Treatment of symptomatic convergence insufficiency with home-based computerized vergence system therapy in children

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PURPOSE To evaluate the efficacy of a home-based computer orthoptic program for symptomatic convergence insufficiency (CI) in children.

METHODS The medical records of participants aged 5 to <18 years who were diagnosed with symptomatic CI and were treated with the Computerized Vergence System (CVS) program were retrospectively reviewed. All participants were prescribed 9 or 15 minutes of daily convergence exercises with the CVS program, 5 days per week, for the initial 6 weeks. Near point of convergence (NPC) and near convergence amplitude (NCA) were measured at baseline, 6 week, and final examinations. The presence or absence of diplopia and asthenopia with reading were recorded at baseline and final examinations.

RESULTS A total of 186 participants were included. At diagnosis, 72 participants (39%) reported diplopia and 182 (98%), reported asthenopia. At final examination, 172 participants (92%) were asymptomatic. Twelve participants (6%) subsequently received other treatment modalities. Mean NPC at baseline (5.9 cm) improved after 6 weeks of CVS therapy (3.3 cm) and at final examination (2.9 cm; $P < 0.0005$). Mean NCA at baseline (20.3^{Δ}) improved after 6 weeks of CVS therapy (37.0^{Δ}) and at the final examination (38.0^{Δ}; $P < 0.0005$).

CONCLUSIONS In this study, home-based CVS therapy reduced symptoms related to CI and improved the NPC and NCA of most children aged 5 to <18 years with symptomatic CI. (J AAPOS 2015;19:417-421)

Convergence insufficiency (CI) is a common binocular disorder characterized by symptoms such as difficulty with reading, eyestrain with near vision activities, headaches, and diplopia. Objective findings include an exophoria at near, a receded near point of convergence (NPC), and a reduced near convergence amplitude (NCA).[1,2] Orthoptic treatment for symptomatic CI may be home- and/or office-based. Recent studies describe using the Home Therapy System (HTS; HTS Inc, Golden Canyon, AZ) or Computerized Vergence System (CVS; HTS Inc.) software programs for the treatment of children with symptomatic CI.[3,4] However, most participants in these studies received computer orthoptic treatment plus pencil pushups,[3,4] and in some cases passive therapies including reading glasses, bifocals, and base-in prism glasses.[4] Therefore, the effect of the computer orthoptic therapy alone was difficult to determine. The purpose of this study was to evaluate the efficacy of receiving only home-based CVS therapy for children with symptomatic CI based on clinical measures and participant symptoms.

Subjects and Methods

This study was approved by the Institutional Review Board of the JAEB Center for Health Research in Tampa, Florida, and conformed to the requirements of the US Health Insurance Portability and Accountability Act of 1996. The medical records of all patients aged 5 to <18 years diagnosed with symptomatic CI at the offices of the Everett and Hurite Ophthalmic Association and who were treated with the CVS program were retrospectively reviewed. Participants met the inclusion and exclusion criteria listed in Table 1. Because the symptoms of patients with CI do not always correlate well to objective measures, no specific values for the near point of convergence (NPC) and near convergence amplitude (NCA) were required for inclusion.[4,5]

Data was collected from 2006 to 2014 by a pediatric ophthalmologist and certified orthoptist in private practice in Southwestern Pennsylvania. Convergence insufficiency was diagnosed after a comprehensive ocular evaluation. The following data were collected and analyzed: best-corrected visual acuities, cycloplegic refraction, NPC, NCA, Titmus stereoacuity, and ocular alignment using the prism and alternate cover test.

The CVS program was demonstrated to participants and their parent/guardian in the office. Participants were prescribed 9 or 15

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Table 1. Inclusion and exclusion criteria

Inclusion	Exclusion
• Patient had access to a computer with a CD/DVD player with an Internet connection	• Constant or intermittent exotropia at distance
• At least one of the following: asthenopic symptoms associated with reading, diplopia associated with reading, reading performance below expectations of a parent or teacher	• Constant exotropia at near
• Exophoria at near ≥4 PD greater than at distance	• Any esotropia at distance or near
• BCVA of at least 20/30 in each eye	• Distance exophoria ≥10 PD
• Stereoacuity (Titmus) of at least 400 arcsec	• Head trauma as the probable etiology of the convergence insufficiency
• At least one follow-up office assessment after distribution of the CVS program	• History of strabismus surgery, prior intraocular surgery, or refractive surgery.
	• Diseases known to affect convergence (eg, Parkinson disease, Graves' orbitopathy)
	• Developmental disability, mental retardation, ADHD, or any other medical condition that would interfere with the ability to perform CVS therapy at home

