Effects of Orthoptic Treatment on the CA/C and AC/A Ratios in Convergence Insufficiency

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Purposes. To evaluate the effect of orthoptic treatment on the AC/A (A, accommodation; C, convergence) and CA/C ratios in subjects with convergence insufficiency (CI).

Methods. The change in AC/A and CA/C ratios after a 12-week period of home-based orthoptic treatment was examined in 10 subjects (mean age, 25.4 ± 4.1 years [SD]). Both the AC/A and CA/C ratios were measured by using gradient response methods. For the AC/A ratio, the gradient phoria method was used, and for the CA/C ratio the prism-induced change in accommodation was measured with a refractometer.

Results. No change in the AC/A and CA/C ratios (P > 0.05) were found after orthoptic treatment. However, improvements were found (P < 0.05) in the fast and slow vergence mechanisms.

Conclusions. Despite improvements in the fast and slow vergence mechanisms no change was found in the AC/A and CA/C ratios after orthoptic treatment in CI subjects. This finding is unexpected in light of the present understanding of CI, and an alternative theory is proposed. (Invest Ophthalmol Vis Sci. 2006;47:2876–2880) DOI:10.1167/iovs.04-1372

Primary convergence insufficiency (CI) is regarded as one of the most frequently occurring binocular problems and is broadly defined as an inability to obtain or, more often, to maintain adequate binocular convergence without undue effort. The literature on CI reports five common clinical characteristics: (1) reduced near point of convergence (NPC); (2) high near exophoria relative to the distance phoria; (3) low AC/A (A, accommodation; C, convergence) ratio; (4) low positive relative convergence or positive fusional amplitude (especially at near); and (5) excess accommodation in near vision (absence or reduced lag of accommodation).

A variety of symptoms are reported in subjects with CI. These include ocular fatigue, asthenopia, headache (especially frontal), blur, and occasional diplopia, which are especially apparent with near work, but do not occur as frequently when the load is light and/or the subject is well rested. These symptoms are consistent with those described in association with CI by von Graefe as early as in 1862. In a presbyopic subject without any signs of ocular disease, experienced clinicians are confident about the diagnosis of CI based on symptoms and a reduced NPC.

The true prevalence of CI is difficult to assess because most investigators have tended to use their own definition (or study criteria) of CI, so that consistency is lacking. However, most recent studies have found a prevalence of ~5%.

North and Henson indicated that patients exhibiting the clinical characteristics of CI seemed to have reduced convergence adaptation. Schor and Horner confirmed North and Henson’s indications and added the observation that CI patients had unusually rapid adaptation of accommodation. Schor and Horner proposed that this adaptation asymmetry might be a major cause of CI. The logic behind their proposal was that rapid accommodative adaptation would replace reflex accommodation nearly as fast as the latter is generated, thereby reducing accommodative vergence to abnormally low levels. This partially explains the large near exophoria often observed in these patients and is responsible for their low measured AC/A ratios. The loss of proportional vergence bias from accommodative vergence is compounded by highly inefficient vergence adaptation, which fails to adapt to disparity vergence and accommodative vergence innervation. Therefore, inefficient vergence adaptation contributes to these patients’ near exophoria and low measured AC/A ratios. Schor and Horner explained the near accommodative excess associated with CI as a result of abnormally high convergence accommodation activity (i.e., a high measured CA/C ratio). Such CA activity is the result of high disparity vergence activity necessitated by insufficient accommodative vergence and vergence adaptation. Negative reflex accommodation offsets the excess convergence accommodation within its capacity to do so, but negative reflex accommodation is often overwhelmed by excess convergence accommodation, leading to accommodative excess in near vision.

Several researchers have shown that CI is amenable to orthoptic exercises. In general, those patients who gain relief of their symptoms also show improved NPC and fusional convergence.

