ARTICLE

Association of Asthenopia with Sustained Attention, Accommodation and Encephalographic Activity

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ABSTRACT

Purpose: Greater accommodative lag and vergence deficits have been linked to attentional deficits similar to those observed in attention deficit hyperactivity disorder (ADHD). The purpose of the present study was to assess the effect of accommodative-vergence stress on sustained attention, lens accommodation and frontal electroencephalographic activity in young adults with high and low symptoms of asthenopia.

Methods: Forty-six college students participated in the study. Based on their scores on the Convergence Insufficiency Symptom Survey (CISS), 18 participants were assigned to the high CISS symptom group, while 21 participants comprised the low CISS symptom group. All of the participants completed a test of sustained attention (Conners CPT) twice while wearing -2.00 D lenses and normally in a counterbalanced order one week apart. Their dynamic accommodative responses and electroencephalographic activity (EEG) during attentional testing was also recorded.

Results: The results showed that the high CISS symptom group performed a significantly greater number of commissions, perseverations and poorer target detectability than the low CISS symptom group across both testing sessions. Accommodative lag was significantly smaller in the non-stress condition compared to the -2.0 D stress condition for both groups. The low CISS symptom group, however, showed lower high beta power (21-29Hz) during completion of Conners CPT than the high CISS symptom group, suggesting greater cortical activation in the high CISS symptom group.

Conclusions: Overall the results of the study demonstrated that symptoms of asthenopia are also correlated with symptoms of inattention and predict performance deterioration in sustained attention. Additional increase in accommodative-vergence stress, however, was not shown to disrupt performance of the high symptom group to a greater extent than in the low symptom group possibly due to the absence of accommodative deficits in the high symptom group, absence of sustained vergence deficits and/or a relatively short duration of accommodative-vergence stress.

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INTRODUCTION

Many of the symptoms of Attention Deficit Hyperactivity disorder (ADHD) have also been reported for individuals with oculomotor problems of vergence and accommodation.

Borsting, Rouse, and Chu[1] found that school-aged children with symptomatic accommodative dysfunction and/or convergence insufficiency (CI) appear to have a higher frequency of ADHD-like behaviors as measured by the Conner's Parent Rating Scale-Revised Short Form (CPRS-R:S). Granet, Gomi, Ventura, and Miller-Scholte[2] also reported a three times greater incidence of ADHD among patients with CI when compared to the general population and, conversely, a three-fold greater incidence of CI in the ADHD population. Additionally Gronlund, Aring, Landgren and Hellstrom[3] reported that 76% of children and adolescents with ADHD in their study had abnormal ophthalmologic findings including subnormal visual acuity, strabismus, reduced stereo-vision, absent or subnormal near point convergence, refractive errors, small optic discs and/or signs of cognitive visual problems. Importantly, administration of stimulant medication did not significantly improve visual function in the ADHD group. These studies suggest a significant degree of comorbidity between oculomotor deficits and ADHD, which may necessitate a two-prong approach to management of some attentional problems in children and adults that besides ADHD-based therapies may also include treatment of oculomotor disorders with Vision Therapy (VT).

Indeed, in their recent study Borsting et al[4] administered 16 weeks of office-based vergence accommodative therapy (OBVAT) to 45 children (range 9-16 years old) diagnosed with CI and high symptoms of asthenopia and somatic problems as measured by the Convergence Insufficiency Symptoms Survey (CISS). At baseline the children had also significantly abnormal d scores on the Conners 3 ADHD Index (M=1.27) with greater severity of inattention symptoms (M=1.17). Following OBVAT significant improvements in binocular and accommodative function were accompanied by similar improvements on the Conners ADHD Index and CISS. The authors noted that CI seems to adversely affect attention and lead to behavioral and academic problems often noticed by parents and teachers.

Similarly, Barnhardt et al.[5] reported higher prevalence of performance-related symptoms on the CISS in 221 children (9 -18 years of age) diagnosed with symptomatic CI. The 5 most frequently reported symptoms in that group were all performance-related and included loss of place while reading, having to reread, reading slowly, loss of concentration and trouble remembering what was read.

In our previous study we also showed that when young adults without ADHD or oculomotor deficits were presented binocularly with a 2.0 D increase in accommodative demand, their cognitive performance declined on a measure of sustained attention (Conners CPT) often used in the diagnosis of ADHD.[6] In this study we were thus able to demonstrate that induction of accommodative-vergence fatigue with -2.0 D lenses could affect attentional processes and would be consistent with self-reported symptoms of an accommodative or vergence nature.

Accommodative insufficiency (AI) is a sensory motor anomaly of the visual system that is characterized by an inability to focus or sustain focus at near. It is often comorbid with Convergence Insufficiency.[7] Accommodation and convergence are coupled physiologically. Through this coupling, when the eyes accommodate, they also converge due to neurological coupling.

AI and CI, along with other binocular disorders such as convergence excess (CE), have been associated with similar symptomatology. In a retrospective review of 96 patients diagnosed with AI, Daum[8] reported a high incidence of blur (59%), headache (56%), asthenopia (45%), and diplopia (30%). Similar symptoms were subsequently reported by Daum[9] for patients diagnosed with symptomatic CI: blur (47%), headaches (54%), asthenopia (36%), and diplopia (47%). Between

the two studies the comorbidity of AI and CI was 65%.

