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Objective Measurement of the Balance Dysfunction in Attention Deficit Hyperactivity Disorder Children

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Abstract: Although attention deficit hyperactivity disorder (ADHD) is frequently associated with subtle neurological signs, no objective evaluation of the sensory integration, which is essential for maintaining balance, has been reported. In this study, we used Balance Master® and the modified clinical sensory interaction on balance to test the balance function of ADHD children. We found that the sway velocity of center of gravity on conditions, firm surface with eyes closed, foam pad with eyes open and foam pad with eyes closed, was significantly higher ($P < 0.03$) in ADHD group than in controls. We concluded that the sensory inputs, the sensory integration, and/or the inhibition of excessive movement are impaired in ADHD children, which result in the balance dysfunction.

Key words: attention deficit hyperactivity disorder, balance, sensory integration

Attention deficit hyperactivity disorder (ADHD) affects about 3-6% of school children and more boys are involved than girls (around 3:1). The main clinical features of ADHD are inattention, hyperactivity and impulsivity, usually associated with learning disability, conduct disorder and subtle neurological signs. These symptoms can impair family and peer relationships and the child's ability to succeed in school. The prevalence of sensory integrative dysfunction (SID) is significantly higher in ADHD children, 84.3%[1], as compared to the general population, 10.3%, of school children [2]. Using the sensory integration and praxis test (SIPT), Mulligan [3] showed that ADHD children demonstrated weakness with vestibular processing and in most areas of praxis or motor planning. Niedermeyer and Naidu [4] postulated that frontal-motor cortex disconnections resulted in the disinhibited motor activity and disturbed attention span seen in ADHD. Basal ganglia volumetric [5] and functional [6] abnormality and smaller cerebellum [7] in ADHD children have been re-ported with neuroimaing approaches. Both basal ganglia and cerebellum play an important role in motor control and balance maintaining. Although these studies suggest that ADHD children showed evident balance dysfunction, we are not aware of any quantitative studies on balance function of ADHD children.

Computerized dynamic posturography was initially used to evaluate vestibular and balance control in astronauts. Now it has being widely used on evaluation and rehabilitation of various disorders or diseases, e.g., inner ear diseases, stroke, Parkinson's disease, multiple sclerosis, traumatic brain injury, disorders of neck and sport-related injuries. In the current study, this objective measurement was used to quantitatively assess the balance dysfunction of ADHD children.

1. Material and Methods

1.1. *Subjects* Thirty-eight children (26 males and 12 females), aged 7.6 - 12.5 (9.76 ± 1.15), who met the ADHD criteria of DSM-IV were included in the ADHD group. Normal IQ (by Raven Progressive Matrices) and no history of tics, neurological or kinetic diseases were required for inclusion. The control group was recruited from a community primary school. There were 49 children (27 males and 22 females) aged 7.5 - 12.0 (9.64 ± 1.18) in the control group. Each parent of either ADHD or control child completed the Child Sensory Integration Scale (CSIS) [2]. In the control group, only the child with a normal CSIS score was included in the present study. Informed consent was obtained from the parent and was approved by the Research Board of the Institute of Mental Health, Peking University.

1.2. *Measurement* The Balance Master® (NeuroCom International, Inc. Clackamas, Oregon, USA) mainly consists of a computer and a force platform with 4 transducers beneath each of the 4 corners of the platform. The transducers transmit the pressure every 10 ms to the computer. Then the dynamic center of gravity (COG) of the subject is calculated and sway velocity (SV, degree/sec) during a certain period is obtained. The subject was asked to stand up straight at the appointed place on the platform and try to keep his/her body as stable as possible (Fig. 1) during the four test conditions: 1) firm surface with eyes open (FirEO), in which, all visual, somatosensory and vestibular inputs interact on balance; 2) firm surface with eyes closed (FirEC), in which visual input is removed; 3) foam pad with eyes open (FoaEO), in which somatosensory input is reduced; and 4) foam pad with eyes closed (FoaEC), in which visual input is removed and somatosensory input is reduced. This testing protocol is commonly referred to in the literature as the modified Clinical Test of Sensory Integration on Balance (mCTSIB) [8]. Three trials, each ten seconds in duration, were recorded for each of the test conditions. The average SV of the subject's COG was calculated for each trial and averaged for each test condition.