ADHD, attention deficit hyperactivity disorder; *BCVA*, best-corrected visual acuity; *CVS*, Computerized Vergence System; *PD*, prism diopter.

minutes of daily convergence exercises (vergence base-out) with the CVS program, 5 days per week, for the initial 6 weeks. Beginning in 2006, we prescribed 15 minutes of daily exercises for all participants. Because less treatment seemed to be effective, we later reduced our prescribed therapy to 9 minutes daily for all participants. After the initial 6 weeks, the dosage of prescribed CVS therapy was maintained or tapered to 1 to 3 days per week depending on the participant's clinical and subjective responses. CVS therapy was stopped after tapering for most participants.

NPC and NCA were measured using an accommodative target. The NCA values were generated using a prism bar with a maximum prism power of 40^{Δ} or 45^{Δ}. The NCA measures the largest amount of base-out prism placed in front of one eye under binocular conditions before the eyes diverge (or "break") and the patient is unable to reestablish fusion; it measures the sum of positive fusional vergence and accommodative vergence. The NPC and NCA measurements in this study were almost always the average of two or more individual measurements. Positive fusional vergence was not measured during the early years of this study, and we do not report these values.

NPC and NCA measures were obtained before beginning CVS therapy, 6 weeks after beginning CVS therapy, and at the final examination. The final examination was the last clinical visit at which both clinical and subjective data were available and the participants had discontinued CVS therapy. We did not collect or analyze data regarding the effect of additional treatment modalities for CI. Subjective measures recorded at the initial and final examinations included the presence or absence of diplopia and of asthenopia associated with near vision activities.

The HTS and CVS computer programs are similar except for accommodative procedures included in the HTS program and excluded from the CVS program. Both programs can be run in the automatic mode or customized using the manual menu. We customized the CVS program so that our patients performed only convergence exercises (vergence base-out).

The Tools Program within the CVS software permitted the monitoring of compliance with the prescribed therapy. We graded compliance between the initial and 6-week evaluation as follows: excellent, 75%-100% of prescribed treatment; good, 50%-74% of prescribed treatment; fair, 25%-49% of prescribed treatment; poor, 0%-24%. Total duration of CVS therapy and the time elapsed between the end of CVS therapy and the final office assessment were recorded.

Participants requiring the correction of a significant refractive error received only single vision lenses. We collected information regarding additional treatments for CI that were performed if the response to CVS therapy was deemed inadequate.

Statistical Package for the Social Sciences version 21 (IBM, Armonk, NY) was used to perform analyses. For sample sizes ≥30, parametric tests (one way repeated measures ANOVA and paired and individual samples *t* tests) were used. For sample sizes <30, nonparametric tests (Mann-Whitney U and Wilcoxon signed rank) were used. If significant differences were found, the effect size was calculated in addition to the *P* value. Mean and median values were calculated for sample sizes ≥30, and only median values were calculated for sample sizes <30.

Results

A total of 186 participants ranging in age from 5 to <18 years (mean, 9 years; 98 females [53%]) met inclusion/exclusion criteria and were analyzed. Racial and ethnic composition of our subjects was as follows: white, 102; unknown, 69; Asian, 11; African Americans, 4. Information regarding race and ethnicity was not routinely collected before our conversion to electronic health records in February 2012.

The duration of CVS therapy averaged 18 weeks (range, 5-164) and was discontinued on average 58.7 weeks (range, 0-256) before the final examination. This last calculation

excludes 35 participants who did not return for a final assessment after stopping CVS therapy. Twelve patients who obtained the CVS program and were study-eligible but did not return for any follow-up visits between 2006 and 2014 were excluded from the analysis.