Under optimal circumstances where the accommodative and vergence responses are closely matched, young persons will typically show a mild underaccommodation to a distance target. When viewing near targets, a mild amount of under-accommodation or accommodative lag can be expected. The amount of accommodative lag is not constant for everyone, but is different from one person to another. On average, the amount of accommodative lag behind the target plane is between 0.25 D and 0.50 D.[10,11] If introduced with a concurrent mental task while viewing near targets, such as reading, subjects will generally show an additional 0.25 to 0.75 accommodative shift toward far, presumably due to the activation of the sympathetic nervous system.[12]

Usually, the accommodative-vergence system is able to cope for short periods of time with some degree of conflict. Thus, a mild dissociation between accommodation and vergence reflected by an accommodative lag or a fixation disparity may not cause visual discomfort for a person engaged in a near visual task because the system is sufficiently flexible. In studies of asthenopia associated with stereoscopic displays, there is evidence that as the conflict between the vergence distance and accommodative distance increases or if such dissociated viewing becomes prolonged, symptoms of fatigue and discomfort are more likely to ensue as the viewer attempts to counteract the accommodation-vergence mismatch.[13,14,15]

Using the WAM-5500 autorefractor, Tosha et al[16] directly examined steady state accommodative responses over a 90 second period among college students with and without visual discomfort based on their scores on the Conlon Visual Discomfort Survey. In their study the high discomfort group showed an increase in accommodative lag over the recording period, whereas the low discomfort group had a stable response. In some of the high visual discomfort participants accommodative lag by the end of the 90-s period was as high as 1.5D at closer viewing distances (4 D and 5 D). The author suggested that the high visual discomfort group developed accommodative fatigue, with a higher lag of accommodation developing at a near viewing distance over time.

In our previous study we also found that an increase in accommodative lag over a 15-minute period induced by an -2.0 D accommodation-vergence stress was associated with deterioration of sustained attention on the Conners CPT.[6]

Following the same methodology in the present experiment we attempted to induce accommodative-vergence stress in young adults with normal CISS scores and those with scores of 21 or greater on the CISS questionnaire. It was previously shown that when a modified 15-question version of CISS was used to evaluate somatic, visual and performance based symptoms in 46 adults diagnosed with CI and 46 adults with normal binocular vision (NBV), the instrument had excellent sensitivity to CI (97.8%) and superior specificity to those with NBV (87%) when cutoff scores of ≥21 were used to identify individuals with CI.[17]

We hypothesized that individuals with high symptoms of asthenopia and associated somatic and performance issues would be less likely to tolerate additional accommodative-vergence stress than those with low CISS scores and would show greater deterioration in attentional performance on the Conners CPT The results of study may thus have direct relevance to prediction of performance in a variety of academic and professional settings.

METHOD

Participants

Forty-six college students (13 males and 33 females) between 18 and 31 years of age (M=21.80; SD=5.01) participated in the study for course credit. The study was approved by

the Institutional Review Board of the University of North Dakota. All participants were required to provide informed written consent prior to their participation. Participants were recruited on the basis of their scores on the Convergence Insufficiency Symptom Survey (CISS) that they completed in paper-and-pencil format in some of their psychology classes. Consistent with the recommendations of the CITT Study group for adults[17] those with symptom scores equal to or greater than 21 were assigned to the high CISS symptom group (n=19) while those with scores below 21 comprised the low CISS symptom group (n=27). Ten participants reported previous history of a stand-alone or co-morbid psychiatric conditions such as ADHD, depression and/or anxiety. Six of these participants were in the high CISS symptom group and 4 - in the low CISS symptom group. This difference in frequency of occurrence of psychiatric conditions between the two groups was not statistically significant ($\chi 2$= 0.28). ADHD prevalence was equally distributed across the two groups with 2 participants reporting previous history of ADHD in the high CISS symptom group and 2 in the low CISS symptom group. At the time of the study none of these individuals experienced any symptoms attributable to their condition either due to successful symptom management with pharmacotherapy (e.g. Adderral, Lisdexamfetamine (Vyvanse), Methylphenidate (Concerta), Duloxetin (Cymbalta), Venlafaxine (Effexor), and Setraline (Zoloft) and Bupropion (Wellbutrin)) or due to complete absence of symptoms at the time of testing (n=2). Thirty-eight of the participants (82.6%) did not report use of any tobacco products at the time of the study with 8 participants (17.4%) indicating regular cigarette smoking. Acute nicotine withdrawal in cigarette smokers have been found to affect their performance on Conners CPT.[18] For this reason smokers were instructed to have their usual number of cigarettes before coming to each testing session. None of the participants had a history of either learning or reading disability.

All participants were further screened for normal or corrected-to-normal visual acuity (20/20 or better in each eye) at distance and near. Uncorrected refractive errors and corrected over-refractions of the right eye all had spherical equivalent (SE, sphere + 0.5 X cyl.) between -0.50 sph. and +0.50 sph. and showed astigmatism < -0.75sph.

Materials

Convergence Insufficiency Symptom Survey

The CISS is a questionnaire with 15 questions designed to quantify symptoms associated with reading and near work. Each question requires a verbal response of "never, infrequently, sometimes, fairly often, and always." The highest possible score is 60, and the lowest possible score is 0. When used to evaluate symptoms in adults age 19 to 30 years by comparing a group with symptomatic CI with those with normal binocular vision, the mean CI Symptom Survey scores were 37.3 ± 9.3 and 11.0 ± 8.2 for CI and the normal binocular vision groups, respectively[17] Good discrimination (sensitivity, 97.8%; specificity, 87%) was obtained using a cutoff score of ≥21 for adults.[17] The CITT Study Group also reported an overall Cronbach's alpha of 0.956 for the survey indicating excellent internal consistency.[19] Reliability was assessed using the Interclass Correlation Coefficient (ICC) and the 95% limits of agreement. The ICC was 0.885 (95% CI: 0.798, 0.936) and the 95% limits of agreement were -9.0 to 7.6. The mean difference between the first and second administration was 0.68 points indicating minimum bias between the two administrations.[17]

Current Symptoms Scale

The Current Symptoms Scale by Barkley and Murphy[20] was used as a self-report measure of inattention and impulsivity. The scale contained 18 symptom items for ADHD

from DSM-IV arranged in such a way that items pertaining to inattention were odd numbered and those pertaining to hyperactive-impulsive symptoms were even-numbered. The items were rated on a four-point scale (from 0 to 3) with zero indicating 'never or rarely', three meaning 'very often' and one and two being 'sometimes' and 'often', respectively.[20] A symptom is considered clinically significant if a rating of 2 (often) or 3 (very often) is endorsed.[21] For adults ages 17-29, the threshold of clinical significance would be four symptoms of inattention and five symptoms of hyperactivity.[22] Reliability coefficients with an adult clinical population range from .84 to .95[23,24] suggesting excellent internal consistency. Negative and positive predictive power of the self- report versions CSS was shown to be adequate.[23] Specifically, the items that had the greatest ability to discriminate ADHD participants from controls were: failure to sustain attention, does not listen, fails to finish work, poor organization, avoids tasks that require sustained mental effort, difficulty working quietly, blurts out answers before questions are complete, and interrupts.[25]