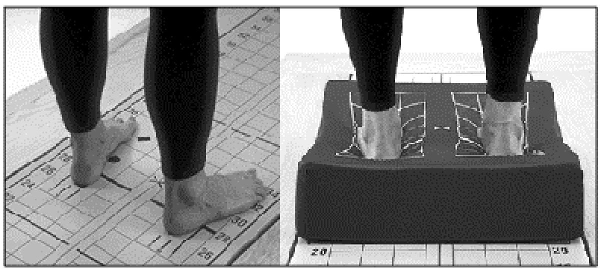

Fig. 1 Positions where subjects stand straight.
Left one: firm pad; Right one: foam pad.

1.3. *Statistics* All statistical comparisons were performed with the standard SPSS package. The correlation of SV with age or/and height, difference of age and height between two groups, difference of SV between two groups (ANOVA, age and height were taken as covariates), correlation of SV with CSIS score (3 items: vestibular-balance, hyper-sensory and proprioception) in ADHD group were tested. Further, when age (within half a year) and gender were matched, difference of SV between ADHD children with and without SID and difference of SV between controls and ADHD children without SID were tested.

2. Results

Of the 38 children in the ADHD group, 31 (81.6%) exhibited SID.

The age difference was not significant (ANOVA) either between groups (controls vs ADHD, P = 0.218) or between genders (P = 0.443). The height difference (ANOVA) was not significant (P = 0.275) between genders (age as covariate), but was significant between groups (controls: 137.48 ± 8.26 cm; ADHD children: 133.08 ± 8.34 cm, P = 0.047. Both age and gender as covariates).

SV of all conditions had significant (P < 0.005) negative correlation with age or height (Table 1). However, there was not significant correlation between SV and age when height was taken as covariate. In contrast, the SV had significant negative correlation (P < 0.005) with height on all conditions when age was taken as covariate.

Table 1. Pearson correlation between SV and the age and height in controls (n = 49)

	FirEO	FirEC	FoaEO	FoaEC
Age[a]	-.3610*	-.5218**	-.5029**	-.2237
Height[a]	-.5107**	-.6608**	-.5964**	-.2145
Age[b]	-.0937	-.2284	-.2415	-.1251
Height[c]	-.3969**	-.5161**	-.4334**	-.1071

[a]: Covariance was gender; [b]: Covariances were height and gender; [c]: Covariance were age and gender. *: P < 0.05; **: P < 0.01.

When both age and gender were controlled, SV on the FirEC, FoaEO and FoaEC conditions was significantly (P < 0.030, see Table 2) greater in ADHD children than in controls. Although SV on FirEO condition tended to be higher in ADHD children than in controls, the difference was not significant (P = 0.09). When patient height was added as a covariance, the SV on the FirEC and FoaEO condition was still significantly (P < 0.026, see Table 2) greater in ADHD children. The SV on the FoaEC condition tended to be higher in ADHD children, though the difference was not significant (P = 0.091). And the SV on the FirEO condition was not different between the two groups.

Within the ADHD group, results of correlations of SV with the 3 main items of CSIS were shown in Table 3. SV of FirEO and FirEC had significant (P < 0.05) negative correlation to items vestibular-balance and proprioception of CSIS. SV of FirEO had significant (P < 0.05) negative correlation with item vestibular-balance of CSIS. No other significant correlation was found between SV and CSIS items.