In a well-designed study with a matched-subjects–control-group crossover design, Cooper et al. found that a statistically significant improvement in the vergence ranges occurred during the training period but not during the control period. In addition, Arner et al. and Sheedy and Saladin found that the forced vergence fixation disparity curves flattened with orthoptic treatment. Schor showed a high correlation between the forced vergence fixation disparity curve and the ability to adapt to prism-induced heterophoria. The fixation disparity data and the results of Schor are compatible with the results of North and Henson, who found that the ability to adapt to prism-induced heterophoria improves in subjects with CI who respond to orthoptic treatment. Some disagreement exists regarding the effect of orthoptic treatment on the size of heterophoria. Cushman and Burt did not find any change in the near phoria, whereas some other studies have indicated that the near phoria decreases. Furthermore, Daum found that the gradient stimulus AC/A ratio did not change.

According to Schor and Horner, the adaptive imbalance between accommodation and vergence is a major cause of CI.
This adaptive imbalance causes the low measured AC/A ratio and elevated CA/C ratio found in persons with CI. Because vergence adaptation has been found to improve in those with CI who become asymptomatic with orthoptic treatment,27,33 it has been assumed that the AC/A increases and the CA/C becomes reduced in CI.20 However, the assumption of changeable AC/A and CA/C ratios seems to be in conflict with the results of Rainey39 who found that the response AC/A ratio did not change after vergence adaptation and with the results of Daumé and Ogle et al.40 who found no change in the gradient stimulus AC/A ratio after orthoptic treatment. Therefore, the purpose of this study was to investigate the validity of the assumption that the AC/A and CA/C ratios become more balanced after a period of orthoptic treatment in persons who have CI.

**METHODS**

The research adhered to the tenets of the Declaration of Helsinki and the participants gave informed consent.

The AC/A and CA/C ratios were measured as part of a comprehensive study of CI. The sequence in which the measurements were taken was chosen to minimize interactions.41 Within the −2.5 hours of each subject’s initial investigation there were breaks of at least 7.5 minutes between the measurements of each parameter. The sequence was as follows: near associated phoria, accommodative lag, NPC, monocular and binocular amplitudes of accommodation, near-positive vergences, phorias, AC/A and CA/C ratios, accommodative after effect, and prism adaptation. After orthoptic exercises, the sequence was repeated.

**Subjects**

The change in AC/A and CA/C ratios after a 12-week period of home-based orthoptic treatment was measured in 10 subjects (mean age, 25.4 ± 4.1 years [SD]) with diagnosed CI. CI was defined as near visual related symptoms such as asthenopia and headache during and/or after periods of near work (e.g., reading or computer work), reduced near work time, occasional diplopia and/or blur during and/or after near work, and a reduced NPC (average, >10 cm on three successive readings with the RAF rule [Royal Air Force accommodation and vergence measurement]). This definition of CI was similar to that used by other researchers and by most practicing clinicians.1,10,11,13–15,42 In addition, all the subjects with CI achieved at least 6/6 Snellen visual acuity (right, left, and binocularly), had stereo acuity (TNO test) of 120 seconds of arc or better, were free of ocular disease, had no history of ophthalmic or orthoptic treatment, and were not taking any medication with known effect on visual acuity and binocular vision.

**Measurements**

During all measurements, the subjects were given directions to discontinue any mid- or long-term treatment, and to report if they felt they were having a bad day (e.g., had any symptoms such as asthenopia and headache during and/or after periods of near work). If this occurred, the subject was asked to rest until they felt they were having a good day, and then to discontinue treatment if this persisted.