Modified Thorington Phoria

This is a measure of the subjects' dissociated nearpoint horizontal phoria. The Saladin Card was placed on the moveable slide of the ACR/21 ruler and placed at 40 cm. while the other end of the slide was gently placed against the subject's forehead. A Maddox rod was held by the subject before their right eye with the lines horizontal. The Saladin Card contains a horizontal line of numbers to the right and left of a small center hole in the card. A penlight was held behind the hole by the examiner and illuminated, creating a percept of the vertical red line of light by the subject against the card when both eyes were open. Subjects were instructed to fixate the center white light, while keeping the numbers on the card clear. Subjects were then instructed to report the number to the right or left of the center white light that the vertical red line passed through. If the red line was reported as moving, subjects were asked to close their eyes and report the location of the red line when they first opened their eyes. The dissociated phoria was recorded as ortho (red line aligned with the center hole) or in prism diopters eso or exo (uncrossed or crossed diplopia, respectively). Measurements were conducted at baseline before cognitive testing and immediately after testing.

Static and Dynamic Accommodation

Static push-up accommodative amplitudes were measured for each subject monocularly and binocularly using an RAF rule according to Donder's clinical method.[26]

Steady-state accommodative responses were measured from the right eye using the Grand Seiko WAM-5500 auto-refractor (Grand Seiko Co. Ltd., Hiroshima, Japan) in HI-SPEED mode. The left eye was not covered during the experiment as all subjects viewed the near target stimulus binocularly, thus insuring a closed vergence loop. The Grand Seiko WAM-5500 is a binocular open-field autorefractor and keratometer that also permits recording of refraction and pupil size by connection to an external PC via an RS-232 port. The instrument can measure refraction in the range of ±22 D sphere and ±10 D cylinder in increments of 0.01, 0.12 or 0.25 D for power, and 1° for cylinder axis. In the present study the WAM-5500 software was set for the maximal resolution of 0.01 D.

Measurement data are displayed on an internal 5.6 in. color monitor, which permits visualization of the pupil to enable alignment of the instrument with the subject's visual axis. In high-speed mode, mean spherical equivalent refractive error (MSE; equal to spherical component + cylindrical power/2) and pupil diameter were recorded at a rate of 5 Hz by interfacing with a PC running the WAM communication system (WCS-1) software, allowing objective measurement of a subject's

steady-state accommodative response to letter targets. A number of research studies have recently showed that the WAM-5500 produces reliable and accurate measurements of accommodation.[27,16,28]

In the present study spherical accommodative response was sampled every 200ms during a 15-minute Continuous Performance Test presented on a laptop computer screen at a distance of 42 cm from the observer. Participants viewed a series of 2.5 cm high-contrast white letters on a black computer screen at a central point of fixation, yielding an approximate near Snellen equivalent letter size of 20/858 (angular subtense at the eye is inverse tangent of 2.5/40 or 3.57 degrees). During recording of steady-state accommodative responses focus of the corneal reflections on the WAM-5500 monitor was continuously maintained by the experimenter using a joystick.

Accommodative lag was determined by subtracting the subject's mean point of focus during testing (WAM-5500 steady-state refraction value 'REF_mean_ss') from accommodative demand of the target distance in diopters (43cm = 2.33 D) and adjusting for the baseline static refraction value ('REF_mean_static'). The baseline static refraction value was determined by sampling MSE 3 times while the subject looked at a distant 'cross' target placed 6 meters away. In the stress condition an additional adjustment was made for the accommodative demand placed by a -2.0 D lens essentially simulating a target distance of 23.09 cm.

Formula 1 (non-stress):

Accommodative lag (D) = -2.33 - REF_mean_ssnonstress – REF_mean_static

Formula 2 (- 2.0 D stress):

Accommodative lag (D) = -4.33 - REF_mean_ssstress – REF_mean_static

EEG recording.

EEG recording was carried out using Neurosky's Mindset headset. The headset incorporates a single active pea-sized electrode (10 mm diameter) that is placed in the left forehead area approximately 2 cm above the left eyebrow. This roughly corresponds to area Fp1 using the International 10-20 System of electrode placement. The reference electrode is integrated into the earpiece of the headset and measures electrical potential from two points on the left earlobe. The electrical potential is supplied directly to the embedded chipset for analog filtering with band pass and notch filters and 128 kHz digital sampling every second. Analogue data is then automatically converted into digital format and analyzed by Fast Fourier Transform (FFT) in the headset circuit board. FFT produces power values for each 1-s epoch and each frequency bin that are transmitted via Bluetooth to the Mindset Research Tools data acquisition software installed on a Mac Book Pro laptop. The extracted data represent the electrical potential difference between active and reference electrodes, and analyses of the power ratio of the frequency components to total power have reliably and accurately shown which frequency range is dominant at the time the data are taken.[29] Power values for each frequency component were then grouped into 3 frequency bands: theta (4-7Hz), alpha (8-11Hz) and low beta (12-20Hz), high beta (21-29Hz), and low gamma (30-40Hz).

Conners Continuous Performance Test (CPT-II)

The Conners Continuous Performance Test (CPT -II) is a neuropsychological task of sustained attention that has repeatedly been shown to differentiate ADHD from normal groups.[30] Moreover, in our previous study[6] we showed that CPT is also sensitive to changes in accommodative demand in normal non-ADHD adults. The test takes 14 minutes to complete and requires participants to make a

response (mouse click) as quickly as possible to any letter displayed in the center of a laptop computer screen except the letter "X" (probability of occurrence =0.10). Each letter (~2.5 cm, white on a black screen) is displayed for 250 ms over 18 blocks of 20 trials on a Sony laptop computer screen (screen resolution 1024 X 768) with high contrast (95.1%) The signal in each block is presented at one of the three interval rates, i.e. 1, 2, or 4 s in a counterbalanced order. Dependent measures include probability of clinical classification, hit reaction time, accuracy (errors of omission and commission), signal detection parameters of d' (sensitivity) and Beta (response bias) as well as response variability between and within the blocks (the standard error estimate of hit reaction time).

