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Original Article

Stereoacuity, Fusional Vergence Amplitudes and Refractive Errors Prior to Treatment in Patients with Attention-Deficit Hyperactivity Disorder

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Abstract

Objectives: To evaluate stereoacuity, fusional vergence amplitudes and refractive errors in Attention-Deficit Hyperactivity Disorder (ADHD) patients.

Materials and Methods: Twenty-three patients, newly diagnosed as ADHD without any previous medication, and 17 healthy control subjects were included. Retrospective data analysis of comprehensive eye examination, stereoacuity and fusional vergence amplitudes of the patients were performed.

Results: The mean age at the time of diagnosis was 10.68±2.34 (7-16) in ADHD group (14 male, 9 female) and 12.23±2.16 (7-15) in the control group (25 male, 23 female) patients (p=0.605). The mean stereoacuity was 142.14±152.65 (15-480) sec/arc in patients with ADHD and 46.3±44.11 (15-240) sec/arc in the control group (p<0.001). For ADHD patients, the mean convergence and divergence amplitudes at distance were 19.87 ± 8.40 (6 to 38) prism diopter (PD) and -9.09 ± -4.34 (-4 to -25) PD, and 37.30 ± 12.81 (14 to 70) PD and -13.13 ± -3.45 (-4 to -20) PD at near, respectively. The mean cycloplegic spherical equivalent was 1.06 ± 1.13 (-1 to 4.63) diopter in ADHD patients, with 6 patients having significant refractive errors (hyperopia in 4 patients, astigmatism in 2 patients). There were no significant difference in between groups, in terms of spherical equivalents, convergence and divergence amplitudes at distance and near (p=0.123, p=0.176, p=0.464, p=0.489, p=0.086, respectively).

Conclusion: Fusional vergence amplitudes did not present significant difference, while the mean value of stereoacuity was significantly lower in newly diagnosed ADHD patients prior to treatment.

Keywords: Attention-deficit and hyperactivity disorder, fusional vergence, stereoacuity

Introduction

Attention-deficit hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders in children and adolescents. The prevalence of ADHD in developed countries is reported to be 2-18% among children at the age of 6-17 years.[1,2] ADHD is characterized by low attention, increased hyperactivity, impulsivity and lack of control of inappropriate behaviors.[3] In addition to quality of life, school performance is likely to be affected in patients with ADHD. In the literature, despite the variable results in studies associating visual dysfunction with school performance, there is a possible relationship between the symptoms of visual problems and ADHD-related behaviors.[4,5]

Brain imaging studies demonstrated a maturation delay in the brains of ADHD patients, with reduced striatal volume and differences in hippocampal, accumbens and amygdala

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volumes as compared to healthy controls. These findings along with dopamine and neuroepinephrine imbalance in the prefrontal cortex, supported the deficits in emotional regulation, motivation, and memory in these patients.[6,7] Since the eyes are thought to be continuation of central nervous system, the ocular system enables the evaluation of neurological changes and nervous system's activatory/inhibitory states.[8] In patients with ADHD, binocular vision changes and oculomotor deficits such as convergence insufficiency[9,10], accomodative dysfunction[11], reduced stereoacuity[12] and ametropia[13] have been reported. Regarding underlying mechanisms, Poltavski et al.[14] suggested a bidirectional relationship between attention and accommodation, however association of oculomotor control changes such as accommodative dysfunction and convergence insufficiency, with ADHD is not clearly known yet. Additionally, there are several contradictory reports in terms of stereoacuity, refractive state etc.[12,13], and treatment status of the patients enrolled in those studies also varied. Therefore, this study aims to investigate stereoacuity, fusional vergence amplitudes and cycloplegic refractive errors in newly diagnosed ADHD patients prior to medication.