Table 2. SV (degree/s) differences of 4 conditions between two groups (x±s, ANOVA)

	n	FirEO	FirEC	FoaEO	FoaEC
Control	38	0.50 ± 0.22	0.54 ± 0.22	0.81± 0.22	1.30± 0.44
ADHD	49	0.60 ± 0.24	0.73 ± 0.31	1.01± 0.34	1.67± 0.85
P^a		>0.05	<0.01	<0.01	<0.05
P^b		>0.05	<0.05	<0.05	>0.05

Note: [a]: Covariates are age and gender; [b]: Covariates are age, gender and height.

Table 3. Correlations of SV on 4 conditions with 3 items of CSIS (Pearson r value. n = 38)

	FirEO	FirEC	FoaEO	FoaEC
Vestibular	-.422**	-.432**	-.326*	-.278
Hyper-sensory	-.145	-.079	.039	-.003
proprioception	-.408*	-.437**	-.055	-.306

*: P < 0.05; **: P < 0.01

Table 4. Difference of SV (degree/s) between ADHD children with and without SID (t-test, two tailed)

	n	FirEO	FirEC	FoaEO	FoaEC
SID ADHD	12	0.62 ± 0.20	0.72 ± 0.23	0.98± 0.26	1.61± 0.43
ADHD no SID	6	0.33 ± 0.18	0.48 ± 0.15	0.83± 0.19	1.22± 0.31
P		0.009	0.041	0.226	0.066

Six ADHD children without SID were age (within half a year) and gender matched with 12 ADHD children with SID. SV on FirEO and FirmEC of ADHD children with SID was significantly higher than that of without SID (P < 0.05, two tailed t-test. see Table 4). SV on FoaEC of children with SID tends to be higher (P = 0.066, two tailed t-test) than that of without SID.

Six ADHD children without SID were age (within half a year) and gender matched with 12 control children. No significant difference of SV between these two groups was found on the 4 conditions (t-test, P > 0.05).

3. Discussion

The results of the current balance testing as well as the SID data support the hypothesis that ADHD children significant balance dysfunction [2]. The significant difference in height reported here (early adolescent ADHD children shorter) has also been reported elsewhere [9]. In addition we found that the objective measure of balance function used here, SV, correlated with height more than with age. And in ADHD group, both height and balance function are lower than in controls. These results indicate that developments of height and balance function are to some extent parallel to each other. But when the height was taken as covariate, the balance dysfunction in ADHD children remained. This indicates that the balance dysfunction measured by mCTSIB is more substantial and sensitive than shorter height of ADHD children. The less obvious difference between ADHD group and controls on FirEO and FoaEC is probably due to too easy FirEO or too difficult FoaEC. In light of the results above, we presume that the sensory inputs, the sensory integration, and/or the inhibition of excessive movement are impaired in ADHD children, which result in the balance dysfunction. In addition, we postulate that hyperactivity, although not readily visible during the testing period, could contribute to the poor static balance of the ADHD children.

Many studies have found that childhood problems such as learning disability [10], dyslexia [11], autism [12], as well as ADHD [3] were associated with SID. Thus sensory integration therapy has been widely used in the treatment of these disorders. We found that objective balance measurement with mCTSIB correlated with the score of some CSIS items. We also observed that SV of ADHD children without SID was lower than that of with SID. These results indicate that objective balance measurement and CSIS overlapped to some extent. However, similar SV of ADHD children without SID to that of controls suggests that measurement with mCTSIB should be more objective than CSIS while revealing the balance dysfunction of ADHD children. Score of CSIS couldn't eliminate reporter's subjective deviation. Therefore, objective measurement proved more valuable in estimating balance function of ADHD children. The addition of visual biofeedback training programs as well as video games on the force platform could make those children more cooperative during rehabilitation therapy.

We conclude that Balance Master® with mCTSIB can objectively reveal the balance dysfunction of ADHD children. It can provide more accurate evaluation on rehabilitation therapy. Combining CSIS and other methods, e.g., neuroimaging, could further uncover the mechanisms of inhibition disability of this group.

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