Procedure

Upon arrival at the lab each participant read and signed the informed consent form and was administered several optometric tests that included distance and near monocular and binocular acuities, monocular and binocular accommodative pushup amplitudes, modified Thorington Phoria testing at near and static WAM-5500 baseline autorefraction measurements of the right eye taken 3 times while subjects binocularly viewed a distant target at 6 m. Lastly, a probe of accommodative-vergence flexibility was given whereby each subject was asked to read aloud a 20/20 reduced Snellen line of letters binocularly at 40 cm. while -2.00 lenses were held before the subject's eyes or habitual correction. All subjects were able to successfully resolve the acuity letters without diplopia. This momentary ability to have accommodation stimulated while the vergence is held constant is known as relative accommodation and indicates a capacity of our subjects to fall within a normal range of clinically established positive relative accommodation values for adults.[31,32]

Following the exam, participants were asked to completely uncover their ears from any hair as well as to remove any earrings. Next the Neurosky Mindset headset was placed over their ears with the active electrode positioned in firm contact with the forehead area approximately 2 cm above the left brow. The subjects then placed their chin in the chin support of the WAM-5500 and were given instructions how to complete the Conners CPT by clicking on the corded mouse extending from the laptop. All participants first completed a 3-minute practice session before beginning the experimental blocks. Dynamic accommodation and pupil diameter of the right eye as well frontal EEG activity were recorded throughout the duration of the CPT.

Testing took place between 9:00 am and 5:00 pm and was comprised of two sessions (separated by at least 24 hours) that were administered in a counterbalanced order. Thus each participant completed a non-stress CPT session, during which participants viewed the laptop screen binocularly using their habitual optical correction of contact lenses or glasses (if they had corrected vision). In the stress condition participants completed the CPT task while wearing -2-D spherical lenses binocularly in a trial frame (if no glasses or contacts were worn) or wearing -2-D trial lenses binocularly clipped over their glasses.

Statistical Analyses

All data were analyzed using SPSS 21.0 statistical software (IBM, 2012). For each set of dependent measures (CPT, EEG and WAM-5500) a series of repeated measures ANOVAs were conducted, where test condition was entered as a within-subject variable (non-stress and -2.0D stress) and group membership (high CISS symptoms vs. low CISS symptoms) was a between-subject factor. Examination of skewness and kurtosis values as well as Q-Q plots with associated significance values for tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk) generated under the Explore procedure in SPSS showed that PSD distributions for all frequency bands

were significantly different from normality and were positively skewed (skewness > 3.0) and leptokurtic (kurtosis >10.0). This was expected as EEG data like many other physiological measures produces distributions of scores that deviate from normality.[33] Thus, following the procedure by Loo et al[34] we first used a natural logarithmic transformation to normalize the data and then applied the repeated ANOVA procedure to ln-transformed PSD data.

Using G-Power 3.1[35] we also calculated achieved statistical power for our 2 x 2 design with 46 participants given a moderate-to-large effect size observed on Conners CPT measures (f=0.4) and an average Pearson r correlation of 0.78 between repeated measures on Conners CPT. Our overall power for ANOVA tests was, thus, 0.80, which is the minimal acceptable power in research studies.

RESULTS

Visual and Self-report Measures

There were 10 males and 17 females in the low CISS symptom group (mean age = 23.7) and 3 males and 16 females in the high CISS symptom group (mean age = 21.0). Neither group displayed any issues with either accommodative insufficiency or positive relative accommodation. Specifically, accommodative insufficiency was assessed with a push-up test, and the near point of accommodation for each participant monocularly and binocularly was then compared to the minimum expected amplitude of accommodation for the participant's age according to Hofstetter's formula (15-0.25 x (age)). The difference of more than 2.00 D between this minimum age-adjusted amplitude of accommodation and recorded amplitude of accommodation is typically considered abnormal.[36] The average monocular (OD) difference of the mean amplitude of accommodation between the age-adjusted minimum and the mean of the high CISS symptom group was – 5.41 (SD=5.27) and for the group scoring low on the CISS it was – 7.52 (SD=11.02). These values did not significantly differ between the two CISS groups (t= -0.68, p=0.50). Since a -2.0 D lens was used in the stress condition, the experimenters made sure none of the participants showed a low positive relative accommodation, i.e. inability to obtain a clear and single percept of 20/20 sized Reduced Snellen letters at 40 cm through -2.00 lenses held binocularly in front of the eyes.

Dissociated phoria testing at near revealed that the two groups significantly differed on mean phoria values at baseline (t=2.33; p=0.25) with the low CISS symptom group being slightly esophoric (M = -0.41Δ, SD=5.1) and the high CISS symptom group significantly exophoric (M = 4.42Δ, SD=8.16). This difference corresponded to a small-to-medium effect size following Ferguson's[37] guidelines (Hedges' g= 0.72). The latter finding is often observed in patients with CI and high CISS scores, although in these studies their exophoria is typically greater (8-9Δ).[38] A mixed ANOVA also showed a significant main effect of test condition ($F_{1,42}$=6.09; p=0.02). After the -2.0 D lenses were removed following completion of the Conners CPT, participants showed significantly greater exophoria (M= 3.12; SE=0.93) compared to post-CPT phoria measurement in the non-stress condition (M=1.91; SE=1.07). The estimated effect size for this difference was moderate (Hedges g=1.21).

A significant testing condition x group interaction ($F_{1,42}$=11.66; p<0.01) was also observed. Simple effects analyses within group showed that the low CISS symptom group became significantly (t=-4.59; p<0.01) more exophoric after CPT testing (M=2.46; SD=4.18) than before testing (M=-0.41; SD=5.1). This mean difference corresponded to a small effect size (Hedges' g =0.61). At the same time there was no significant difference in dissociated phoria values before and after testing for the high CISS symptom group (M=4.23 vs. M=3.76).