**Baseline Binocular Measurements.** As part of the visual examination, several baseline binocular vision measurements were made. (1) The Mallett near unit was used to measure the near (40 cm) associated phoria. The subjects, wearing prescription and polarized filters, were instructed to keep the test surrounding the nonius lines clear. Then they were told to shift fixation to the letter X in the gap between the nonius lines and to report whether the lines seemed to be displaced. If the lines were perceived as displaced, prisms were inserted in 0.5∆ steps until the lines appeared aligned. (2) The lag of accommodation was measured with Nott dynamic retinoscopy while the subjects fixated at 40 cm. The subjects, with the prescription housed in the refractor head, were instructed to fixate a vertical row of Snellen acuity letters subtending 7.5 minutes of arc. Dynamic retinoscopy started at 40 cm, and then the working distance was increased until a neutral reflex was observed. The difference between the fixation distance and the position for which a neutral reflex was observed was taken as a measure of the lag of accommodation. (3) NPC was measured according to the RAF rule while the subjects fixated the vertical line target. The average of three successive readings was taken as the NPC. (4) The amplitude of accommodation was measured monocularly and binocularly using the RAF rule while fixating the N5 line. The subjects were instructed to keep the text clear as it approached the eyes and to report when it first started to become defocused. The average distance from the eyes, of three successive readings, for which the text was first observed as blurred was taken as a measure of the accommodative amplitude. (5) For measurement of the positive vergence at near (40 cm) the subjects viewed a vertical row of letters subtending 7.5 minutes of arc through the refractor head housing the prescription. Prisms were then inserted binocularly in 0.5∆ steps. The subjects were instructed to keep the letters single and clear and to report when the letters first became blurred. (6) Distance (D) and near (40 cm) phoria using a flashed Maddox rod test (for detailed description of the flashed Maddox rod technique, see the description of the AC/A method). The near and distance measurements were made in the order stated, to reduce the amount of influence they may have had on each other.41

**AC/A and CA/C Ratios.** The stimulus AC/A ratio was measured with a gradient response method. With this method, the AC/A ratio was determined by first measuring the phoria at 40 cm with the subject’s correction in place, and then with additional pairs of plus and minus lenses (+1.00, +2.00, −1.00, and −2.00 DS). The subjects’ phoria, both with and without the additional pairs of lenses, was measured with a flashed Maddox rod and tangent scale technique16,27 to the nearest 0.25∆. The five phoria measurements obtained were then plotted against the change in accommodative demand. A linear regression was then fitted to the plot, and the slope of the regression line used as a measure of the AC/A ratio. For all the phoria measurements taken with the flashed Maddox rod technique,15,27 the exposure through the rod was limited to 0.25 second with the aid of a photographic shutter and shutter controller (model 05 ISC 850/04 EBS; Melles Griot, Carlsbad, CA). The shutter was mounted on the refractor head in front of the right eye. The refractor head (Auto Optoteseter OT-7A, Nikon, Tokyo, Japan) housed the subject’s prescription and the Maddox rod. The refractor head was parallel to the plane of the tangent scale, and the visual axes through the refractor head were at the level of the central spot of the tangent scale. Before each phoria measurement, the subjects were allowed 15 seconds of binocular viewing on the test chart. Then the subject’s right eye was occluded for 15 seconds to allow fast vergence to decay.25 One second before a phoria measurement (i.e., the 0.25-second exposure of the rod), the subject was notified by the use of a sound stimulus, which he or she reacted to by changing fixation from the test chart to the central spot of the tangent scale. The test chart was located at the same distance from the subject as the spot but 2° from the spot in a 45° angle, up and to the right. The test chart consisted of a vertical row of Snellen acuity letters subtending 7.5 minutes of arc, and the subject was instructed to fixate the letters except for the short periods when the phoria was being measured.