Materials and Methods

The charts of 23 consecutive patients who are newly diagnosed with ADHD according to DSM-IV criteria[3] and received no medication earlier, and the data of 48 age and sex similar control patients without ADHD who consecutively admitted to Ophthalmology Outpatient Clinic for routine evaluation were retrospectively reviewed. The study was approved by the Institutional Ethics Review Board of University and is compliant with the precepts of Helsinki Declaration. Patients with congenital or acquired ophthalmic pathologies (such as optic nerve disease, glaucoma, cataract or additional media opacities, amblyopia and strabismus), ophthalmic surgery history and systemic or neuropsychiatric diseases other than ADHD were excluded. Stereoacuity with TNO random-dot stereo test (Lameris Intrumenten, Groeningen, the Netherlands, 17th Edition), fusional vergence amplitudes, presence of heterophoria with cover/uncover test, best corrected visual acuity (BCVA) according to Snellen scale and spherical equivalent (SE) of refractive errors (Topcon KR-7000P) (Topcon Europe BV, Capellea/dIJssel, the Netherlands) after cycloplegia (with 1% cyclopentolate hydrochloride) were recorded for all patients. As described in the literature[15], fusional convergence and divergence amplitudes at distance (6m) and at near (33cm) were measured by the same two examiners (IK, EDB) 3 times with 15 minutes intervals with placement of the fixed horizontal prism bar (1D-40D) in front of an eye in all patients, while patients were fixating on an accommodative target. The base-out prism power was gradually increased for convergence and the base-in prism bar was gradually increased for divergence, and the patient was asked to identify the point at which the target image appeared to be doubled; this prism power was designated as "the break point". Cases with spectacles were tested with habitual optical correction in glasses or contact lenses. The mean value of the fusional vergence measurements were taken into account for the statistical analysis. Significant refractive errors were described as a SE of myopia ≥0.5 diopter (D) or hyperopia ≥1.0 D. Significant astigmatism was defined as a level of ≥1.0 D and anisometropia, ≥1.0 D SE.[16]

The statistical analysis was performed using SPSS software for Windows version 15.0 (SPSS Inc, Chicago, Illinois, USA) and Microsoft Office Excel (Microsoft, Redmond, Washington, USA). For stereoacuity, all values were transformed to the logarithm of arc seconds.[17] Statistical analyses were performed by Independent t-test, Chi-square test. A value of $p<0.05$ was accepted as statistically significant.

Results

The mean age of the subjects were 10.68±2.34 (range, 7-16) and 12.23±2.16 (range, 7-15) in patients with ADHD (14 male, 9 female) and in the control group (25 male, 23 female), respectively. Anterior segment and fundus examinations were unremarkable and BCVA was 20/20 in both eyes of all subjects. No patient was found to present with either restriction in eye movements, heterotropia, or anisometropia. Twenty-two patients (95.5%) with ADHD, who were able to perform TNO random-dot stereo test, had stereoacuity (at least 480 sec/arc) with full refractive correction. The mean and the median values for stereoacuity were 142.14±152.65 (range, 15-480) sec/arc and 60 sec/arc, respectively. The mean of convergence and divergence amplitudes at distance were 19.87 ± 8.40 (range, 6 to 38) prism diopter (PD) and -9.09 ± -4.34 (-4 to -25) PD, and at near 37.30 ± 12.81 (14 to 70) PD, and -13.13 ± -3.45 (-4 to -20) PD, respectively. The SE following cycloplegia was 1.06 ± 1.13 (range, -1 to 4,63) D. Thirteen patients were found to have significant refractive errors (hyperopia in 13 patients, astigmatism in 2 patients). Two patients who had hyperopia higher than 3.5 D were initiated on spectacles due to asthenopia and decreased BCVA. In the control group, all subjects were able to perform TNO random-dot stereo test and had stereoacuity with the mean of 46.3 ± 44.11 (range, 15 to 240) and the median of 30 sec/arc. The mean of convergence and divergence amplitudes at distance were 23.54 ± 6.24 (range, 14 to 36) and -9.67 ± -3.71 (range, -4 to -16) PD, and at near 38.21 ± 8.13 (range, 25 to 64) and -15.76 ± -3.52 (range, -12 to -25) PD, respectively. Following cycloplegia, the mean SE was 0.53 ± 1.76 (range, -2,75 to 2,12) D, while 8 subjects had significant refractive errors (myopia in 3 patients, hyperopia in 5 patient and astigmatism in 2 patient). There were no statistically significant difference in between groups in terms of SE, convergence and divergence amplitudes at distance and at near ($p=0.358$, $p=0.289$, $p=0.492$, $p=0.452$ and $p=0.127$; t-test, respectively). Stereoacuity, fusional vergence amplitudes and refractive status of the subjects are summarized in Table 1.