The two CISS groups significantly (t= -8.70 p< 0.01) differed on their total CISS scores

with the high symptom group reporting more CI symptoms (M=28.68; SD=7.56) than the low symptom group (M=12.48; SD=5.09). The magnitude of effect for this group difference was large (Hedges g =2.56). The two groups also significantly differed (t=2.41; p=0.02) on their scores on the Inattentiveness subscale of the Current Symptoms Scale by Barkley and Murphy[20] with the high CISS symptom group showing greater symptoms of inattention (M=18.6; SD=10.4) than the low CISS symptom group (M=11.63; SD=7.90). This difference corresponded to a small-to-moderate effect size (Hedges g = 0.77). The scores on the two questionnaires were also significantly positively correlated (r=0.54, p<0.01). Baseline group characteristics are presented in Table 1.

Table 1. Means, standard deviations, and p-values for mean differences on visual measures as well as visual, somatic and behavioral symptoms between the low and high CISS symptom groups.

Measures	Low CISS (n=27)	High CISS (n=19)	*p*-Value
Visual Acuity at Near (LogMAR)	Mean (SD)	Mean (SD)	
OD	-.09 (.14)	-.11 (.05)	.63
OS	-.09 (.12)	-.09 (.07)	.83
OU	-.14 (.12)	-.14 (.09)	.89
Accommodative Amplitude (Diopters)			
OD	16.93 (11.48)	15.21 (5.38)	.61
OS	15.47 (6.77)	15.54 (6.66)	.97
OU	16.20 (8.76)	15.37 (5.79)	.75
Phoria at near (prism diopters; + = exo; - = eso)	-.41 (5.10)	4.43 (8.17)	.03
Self-Report Measures			
Convergence Insufficiency Symptom Survey (CISS)	12.48 (5.09)	28.68 (7.55)	<0.01
Current Symptoms Scale	11.62 (7.88)	18.64 (10.45)	.02

Conners CPT

A significant main effect of group was found for the number of commissions ($F_{1,42}$ =6.43, p=0.034 with high CISS symptom group showing a significantly greater number of commissions (M=18.69; SD=1.60) than the low CISS symptom group (M=14.17; SD=1.33) across both testing sessions. This difference corresponded to a large effect size (Hedges' g = 3.10). There was also a significant main effect of test condition for the number of commissions ($F_{1,42}$=6.43, p= 0.015) with participants showing significantly more commissions in the -2.0 D stress condition (M=17.31; SE=1.18) compared to the non-stress condition (M=15.56, SE=1.01). The magnitude of this effect was moderate (Hedges' g = 1.60). The time x group interaction was not significant.

A significant main effect of group was also found for target detectability ($F_{1,42}$=3.96; p=0.05) with the high CISS symptom group showing significantly poorer detectability (M=0.51; SE=0.09) than the low CISS symptom group (M= 0.73; SE=0.08). The magnitude of this effect was large (Hedges' g= 2.59). There was no significant main effect of test condition. The test condition x group interaction was not significant.

A significant main effect of group was also found for the number of perseverations ($F_{1,42}$=4.01; p=0.05) with the high CISS symptom group committing a greater number of perseverations (M=1.28; SE=0.36) than the low CISS symptom group (M= 0.61; SE=0.30). This difference corresponded to a moderate-to-large effect size (Hedges' g = 2.03). There was no significant main effect of test condition. The test condition x group interaction was not significant.

No significant main effects or interactions were found for probability of clinical classification, number of omissions, hit reaction time, hit reaction time standard error, variability, and response style. These results are summarized in Table 2.

WAM-5500

No significant main effects of either test condition or group were found for mean pupil diameter during completion of Conners CPT.

Table 2. Means and standard deviations for measures of Conner's CPT

Variable Name	Low CISS		High CISS	
	No Stress	-2.0 Stress	No Stress	-2.0 Stress
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Clinical probability	.35 (.23)	.39 (.19)	.40 (.29)	.35 (.18)
Omissions	4.12 (9.20)	3.00 (6.20)	3.44 (3.94)	3.11 (3.41)
Commissions	13.35 (5.45)	15.00 (7.82)	17.78 (7.96)	19.611 (7.43)
Hit Reaction Time (ms)	350.26 (37.07)	349.65 (42.91)	336.97 (28.31)	339.54 (31.72)
Hit Reaction Time SE	5.14 (2.27)	5.58 (4.15)	5.11 (1.61)	5.3839 (2.2850)
Variability	8.37 (6.14)	9.74 (13.51)	8.38 (5.25)	9.88 (10.93)
Detectability	.73 (.40)	.73 (.52)	.54 (.40)	.49 (.40)
Response Style	.57 (1.16)	.40 (.52)	.45 (.35)	.29 (.29)
Perseverations	.58 (1.14)	.69 (1.32)	1.50 (3.75)	1.06 (1.59)

Table 3. Means and standard deviations for autorefraction, pupil diameter and frontal ln-transformed Power Spectral Densities (PSD) of 5 EEG frequency bands.

Variable Name	Low CISS		High CISS	
	No Stress	-2.0 Stress	No Stress	-2.0 Stress
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Accommodative Lag (D)	- 1.16 (.51)	-4.41 (.58)	-1.12 (.99)	-4.22 (1.19)
Pupil diameter (mm)	4.30 (.79)	4.10 (.98)	4.61 (.59)	4.65 (.54)
Ln-theta (4-7 Hz)	3.11 (.93)	3.15 (1.29)	3.45 (1.33)	3.25 (.96)
Ln-Alpha (8-12 Hz)	2.55 (1.02)	2.48 (1.15)	3.18 (1.56)	2.67 (.82)
Ln-Beta (13-20Hz)	2.34 (2.15)	2.01 (1.55)	3.11 (3.15)	3.32 (2.73)
Ln-High Beta (21-29Hz)	1.17(1.47)	.94 (1.03)	2.02 (2.22)	1.63 (1.12)
Ln-High Gamma (30-40Hz)	-1.27 (2.61)	-1.52 (1.68)	.02 (4.18)	-.14 (3.24)