For the measurement of the stimulus CA/C ratio a method based on the technique developed by Tsuetaki and Schor45 was used. The change in accommodation was measured using a refractometer. The PowerRefractor (MultiChannel Systems, Reutlingen, Germany, now manufactured by PlusOptix, Nürnberg, Germany) is an objective refractometer based on eccentric infrared photograph refraction and is capable of continuous measurements of the refractive status. The instrument enables overrefraction through contact lenses or spectacles but needs a relatively low level of room lighting to operate. To ensure the proper light intensity, the room was darkened (105 lux), but at the same time the fixation target was illuminated with short-wavelength light (>560 nm) to ensure stable fixation. This short-wavelength light does not interfere with measurements made by the refractor. For measuring the CA/C, a stimulus consisting of one cycle of a 0.2 cyc/deg DOG (difference of Gaussian) target (when viewed at 40 cm), was placed on the midsagittal plane 40 cm from the subject’s eyes and served as a binocular fixation target. The DOG target is relatively
incapable of stimulating any reflex accommodation, yet it is localized in space and has been found to be an ideal stimulus for disparity vergence, inasmuch as it is a nonrepeating target that avoids false fusion problems such as the wallpaper illusion. When the subject views the DOG target with natural pupils, it acts as a quasi open-loop condition for accommodation and so permits measurements of vergence accommodation. During the measurements, the subject’s head was fixed in a head and chin rest, and the refractometer was positioned along the midsagittal plane 1.0 m from the subject’s eyes. During the measurement, the subject was instructed to keep the DOG target single. Before measurements were started, the subject viewed the DOG target for 5 minutes to allow accommodation to stabilize. The subject wore his or her refractive correction and the left eye was overrefracted with the refractometer. The value of overrefraction served as a baseline measure of the resting level of accommodation. An 8Δ base-out (BO) prism was then inserted over the subjects’ right eye, and the left eye was again overrefracted within 1 to 2 seconds of the subject reporting that he or she had obtained fusion of the target through the prism. The CA/C was calculated by dividing the dioptric difference in overrefraction as obtained with and without the prism. All the subjects tested were able to fuse through the 8Δ prism and gave a clear indication that binocular vision had been restored through the prism. Each subject had the CA/C ratio measured twice.

**Adaptation.** For measurements of accommodative adaptation, the method developed by Tsuetaki and Schor was used; however, as for the measurement of the CA/C ratio, changes in accommodation were measured with the refractometer (PowerRefractor; MultiChannel Systems). The DOG target was positioned in the same way as for the CA/C ratio measurement (i.e., at 40 cm distance and on the midsagittal plane). The refractometer was at 1.0 m and the subjects fixated the 0.2-cyc/deg DOG target monocularly. A measure of the baseline accommodative response was then obtained with the refractometer. A vertical row of black letters subtending 7.5 minutes of arc (printed on tracing film) was then superimposed on the central white area of the DOG target. The subjects were instructed to fixate and obtain a clear image of the letters and to continue fixating the letters for 30 seconds. By the subjects’ keeping the letters clear and well focused, accommodation was stimulated and the monocular fixation prevented convergence accommodation from contributing to the accommodative response. After 30 seconds the transparent visual acuity target was removed, and the subjects were instructed to view the 0.2 DOG target passively. At the time when the acuity target was removed, the refractometer started to measure the refractive state of the eye and continued doing so until the refractive state had returned to the baseline value. This procedure enabled measurement of the duration of the accommodative aftereffect (adaptation).

Prism-induced vergence adaptation was measured in response to 6Δ BO at 40 cm, by the flashed Maddox rod and tangent scale technique. After measuring the baseline phoria (as described earlier) the subjects were allowed 30 seconds of binocular viewing of the acuity chart, followed by 15 seconds of monocular occlusion, during which the adapting prism was inserted in front of the occluded eye. The subsequent measure of the phoria was taken before any binocular viewing through the prism and was consequently a measure of the induced phoria for which adaptation was to be measured. The procedure of 30 seconds of binocular viewing followed by 15 seconds of monocular occlusion, which again was directly followed by a phoria measurement, was repeated until 15 phoria measurements with the prism had been made. This time course allowed a total of 7.5 minutes of adaptation.

**Orthoptic Treatment and Follow-Up**

After the completion of the initial examination, the subjects started a 12 week, home-based, conventional orthoptic exercise program. The subjects were seen after the 2nd and 4th weeks and then again after the 12th week.

The subjects were instructed to perform 10 minutes of training twice every day at times when they were not feeling tired or having visual problems. Two different exercises were given for the first 2 weeks. Physiological diplopia (vergence jump between two pencils, one located at arm’s length and the other at half arm’s length) and pencil-to-nose (one pencil held at arm’s length, the other starting off at arm’s length but then brought toward the eyes along the midline until diplopia and then moved away until recovery). With both exercises, the subjects were to observe physiological diplopia of the pencil that was not being fixated, to avoid development of suppression. Both exercises were to be completed (5 minutes each) during each of the two 10-minute daily training periods.