For the 139 participants with data available for all three time points, the mean NPC (with standard deviation) after 6 weeks of CVS therapy (3.3 ± 1.7 cm; range, 2–10 cm) and at the final examination (2.9 ± 1.5 cm; range, 1–15 cm) improved significantly ($P < 0.0005$, $\eta_p^2 = 0.45$) compared to the baseline NPC (5.9 ± 3.6 cm; range, 2–15 cm). For the 140 participants who had stopped CVS therapy at the final examination, the mean NCA measure after 6 weeks of CVS therapy ($37.0^\Delta \pm 6.7^\Delta$; range, 14^Δ-45^Δ) and at the final examination ($38.0^\Delta \pm 5.6^\Delta$; range, 18^Δ-45^Δ) also improved significantly ($P < 0.0005$; $\eta_p^2 = 0.88$) compared to baseline NCA ($20.3^\Delta \pm 5.7^\Delta$; range, 2^Δ-40^Δ).

During the first 6 weeks, 161 participants (87%) demonstrated excellent (72 [39%]) or good (89 [48%]) compliance with CVS therapy; 22 participants (12%) demonstrated fair or poor compliance, and no compliance data was available for 3 participants (1%). No significant differences emerged between baseline and 6-week NPC measures or baseline NCA measures (median, 20^Δ) for people with excellent/good compliance compared to people with fair/poor compliance. Subjects with excellent/good compliance achieved a median NCA of 40^Δ (mean, 37.1^Δ) after 6 weeks of CVS therapy compared to a median NCA of 25^Δ for those with fair/poor compliance, a significant difference ($P < 0.0005$, $r = 0.32$).

Initially 23 participants (12%) were prescribed 15 minutes of daily CVS therapy, and 163 (88%) were prescribed 9 minutes of daily CVS therapy. There were no significant differences between their baseline NPC ($P = 0.22$) and NCA ($P = 0.85$) measures, and their 6-week post-treatment NPC ($P = 0.09$) and NCA ($P = 0.34$) measures.

Of 84 participants (45%) with an NPC of ≥6.0 cm before CVS treatment (mean duration, 15.9 weeks; range, 5-164), 59 had a final assessment off CVS therapy. The mean baseline NPC measure (9.3 ± 2.9 cm; range, 6–15 cm) improved after 6 weeks of CVS therapy (4.2 ± 2.1 cm; range, 2–10 cm [$P < 0.005$]) and at the final examination (3.2 ± 2.0 cm; range, 2–15 cm [$P < 0.005$]). The differences between the mean NPC value after 6 weeks of CVS therapy and at final examination were significant ($P = 0.003$).

Of 49 participants (26%) with an NCA of $\leq 16^\Delta$ before CVS treatment (mean duration, 20 weeks; range, 6-156), 34 had a final assessment off CVS therapy. Their mean baseline NCA measure ($12.8^\Delta \pm 3.9^\Delta$; range, 2^Δ-16^Δ) improved after 6 weeks of CVS therapy ($34.4^\Delta \pm 8.3^\Delta$; range, 16^Δ-45^Δ [$P < 0.0005$]) and at the final examination ($36.7^\Delta \pm 6.8^\Delta$; range, 18^Δ-45^Δ [$P < 0.0005$]).

Prior to treatment, 72 participants (39%) reported diplopia and 182 (98%) reported asthenopia for reading. At the final office assessment, 172 participants (92%) were asymptomatic, denying diplopia or asthenopia associated with near vision activities. There were no differences between baseline NPC scores (median, 5 cm), NPC scores at the time CVS therapy ended (median, 3 cm), and baseline NCA scores (median, 20^Δ) for people who were asymptomatic compared to those who were symptomatic (median, 7 cm, 3 cm, and 20^Δ, respectively) at the final examination. However, at the time CVS therapy ended, asymptomatic participants had a significantly higher median NCA score than symptomatic participants (40^Δ vs 25^Δ [$P < 0.0005$, $r = 0.34$]). Only 6 of the 14 symptomatic participants (43%) demonstrated excellent or good compliance with CVS therapy during the first 6 weeks of treatment.

Twelve participants (6%) received other home-based treatment modalities, including Brock string eye exercises (8), pencil push-ups (1), and prism glasses (3) to address residual symptoms associated with their CI. Two patients required referral to an optometrist offering in-office vision therapy because the response to prescribed home therapies was deemed inadequate.

