push-up treatment, the outcomes visit was at 12 weeks. This study was also biased by a design flaw comparing vigorous weekly office-based vision therapy to far less vigorous PPT of just a few minutes per day, pointed out in an editorial by Kushner, who felt that this amount of PPT did not reflect the practice pattern and level of therapy recommended by the orthoptists with whom he worked, and of those whom he surveyed.[22] In the Momeni-Moghaddam trial from Iran in 2015,[27] another direct comparison of office-based vision therapy utilising computer orthoptics to smooth vergence pencil pushup treatment, outcomes visits were at 4 weeks and 6 weeks after initiation of treatment. Finally, in the PEDIG trial from 2016, a direct comparison of computer vergence training to smooth vergence pencil pushup treatment, the outcomes visit was completed at 12 weeks. One could argue that these time periods are insufficient time to draw long-term conclusions about the efficacy of any treatment for CI. The timeline of these shortened outcome visits may have masked asthenopic symptoms that could have developed with longer periods of computer-based treatment. Prolonged uncoupling of vergence from accommodation by using screen-based therapy for extended periods has been shown earlier to induce symptoms in healthy volunteers, possibly making it less effective than in office-based or home therapies. Could this then have explained why there was better compliance with PPT than with computer orthoptics reported by Scheiman in the 2011 Cochrane review discussed earlier in this report?[31]

Two of the cases described in this report were followed for extended periods, from 5 months (Case 3) to almost a year (Case 2). Both patients demonstrated improvement in objective measures and reported symptoms. The author's personal clinical experience echoes that expressed by Kushner, who reported resolution of symptoms and clinical improvement in positive fusional vergence and NPC in 16 consecutive patients treated over an unspecified period of time with home jump vergence or smooth vergence exercises prescribed by the certified orthoptists with whom he worked.[22]

As previously discussed, evidence exists in the visual sciences literature that describes how the process of neural coupling occurs in human free-space viewing situations to ensure that the accommodative demand required to provide clear vision in both eyes at any given focal distance is synchronised with the vergence demand required to provide a single image in clear focus at the specified viewing distance. The data are clear that asthenopia develops in healthy volunteers when neural uncoupling of vergence from accommodation occurs as test subjects in a controlled laboratory environment attempt to maintain fixation on static, simulated 3-D display monitor like those used routinely in computer orthoptic treatment of symptomatic convergence insufficiency. For patients with convergence insufficiency, the static screen necessary to generate and display the simulated 3-D images used in popular computer orthoptics exercises could derail initial improvement of symptoms by inadvertently uncoupling vergence from accommodation.

CONCLUSION

An uncoupling occurs between vergence and accommodation while maintaining fixation on static, simulated 3-D displays like those used in 3-D cinema projection, 3-D gaming on tablets and smart phones, and on display screens used in popular computer vergence training programs, producing symptoms in healthy volunteers. Controlled studies comparing computer vergence training to jump and/or smooth vergence orthoptic exercises for symptomatic convergence insufficiency should be carried out for extended periods of time greater than the one to three months precedent in the current CI literature to further explore the potential consequences of inadvertently uncoupling vergence from accommodation in the treatment of symptomatic convergence insufficiency. Simple smooth or jump convergence orthoptic exercises remain an inexpensive, safe, readily obtainable, and clinically effective way to treat these patients. Orthoptic exercises that utilise real targets preserve the coupled relationship of vergence to accommodation that occurs normally as individuals attempt to maintain clear, single binocular vision in free space, and in particular, with near activities.

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