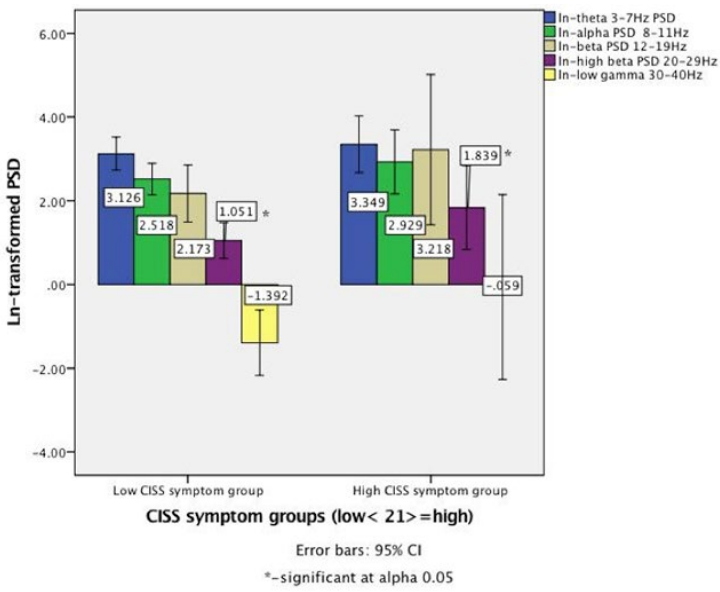

Figure 1. LN-transformed PSDs for High and Low CISS symptom groups during completion of the Conners CPT averaged across 2 testing sessions.

The test condition x group interaction was not significant. These results are summarized in Table 3.

A significant main effect of test condition ($F_{1,42}$ = 85.21, p<0.01) was found for accommodative lag during completion of Conners CPT. Accommodative lag was smaller in the non-stress condition (M = -1.14; SE=0.12) compared to the -2.0 D stress condition (M=-4.31; SE=0.14). The magnitude of the effect was very large (Hedges' g = 22.64). There was no significant effect of group. The test condition x group interaction was not significant. These results are presented in Table 3.

EEG

A significant main effect of group was found for Ln-transformed high beta power (21- 29Hz; $F_{1,40}$ = 3.94, p=0.05) with low CISS group showing lower high beta power during completion of Conner's CPT (M=1.05; SD=0.23) than the high CISS group (M=1.84; SD=0.35). The effect size for this group difference was large (Hedges' g= 2.72). No significant effects of either test condition or group were found for theta, alpha, low beta, or low gamma groups. None of the test condition x group interactions were significant. These results are summarized in Table 3 and Figure 1.

DISCUSSION

Consistent with previous findings by Borsting et al[1] who found an association between symptoms of inattentiveness and oculomotor deficits in children who also scored high on the CISS, in the present study those individuals who reported high symptomatology on the CISS questionnaire also reported significantly greater symptomatology of inattentiveness than the low CISS symptom group on the Current Symptom Scale, often used in diagnosis of ADHD.

Performance on the Conner's CPT also partially supported our original hypothesis that the high CISS symptom group would show greater inattentiveness than the low CISS

symptom group. Specifically the former group performed significantly more perseverations, errors of commission and displayed significantly poorer target detectability than the latter group. On physiological level poorer performance on a sustained attention task may be related to significantly greater high beta power (21-29Hz) recorded in the high CISS symptom group compared to the low CISS symptom group. Beta power has been shown to play a significant role in visual attention and to predict better performance on visual attention tests in humans without attentional or visual deficits.[39] Brookings, Wilson & Swain[40] also reported that an increase in frontal and central high beta power (16.2-24.9Hz) in their study was associated with increases in complexity of a computerized air-traffic control simulation task. Previous studies of EEG patterns in ADHD adults have identified alpha, theta and beta activity as important indicators of activation[41,42] with ADHD individuals demonstrating lower resting state arousal (i.e., increased alpha activity) but requiring greater activation (i.e., decreased theta activity and increased beta activity) in order to engage in the sustained attention task. More recently, Loo et al[34] compared patterns of EEG activity of 38 adults with ADHD with similar activity of 42 non-ADHD controls during performance of the Conners CPT. The researchers reported greater cortical activation in the ADHD group as indexed by greater attenuation of frontal alpha power (8-10Hz) and significant increase in frontal beta power (17-18Hz) compared to normal controls. They concluded that increased cortical activation particularly in frontal areas may be necessary in adults with ADHD to sustain attention over a long period of time. Similarly in the present study the high CISS symptom group with greater ADHD symptomatology may have found the CPT task visually and/or cognitively as more challenging than the low CISS, low ADHD symptom group, which resulted in greater cortical activation in the frontal high beta range.

Contrary to our hypothesis, however, the high CISS group did not perform worse on the Conners CPT than the low CISS group when accommodative demand was increased by using -2.0 D lenses. In our previous study we showed that such an increase in accommodative demand is stressful for the visual system resulting in deterioration of sustained visual attention and increase in accommodative lag.[6] Similarly in the present study we did observe performance deterioration in both groups in the -2.D stress condition on the number of errors of commission as well as a significantly greater accommodative lag. Mean accommodative lags across the two groups for the baseline and -2.D stress conditions were virtually identical to the ones reported in our original study (-1.02D and -4.24 D) and were -1.14D and -4.32D, respectively. The reason why the high CISS group did not do worse compared to the low CISS group may be related to the absence of any measurable accommodative issues found in the high CISS symptom group. Specifically, both groups had similar accommodative amplitudes, which fell in the normal range according to Hofstetter's formula, had normal accommodative facility and did not have any significant phoria issues. Both groups showed increased accommodative lag in the stress condition but the magnitude of the lag was not different between the groups.

Although the CISS questionnaire seems to be a valid and reliable tool when used in conjunction with conventional diagnostic measures such as Near Point of Convergence (NPC) and fusional vergence amplitudes (PFV/NFV) and has been found useful in assessment of symptom improvement following vision therapy, its utility as a stand-alone screening tool for vergence and accommodative disorders has been disputed.[43] It is very possible that our high CISS symptom group did not have significant binocular issues driving their CISS symptoms (in the absence of NPC and PFV evaluation it cannot be ruled out).