There were no significant differences between those who received additional treatment and those who did not in median baseline NPC scores (7 cm vs 5 cm), NPC scores at the time CVS therapy ended (3 cm vs 3 cm), and baseline NCA scores (18^Δ vs 20^Δ). There was a significant difference between NCA scores at the time therapy ended ($P = 0.003$, $r = 0.23$), favoring those who did not receive additional therapy (median, 40^Δ) compared to those who received additional therapy (median, 30^Δ). Of the 12 people who received other treatment modalities, 7 (58%) demonstrated excellent or good compliance with the CVS therapy during the first 6 weeks.

Near exodeviation after CVS therapy from baseline (mean, $6.5^\Delta \pm 2.7^\Delta$; range, 4^Δ-20^Δ) to final examination (mean, $5.1^\Delta \pm 2.8^\Delta$; range, 1^Δ-20^Δ) improved ($P < 0.0005$, $r = 0.59$). No participants developed an esodeviation.

No significant differences between baseline NPC measures, NPC measures after 6 weeks of CVS therapy, and baseline NCA measures were found between males and females. There was a difference in NCA measurements after 6 weeks of CVS therapy favoring females over males (mean of 37.3^Δ vs mean of 34.9^Δ [$P = 0.036$, $r = 0.17$]).

At initial assessment, 99 participants (53%) were under age 9 years; 87 were age 9 to <18 years. Comparing these two age cohorts, no significant differences emerged between baseline NPC measures ($P = 0.45$) and NPC measures after CVS therapy ended ($P = 0.67$). Similarly, no significant differences emerged between baseline NCA measures ($P = 0.45$) and NCA measures after CVS therapy ended ($P = 0.16$).

Thirty-five participants did not have a follow-up examination after discontinuation of CVS therapy. Of these, 27 had NPC and NCA measurements at baseline, 6 weeks after beginning CVS therapy, and the examination at which CVS therapy was stopped. Compared to median NPC at baseline (6 cm), NPC after 6 weeks of CVS therapy (4 cm) improved ($P < 0.0005$), as did median NPC at the

examination at which CVS therapy was stopped (4 cm [$P = 0.003$]). Differences also arose between the median baseline NCA (20^{Δ}) and the median NCA after 6 weeks of CVS therapy (35^{Δ} [$P < 0.0005$]) and between the median baseline NCA and the median NCA at the examination at which CVS therapy was discontinued (40^{Δ} [$P < 0.0005$]).

Discussion

HTS and CVS software programs have been used in several treatment trials for children with symptomatic CI.[3,4] The Convergence Insufficiency Treatment Trial (CITT) Study Group used the HTS program for their Home-based Computer Vergence/Accommodative Therapy and Pencil Push-up treatment group (HBCVAT+) and as part of the home-based reinforcement regimen of the Office-based Vergence/Accommodative Therapy with Home Reinforcement treatment group (OBVAT). For 12 weeks participants randomized to the HBCVAT+ group performed an HTS program 15 minutes per day, 5 days per week. The program included fusional vergence procedures (base-in, base-out, autoslide, and jump ductions) and an accommodative rock program.[3] Serna and colleagues[4] described the use of the CVS program, prescribing 3 minutes of convergence and 3 minutes of divergence exercises over a period of 3-30 weeks (mean, 12.6 weeks) for children with symptomatic CI. All patients in the CITT study and most patients in the study by Serna and colleagues concurrently received additional home treatments, such as pencil pushups[3,4] reading glasses or bifocals,[4] and base-in prism glasses.[4] Therefore, the effect of the computer program alone was difficult to discern.

We evaluated the CVS program as a single method of therapy, using only convergence exercises (vergence base-out) for children with symptomatic CI. The differences between baseline and post-treatment NPC and NCA measures were not only statistically significant ($P < 0.0005$), but the effect sizes were large. Our calculated η_p^2 values of 0.45 for NPC improvement and 0.88 for NCA improvement indicate a large difference after CVS therapy. Statisticians consider partial eta squared values ≥0.14 to be a large effect size. Of the 186 participants, 172 (92%) denied symptoms of diplopia and of asthenopia for near vision activities at their final office evaluation.