For the third and fourth weeks, the subjects were given one prism flipper (3 base in [BI]/12 BO) and one spherical flipper (±1.50 DS). Both flipper exercises were performed at 40 cm, four times for 1 minute each, during both the daily training sessions. Each subject was also given a fixation target (a vertical row of Snellen letters subtending 7.5 minutes at 40 cm).

From week 5 until the completion of week 12, the subjects continued with 10 minutes of training twice daily, though now with a combination of all four exercises. During the first daily period, physiological diplopia (vergence jump) and spherical flipper (±1.50 DS) were combined; during the second period, pencil-to-nose and prism flipper (3 BI/12 BO) were combined. The subjects were not examined by the investigators during these last 8 weeks of training.

After the 12 weeks of training were completed, the experiment was repeated in all the subjects. All the measurements and the treatment were performed at the Karolinska Institutet in Stockholm. Even though the orthoptic exercises were performed only at near, the high-power flipper combinations used were demanding on the visual system and exercised both the near and distance aspects of vergence control.

**RESULTS**

After completion of the 12-week treatment program, the subjects graded whether they felt that their symptoms had been relieved (0, all symptoms still present; 10, all symptoms relieved) and their own overall level of compliance (0, 0% compliance; 10, 100% compliance). The results can be seen in Figure 1.

In Table 1, the average results (±95% confidence intervals) of AC/A and CA/C ratios, phoria and associated phoria, and accommodative and vergence measurements taken before and after the 12-week treatment period are shown.

In Figure 2, the prism vergence adaptation response before and after orthoptic treatment is shown.

A one-way, repeated-measures ANOVA (Origin, ver. 7.0; OriginLab Corp., Northampton, MA) showed the effect of orthoptics to be statistically significant (P < 0.0001). Examination of the data by the Tukey test showed that there was statistically significant improvement in NPC with orthoptics (P < 0.001), whereas no significant change in the AC/A and
CA/C ratios was found ($P > 0.05$). In addition, significant improvement with orthoptics was also found in Mallett-associated phoria (40 cm), accommodative lag, the binocular accommodation amplitude, and positive fusional vergence range at near ($P < 0.05$); however, no significant change was found in the phoria at both distance and near, nor in the monocular accommodation amplitude ($P > 0.05$). For adaptation, a statistically significant improvement was found in the accommodative after effect ($P < 0.05$) and analysis of the time constant of the vergence adaptation response, after having fitted the response to the exponential decay function ($y = Ae^{-x/t} + y_o$; Origin, ver 7.0; OriginLab Corp.) showed that vergence adaptation had also improved ($P < 0.05$).

Analysis of the repeatability of the CA/C ratio measurement shows that there was significant correlation ($r = 0.91$, $P < 0.05$) between the two measurements of the ratio taken in each subject before and after treatment.

**Discussion**

The results of this study show that, in subjects with CI responding to orthoptic treatment, the AC/A ratio does not change, a finding that is in agreement with the results of Daum,7 Rainey,36 and Ogle et al.40 Neither was any change found in the CA/C ratio of these subjects. In contrast, as has also been found in several other studies,4,6-15,27,51-55 the NPC, the near-associated phoria, and the positive vergence at near all improved, indicating enhanced disparity-driven fast vergence after orthoptic treatment. In addition, the binocular accommodative amplitude improved, whereas the monocular amplitude did not. It is likely that the measurement of the binocular accommodative amplitude in subjects with CI is more of a measure of NPC than of accommodation, since their reduced disparity vergence mechanism is likely to result in the fixation target’s becoming double before it becomes blurred. Presumably the binocular amplitude improves without the monocular improving, as a result of the improved convergence ability after orthoptic exercises.