Discussion

ADHD is thought to be related with several negative outcomes, such as antisocial behaviors, social and peer problems, and psychiatric disorders later in life.[18,19] Specifically school performance, along with intellectual capacity, social abilities and occupational functions were impaired in patients with ADHD. In addition, ADHD is considered to be a major public health problem, since economic burden to families and community is noteworthy.[3,20,21]

A possible association between ADHD and visual problems was reported.[4,5] In the literature, there are only few studies revealing relationship of ADHD with ocular abnormalities.[8,13,22-23] Granet et al.[8] retrospectively evaluated 266 children with convergence insufficiency and presented 26 (21 male, 5 female) patients (9.8%) with ADHD, either at the time of diagnosis or during the follow-up period. Among them, 20 (76.9%) patients were on medical treatment and 6 patients did not receive any treatment before or stopped the treatment long time ago. Additionally, review of 176 patients with ADHD, who had also undergone ophthalmic evaluation, revealed that 29 patients (15.9%) were diagnosed with convergence insufficiency based on their medical records. Thus, they suggested that convergence insufficiency should be investigated in patients with ADHD, despite the lack of causal relationship.

Vergence defines simultaneous movements of eyes in opposite directions in order to have single binocular vision.[24] Viewing through a range of prisms in both a base-in and then base-out direction, placed in front of the eyes, has been used for a long time as a diagnostic measure of dysfunction of vergence and accommodation.[25] The capacity to see a single image via the base-out prisms without diplopia or blur is named as fusional limit and determines the strength of convergence response, and vice versa.[26] Therefore, fusional amplitudes display an important role in maintenance of single binocular vision.[15] For instance, low positive fusional limits, with the accompanying complaints of asthenopia, blur or diplopia leading to frontal headaches following prolonged periods of near work, might be distracting and affect school performance adversely.[27-29] Besides, oculomotor dynamics are related to brain areas controlling attention, and also demonstrated sensitive to alterations in the attentional status.[14] Animal models also indicated that superior colliculus (SC) which constitutes the principal subcortical area involved in ocular control, participated in the regulation of near response, visual fixation, accommodation and convergence.[30,31] SC is also linked to distractibility and proposed to be dysfunctional in ADHD.[32] Therefore, the evaluation of steroacuity and fusional vergence amplitudes are of special importance in patients with ADHD. Gronlund et al.[12] investigated ADHD patients, who were on medical treatment, both before and 2 hours after the stimulant use. They reported that the rate of patients whose stereoacuity ≥60 sec/arc was significantly higher in ADHD population, independent of stimulant use. The rate of convergence near point <6 cm was significantly lower in ADHD patients before the stimulant use, while there was no significant difference between the groups 2 hours after the stimulant use. Fabian et al.[23] compared 56 ADHD patients with 66 control subjects and did not find statistically significant difference in terms of stereoacuity (41.5 sec/arc and 40.8 sec/arc, respectively; p=0.29) and fusional vergence amplitudes. They also noted that 15 patients (27%) were currently taking methylphenidate treatment. On the other hand, Fabian et al.[23] did not report convergence insufficiency in any of their patients. Despite the near point of convergence was

Table 1. Stereoacuity, fusional vergence amplitudes and refractive status of children

	ADHD (n=23)	Control (n=17)	
BCVA (Snellen)	20/20	20/20	p=0.500*
TNO Mean (sec/arc) ≥480 sec/arc (n, %)	 142.14±152.65 (15-480) 21 (%95.5)	 62.5±56.65 (15-240) 17 (%100)	 p=0.013* p=0.132**
DCA (PD)	19.87±8.40 (6 to 38)	21,16±5,73 (14 to 36)	p=0.289*
DDA (PD)	-9.09±-4.34 (-4 to -25)	-9.11±- -3.16 (-4 to -16)	p=0.492*
NCA (PD)	37.30±12.81 (14 to 70)	36.89±7.77 (24 to 54)	p=0.452*
NDA (PD)	-13.13± -3.45 (-4 to -20)	-14.38± -3.64 (-10 to -20)	p=0.127*
Spherical equivalent (D)	1.06±1.13 (-1 to 4.63)	0.53±1.76 (-2.75 to 2.12)	p=0.358*
Myopia (n, %)	1 (%4.3)	3 (%17.6)	p=0.087**
Hyperopia (n, %) ≥1 D ≥3,5 D	 13 (%56.5) 2 (%8.7)	 5 (%29.4) 0 (%0)	 p=0.087** p=0.111**
Astigmatism (n, %)	2 (%8.7)	2 (%11.76)	p=0.378**
Anisometropia (n, %)	0 (%0)	0 (%0)	p=0.500**