The CVS program dispensed to users with Internet access allows treating practitioners to accurately monitor compliance. We collected and analyzed this data for the first 6 weeks of prescribed therapy and found that participants demonstrating excellent/good compliance had significantly higher NCA measures after 6 weeks of CVS therapy than did those with fair/poor compliance. Asymptomatic patients at the final examination also achieved significantly higher post-treatment NCA measures compared to symptomatic patients. Finally, patients receiving no additional treatment modalities at the final examination achieved significantly higher post-treatment NCA measures than those receiving additional treatment modalities. These findings suggest that post-treatment NCA measurements may help to predict clinical success in treating symptomatic children with CI and that this success is positively correlated to excellent/good compliance with our prescribed CVS protocol.

The CITT study[3] and the study by Sarna and colleagues[4] had strict entry criteria regarding values for near point of convergence (≥6 cm) and positive fusional vergence at near ($\leq 15^{\Delta}$) in their evaluations of children with symptomatic CI. We analyzed subsets of our study population that met or resembled these more stringent entry criteria for NPC and positive fusional vergence. Fifty-nine participants with a baseline NPC of ≥6 cm (mean, 9.3 cm) achieved excellent measures at 6 week (mean, 4.2 cm) and final examinations (mean, 3.2 cm). Thirty-four patients with baseline NCA measures of $\leq 16^{\Delta}$ (mean, 12.8^{Δ}) achieved 6-week and final mean NCA measurements of 34.4^{Δ} and 36.7^{Δ}, respectively. This data suggests that our CVS protocol was effective in improving NPC and NCA measurements for both severe and milder cases of symptomatic CI.

Our apparently successful treatment outcomes could be attributed to several factors. Overall compliance during the first 6 weeks of therapy was excellent/good in 87% of patients. We were able to accurately review compliance at office visits. Most families paid cash for the software program and were aware of the much higher cost and time commitment of in-office vision therapy. Our patients' overall success and rapid improvement may also be due to the purposefully concentrated program of exercises (only vergence base-out) designed only to improve their convergence. No extra time was allocated to exercises designed to improve divergence or accommodation. This contrasts with the diversified computer vergence/accommodative programs completed by patients in the CITT[3] and in the study by Serna and colleagues.[4] No adverse consequences from this focused strategy were identified.

After the cessation of CVS therapy, 35 patients did not return. However, for 27 of these 35 participants information was available for 2 clinical visits at 6 weeks and later after initiating CVS therapy. Information from these clinical visits suggests that they achieved a treatment response similar to those subjects who returned after stopping CVS therapy based on their follow-up NPC and NCA measures.

The weaknesses of our study are those inherent to most retrospective studies: there was no placebo control, patients and examiners were unmasked, and there was potential bias in favoring a positive outcome from treatment by the patient and examiners. Subjective complaints were not quantified using a measure like the Convergence Insufficiency Symptom Survey (CISS).[5,6] Follow-up visits were not protocol specified, and the study was not prospectively designed and statistically powered to address a specific question.

Study strengths included our evaluation of a single treatment method for symptomatic CI during the first 6 weeks of therapy. Any therapy received after 6 weeks was the same, but generally less intensive. Furthermore, a large

population was studied. Over half of our patients were under age 9 years at presentation and would have been excluded from the CITT on that basis alone. Clinical measurements were obtained in a uniform manner by the same examiners. Long-term follow-up after the cessation of therapy averaged over 1 year.

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Seeing Is Believing

In 1824, Braille was ready to show Dr. Pignier his changes. He brought a writing board carved with thin, horizontal grooves to their meeting in the director's office. He sat down opposite Dr. Pignier and placed a piece of paper on the board. Then he laid a sliding bar with tiny rectangular windows, each the size of a single cell, over the paper. Holding a pointed stylus in his hand, he asked Dr. Pignier to choose a book and to read a passage from it out loud.

The director chose a poem by Charles d'Orleans.

Time has lost her wintry gear
Of wind, and cold, and rain,
And is attired again
In radiant sunlight, bright and clear

Braille punched the words quickly into his paper, and told the director that he could read faster.

When Dr. Pignier was finished, Braille turned the paper over and ran his fingers over the raised dots. He then steadily read every word the director had spoken, without one mistake.

Dr. Pignier was overcome with surprise and admiration. He rushed to Braille and embraced him. He promised to introduce the whole school to Braille's method.

—Andrew Lam, *Saving Sight* (Bokeelia, Fla.: Irie Books, 2013), 176.