**Table 1. Effect of Othoptic Treatment**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Before</th>
<th>After</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPC (cm)</td>
<td>19.53 ± 3.64</td>
<td>8.43 ± 1.01</td>
<td>11.10*</td>
</tr>
<tr>
<td>AC/A (Δ/DS)</td>
<td>2.04 ± 0.34</td>
<td>2.06 ± 0.22</td>
<td>0.02</td>
</tr>
<tr>
<td>CA/C (DS/Δ)</td>
<td>0.142 ± 0.019</td>
<td>0.136 ± 0.012</td>
<td>0.06</td>
</tr>
<tr>
<td>Phoria 6m (Δ)</td>
<td>1.55 exo ± 1.59</td>
<td>1.50 exo ± 1.26</td>
<td>0.05</td>
</tr>
<tr>
<td>Phoria 40 cm (Δ)</td>
<td>8.90 exo ± 1.52</td>
<td>8.40 exo ± 1.20</td>
<td>0.50</td>
</tr>
<tr>
<td>Mallett 40 cm (Δ)</td>
<td>2.70 exo ± 1.01</td>
<td>1.45 exo ± 0.62</td>
<td>1.25†</td>
</tr>
<tr>
<td>Acc lag (DS)</td>
<td>0.10 ± 0.21</td>
<td>0.42 ± 0.23</td>
<td>0.32†</td>
</tr>
<tr>
<td>Mono acc amp (DS)</td>
<td>10.55 ± 1.60</td>
<td>10.87 ± 1.41</td>
<td>0.32</td>
</tr>
<tr>
<td>Bino acc amp (DS)</td>
<td>9.23 ± 1.84</td>
<td>11.15 ± 1.73</td>
<td>1.95†</td>
</tr>
<tr>
<td>PV 40 cm (ΔBO to blur)</td>
<td>18.90 ± 2.91</td>
<td>24.10 ± 2.04</td>
<td>5.20†</td>
</tr>
<tr>
<td>Verg adaptation (time constant)</td>
<td>6.25 ± 2.15</td>
<td>3.60 ± 0.74</td>
<td>2.65†</td>
</tr>
<tr>
<td>Acc after-effect (sec)</td>
<td>29.60 ± 4.63</td>
<td>26.40 ± 4.20</td>
<td>3.20†</td>
</tr>
</tbody>
</table>

Data show average ($±95\%$ CIs; $n = 10$). All near phoria measurements were in the exo direction. For vergence adaptation, the average time constant is stated after the adaptive response was fitted to the exponential decay function $y = Ae^{-x/t} + y_o$. NPC, near point of convergence; Mono, monocular; Bino, binocular; acc, accommodation; amp, amplitude; Mallett, associated phoria; PV, positive vergence; Verg, vergence.

*Significant at $p < 0.001$ level.
†Significant at $P < 0.05$ level.

Like Cushman and Buri,31 we found no significant change in either distance or near phorias after orthoptic treatment.

A suggested cause of CI (Schor and Horner20) is an imbalance of vergence and accommodative adaptation resulting in a large near exophoria and unbalanced AC/A and CA/C ratios. In this study, changes in adaptation were found after orthoptic treatment. According to the Schor and Horner theory of CI,20 it might have been expected that the more normal adaptation after orthoptic treatment would allow the AC/A and CA/C ratios to become more balanced and the near exophoria to decrease, but we did not observe these improvements. It could be that the changes in adaptation found in this study are not sufficient to alter either the AC/A or the CA/C ratio, and it is not impossible that small changes in the response AC/A occurred after treatment, since the accommodative response did change. However, the absence of change in the near phoria makes this unlikely.

The reduction in the subject’s symptoms after orthoptic treatment can be explained by the improvement in fusional vergence and adaptation.

The failure of the AC/A and CA/C ratios to change as the fusional vergence and adaptation change is puzzling and difficult to reconcile with the present theory. We therefore suggest that the large near exophoria and related low AC/A and elevated CA/C ratio, is the primary anomaly underlying CI. However, the exact role of accommodative and vergence adaptation in CI remains to be clarified.

**Acknowledgments**

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**Figure 2.** Average adaptation in response to 6Δ BO at 40 cm before and after orthoptic treatment ($n = 10$).
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