ADHD: Attention-deficit hyperactivity disorder, BCVA: Best corrected visual acuity, PD: prism diopter, DCA: Convergence angle at distance, DDA: Divergence angle at distance, NCA: Convergence angle at near, NDA: Divergence angle at near.
* Independent t-test
** Chi-square test

Table 2. Spherical equivalents after cycloplegia in patients with ADHD in the literature			
	ADHD	**Control**	
Gronlund et al.[12]	Right; 1.16±1.91 ((-2.0)- (8.25)) Left; 1.24±1.90 ((-1.75) - (9.25)	Right; 0.59±1.19 ((-2.13) - (2.75)) Left; 0.68±1.40 ((-2.75) - (6.75))	p>0.05*
Fabian et al.[22]	0.63 ((-1.88) - (2.75))	0.89 ((-1.25) - (5.38))	p=0.16**
Larranaga-Fragoso et al.[26]	Right; 0.75±0.94 ((-1.25) - (2.88)) Left; 0.90±1.06 ((-1.33) - (3.0))	-	
Present study	1.06±1.13 ((-1) - (4.63))	0.53±1.76 ((-2.75) - (2.12))	p=0.358**

ADHD: Attention-deficit hyperactivity disorder.
* Mann Whitney U test
** Independent t-test

significantly lower in patients with ADHD (5.3 (range, 3 - 15) and 4.1 (range, 2 -10); p=0.002), this did not reveal any clinical importance, since these values were <6 cm. In the present study, although all patients with ADHD had stereoacuity of at least 480 sec/arc, the mean value of stereoacuity in these patients was significantly lower as compared to control group. In addition, there was no significant difference in terms of fusional vergence amplitudes. The limitation of the present study is the lack of data regarding near point of convergence. However, convergence insufficiency was not present in any of the patients in terms of symptoms or decreased positive fusional vergences (both at the nearpoint). These findings also go along with the report of Fabian et al.[23]. Differently, in the present study, all patients were newly diagnosed with ADHD and did not receive any medication earlier, which eliminates the confounding effect of medication on these parameters. On the other hand, Bennet et al.[33] suggested that some of the medications used in the treatment of ADHD might worsen convergence insufficiency and certain drugs may lead to blurry vision due to difficulty in accommodation. Herein, convergence insufficiency was thought to be a comorbidity rather than being a disease-related problem, since fusional vergence amplitudes were similar in both groups. Also, when convergence insufficiency is thought to be as little as 2.25-13% in school age children[34,35], the sample size of our study does not seem to be adequate to make a definite conclusion. Therefore, more precise results will be achieved with larger sample prospective studies which will also evaluate follow-up of ADHD patients. Another potential bias might have occured in relation to the examiner who is only partially masked as to which children were in which group.

Refractive changes in patients with ADHD were previously investigated (Table 2) and no statistically significant difference was determined as compared to controls.[11,23] Larranaga-Fragoso et al.[36] reported that in patients with ADHD, SE before and after cycloplegia did not differ significantly, during 9 months of follow-up. As compared with the literature, they suggested that methylphenidate treatment does not affect refraction in children with ADHD. Besides, the relationship between hyperopia and learning difficulties has not yet been clarified. Although some studies reported that hyperopia is associated with different developmental problems and low school performance[37], some studies did not reveal such association.[38,39] However, in most studies measurements were obtained without cycloplegia. In hyperopia, unlike myopia, diagnosis may be delayed due to clear visualization through excessive accommodation at near. Excessive accommodation, may also end up with asthenopia, distractibility, hyperactivity and learning difficulties.[39,40] Additionally, it is stated that hyperopia >3.5 D increases strabismus and visual acuity problems and accepted as an amblyogenic risk factor.[40] In the present study, SE did not show significant difference in between groups. However the prevalence of hyperopia was higher in patients with ADHD, whereas myopia was more commonly observed in control subjects (Table 2). This also suggests that visual problems may be associated with disorders such as ADHD.

Conclusion

In conclusion, this study unveiled that fusional vergence amplitudes did not present significant difference, while the mean value of stereoacuity was significantly lower in newly diagnosed ADHD patients under no medication. Despite the similar fusional vergence amplitudes, it is possible that low stereoacuity in patients with ADHD may suggest the lack of adequate attention while performing TNO random-dot stereo test. Nevertheless, it could be beneficial for children with vision problems to be examined for signs and symptoms of ADHD and vice versa.

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