Another reason may be that there may have been a lack of additional sustained fusional vergence difficulty transpiring when accommodation and vergence were dissociated by the -2.00 stress-inducing lenses. That is, when the high CISS symptom group was presented with the -2.00 D binocular stress, an adequate physiological vergence response may have been maintained without causing any additional adverse attentional distractions. For example, it is presumed that when putting on -2.00 lenses, an initial blur-driven accommodative convergence response in the less exo/more eso direction will ensue. This would be followed by an immediate fixation disparity-induced fusional vergence response in the opposite direction (divergence, if an eso fixation disparity is induced) as the system attempts to achieve and maintain a single, clear image and to reach some sort of homeostasis between the accommodation and vergence systems. Although vergence responses, were not directly measured in the present study, we did observe significantly greater exophoria in the low CISS symptom group following increased accommodative /vergence demand, but the same was not true for the high CISS symptom group.

At the same time both groups may have simply chosen blur over accommodation, which would have produced little change to the vergence system through the AC/A ratio and would explain absence of group differences on the Conners CPT in the -2.0D stress condition. Indeed, accommodative lag across the groups was on average 4.33 D over the 15-minute period. Accommodative lags of greater than 1.75D are very likely to exceed subjective depth of focus (DOF), which has been defined as a blur detection threshold, thus resulting in blurry retinal images.[44]

Chung et al[45] previously showed that with increasing amount of blur (up to 3D), larger print sizes are required to maintain maximum reading speeds. The blur may be easier to deal with on the Conners CPT task compared to reading as it involves response inhibition only during presentation of one relatively large letter X, which may not have increased cognitive load to the level necessary to significantly disrupt performance of the high CISS symptom group compared to the low CISS symptom group. Yet, increases in cognitive demand during cognitive testing have been suggested to increase accommodative lag independently of stimulus characteristics and autonomic arousal.[46] It would thus be of interest to evaluate attentional and cognitive performance of patients with high symptoms of asthenopia over longer periods of near work and on a variety of cognitive tests and with various sized print to tease out contributions of visual, cognitive, physiological factors and stimulus characteristics to performance. Furthermore, in addition to the dynamic measurements of accommodation as was used in this study, dynamic measurement of the disjunctive (vergence) eye movement fluctuations from binocular instability using a real-time eye tracking device may also prove to be insightful. Such research will help clinicians better understand what type of attentional problems may be related to ADHD and which problems may be successfully remediated non-pharmacologically with oculomotor vision therapy that depending on the visual deficit may emphasize vergences, accommodation activities or both. Such therapy has been reported to produce 80- 91% improvement rates in visual measures and symptoms severity.[47]

Study Limitations

As mentioned previously in the present study we neither confirmed nor ruled out binocular problems in our high CISS symptom group, which alone may have accounted for the pattern of observed results. Another limitation involves a relatively small sample size especially for the high CISS symptom group (n=18), which allowed detection of only medium-to-large effect sizes for the between-subject variable of group type. Other limitations include the use of only one

frontal EEG electrode. Although Loo et al[34] did report greatest differences in the alpha range between ADHD and non-ADHD adults in the frontal region, the researchers also found differences in the parietal region, and to the knowledge of the author's patterns of EEG activity during cognitive testing have not been measured in adults with Convergence Insufficiency. It is, therefore, possible that there may have been shifts in the band activity in other brain regions under the condition of increased accommodative demand but the measurements from these regions were not taken.

CONCLUSION

Overall the results of the study demonstrated that symptoms of asthenopia usually associated with oculomotor deficits such as Convergence Insufficiency and Accommodative Insufficiency are also correlated with symptoms of inattention and predict performance deterioration in sustained attention. Additional increase in accommodative-vergence stress intended to augment visual discomfort, however, was not shown to disrupt performance of the high symptom group to a greater extent than in the low symptom group. This finding may be related to the absence of accommodative deficits in the high symptom group, the absence of sustained vergence deficits and/or a relatively short duration of accommodative-vergence stress.

REFERENCES

1. Borsting E, Rouse M, Chu R. Measuring ADHD behaviors in children with symptomatic accommodative dysfunction or convergence insufficiency: a preliminary study. Optometry 2005;76:588-92.
2. Granet DB, Gomi CF, Ventura R, Miller-Scholte A. The relationship between convergence insufficiency and ADHD. Strabismus 2005;13:163-68.
3. Gronlund MA, Aring E, Landgren M, Hellstrom A. Visual function and ocular features in children and adolescents with attention deficit hyperactivity disorder, with and without treatment with stimulants. Eye 2007;21:494–502.
4. Borsting, E., Mitchell, G. L., Arnold, L. E., Sheiman, M., Chase, C., Kulp, M., & Cotter, S. (2013). Behavioral and Emotional Problems Associated With Convergence Insufficiency in Children: An Open Trial. J Atten Disord, 1087054713511528.
5. Barnhardt C, Cotter SA, Mitchell GL, Scheiman M, Kulp MT. Symptoms in children with convergence insufficiency: before and after treatment. Optom Vis Sci 2012;89(10):1512.
6. Poltavski DV, Biberdorf D, Petros TV. Accommodative response and cortical activity during sustained attention. Vision Res 2012;63:1-8.
7. Marran LF, De Land PN, Ngyen AL. Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency. Optometry Vis Sci 2006;83:281-89.
8. Daum KM. Accommodative dysfunction. Documenta Ophthalmol 1983;55: 177-98.
9. Daum KM. Convergence insufficiency. Am J Optom Physiol Opt 1984;61:16-22.
10. Fincham EM, Walton J. The reciprocal actions of accommodation and convergence. J Physiol 1957;137:488-508.
11. Wasaki T, Tawara A, Miyake N. Effects of visual optical stimuli for accommodation-convergence system on asthenopia. Nippon Ganka Gakkai Zasshi 2006;110:5-12.
12. Bullimore MA, Gilmartin, B. The accommodative response, refractive error and mental effort: 1. The sympathetic nervous system. Documenta Opthalmol 1988; 69:385-97.
13. Yano S, Ide S, Misuhanshi T, Thwaites, H. A study of visual fatigue and visual comfort for 3D HDTV/HDTV images. Displays 2002;23:191-201.
14. Emoto M, Niida T, Okano F. Repeated vergence adaptation causes the decline of visual functions in watching stereoscopic television. J Disp Technol 2005;1:328-40.
15. Hoffman D, Girshick A, Akely K, Banks M. Vergence-accommodation conflicts hinder visual performance and cause visual fatigue. J Vision 2008;8:33.1-3330.
16. Tosha C, Borsting E, Ridder III WH, Chase C. Accommodation response and visual discomfort. Ophthalmic Physiol Opt 2009;29:625-33.
17. Rouse MW, Borsting EJ, Lynn Mitchell G, Scheiman M, Cotter SA, Cooper J, Wensveen J. Validity and reliability of the revised convergence insufficiency symptom survey in adults. Ophthalmic Physiol Opt 2004;24:384-90.
18. Conners CK, Levin ED, Sparrow E, Hinton SC, Erhardt D, Meck WH, Rose JE, March J. Nicotine and attention in adult attention deficit hyperactivity disorder (ADHD). Psychopharmacology bulletin 1996; 32(1):67-74.
19. Borsting EJ, Rouse MW, Mitchell GL, Scheiman M, Cotter SA, Cooper J. Convergence Insufficiency Treatment Trial Group. Validity and reliability of the revised convergence insufficiency symptom survey in children aged 9 to 18 years. Opt Vis Sci 2003;80:832-38.
20. Barkley RA, Murphy KR. Attention-deficit hyperactivity disorder: a clinical workbook, 2nd ed. New York: The Guildford Press, 1998.

21. Barkley RA, Murphy KR. Attention Deficit Hyperactivity Disorder: A clinical Workbook, 3rd ed. New York: Guilford Press, 2006.
22. Murphy KR, Barkley RA. Prevalence of DSM IV symptoms of ADHD in adult licensed drivers: Implications for clinical diagnosis. J Atten Disorders 1996;1:147-61.
23. Barkley RA, Knouse LE, Murphy KR. Correspondence and disparity in the self-and other ratings of current and childhood ADHD symptoms and impairment in adults with ADHD. Psychol Assessment. 2011;23:437-46.
24. Zucker M, Morris MK, Ingram SM, Morris RD, Bakeman R. Concordance of self- and informant- ratings of adults" current and childhood attention-deficit/hyperactivity disorder symptoms. Psychol Assessment 2002;14:379-89.
25. O'Donnell JP, McCann KK, Pluth S. Assessing adult ADHD using a self-report symptom checklist. Psychol Rep 2001;88:871-81.
26. Donders FC. On the Anomalies of Accommodation and Refraction of the Eye. With a Preliminary Essay on Physiological Dioptrics, vol. XXII (Translated by Moor WD). London: The New Sydenham Society, 1864.
27. Chase C, Tosha C, Borsting E, Ridder III WH. Visual discomfort and objective measures of static accommodation. Optom Vis Sci 2009;86:883-89.
28. Sheppard AL, Davies LN. Clinical evaluation of the Grand Seiko Auto Ref/Keratometer WAM-5500. Ophthalmic Physiol Opt 2010;30:143-51.
29. Yasui Y. A brainwave signal measurement and data processing technique for daily life applications. J Physiol Anthropol 2009;28:145-50.
30. Epstein JN, Conners CK, Klaric J, Costello JE, Angold A. Relations between Continuous Performance Test performance measures and ADHD behaviors. J Abnorm Child Psych 2003;31:543-54.
31. Fry GA. Basic concepts underlying graphical analysis. In: Schor CM, Ciuffreda K, eds. Vergence Eye Movements: Basic and Clinical Aspects. Boston: Butterworths;1983:605-46.
32. Morgan MW. Accommodation and vergence. Amer J Opt Arch Am Acad Optom 1968;45:417–54.
33. Arruda JE, McGee HA, Zhang H, & Stanny CJ. The effects of EEG data transformations on the solution accuracy of principal component analysis. Psychophysiology 2011;48:370-76.
34. Loo SL, Hale TS, Macion J, Hanada G, McGough JJ, McCracken JT, Smalley SL. Cortical activity patterns in ADHD during arousal, activation and sustained attention. Neuropsychologia 2009;47:2114-19.
35. Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods, 41, 1149-1160
36. Bartuccio M, Taub MB, Kieser, J. Accommodative Insufficiency: A Literature and Record Review. Optom Vis Dev 2008;39:35-40.
37. Ferguson CJ. An effect size primer: A guide for clinicians and researchers. Prof Psych Res Pract 2009;40(5):532.
38. Cooper J and Jamal N. Convergence insufficiency – a major review. Optometry 2012;83(4):137-58.
39. Gola M, Magnuski M, Szumska I, Wróbel A. EEG beta band activity is related to attention and attentional deficits in the visual performance of elderly subjects. Int J Psychophysiol 2013;89:334-41.
40. Brookings JB, Wilson GF, Swain CR. Psychophysiological responses to changes in workload during simulated air traffic control. Biol Psychol 1996;42:361-77.
41. Chabot RJ, Serfontein G. Quantitative electroencephalographic profiles of children with attention deficit disorder. Biol Psychiat 1996;40:951–963.
42. Clarke AR, Barry RJ, McCarthy R, Selikowitz M, Brown CR. EEG evidence for a new conceptualisation of attention deficit hyperactivity disorder. Clin Neurophysiol 2002;113:1036–44.
43. Horwood AM, Toor S, Riddell PM. Screening for convergence insufficiency using the CISS is not indicated in young adults. British Journal of Ophthalmology. 2014 Feb 14:bjophthalmol-2013.
44. Yao P, Lin H, Huang J, Chu R, Jiang BC. Objective depth-of-focus is different from subjective depth-of-focus and correlated with accommodative microfluctuations. Vision Res 2010;50:1266-73.
45. Chung ST, Jarvis SH, Cheung SH. The effect of dioptric blur on reading performance. Vision Res 2007;47(12):1584-94.
46. Jainta S, Hoormann J, Jaschinski W. Ocular accommodation and cognitive demand: An additional indicator besides pupil size and cardiovascular measures? J Neg Res Biomed 2008;7:6. Available at: http://goo.gl/LzzOtY. Accessed February 24, 2016.
47. Convergence Insufficiency Treatment Trial Investigator Group Randomized clinical trial of treatments for symptomatic convergence insufficiency in children. Arch Ophthalmol 2008;126: 1336-1349.

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