Visual Spatial Attention in Children with Attention Deficit Hyperactivity Disorder

Chung-Yao Chen, MD; Chia-Ling Chen, MD, PhD; Ching-Yi Wu[1], PhD; Hsieh-Ching Chen[2], PhD; Fuk-Tan Tang, MD; May-Kuen Wong, MD

Background: Attention deficit hyperactivity disorder (ADHD) was characterized by deficit in the attention mechanism. Until now, the visual-spatial attention deficit in children with ADHD remains controversial. We report a study of the visual spatial attention to assess covert shifts of attention and sustained attention theoretically linked to two neuroanatomically defined attentional system in the posterior and anterior parts of the human brain.

Methods: Using the Neuroscan system, the reaction time (RT) was measured according to three different within-subject conditions including cueing (valid, invalid and neutral); delay (800 msec and 100 msec); side [right visual field (RVF) and left visual field (LVF)] as well as one between-subject condition (healthy, ADHD).

Results: The AHDH group showed slower RTs overall (RT=760 msec) than the comparison group (RT=650 msec) ($p = 0.001$). RTs in the delayed condition of 800 msec (RT=680 msec) were faster than in the delayed condition of 100 msec (RT=730 msec) in all children ($p < 0.001$). The ADHD group showed significant lateral differences in RT (RT_{RVF}: 880 msec > RT_{LVF}: 830 msec) in the 100 msec delay for the invalid cueing condition ($p = 0.045$) that was not found in the comparison group.

Conclusion: General dysfunction including posterior-based covert shift of attention and anterior-based sustained attention was found in ADHD group. Furthermore, asymmetric left parietal dysfunction in the disengaged operation was noted in those with ADHD.

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Key words: attention deficit hyperactivity disorder, children, reaction time, attention.

Childhood attention deficit hyperactivity disorder (ADHD) is common and impairing, but the nature of the attention deficit remains a neuropsychological puzzle.[(1)] ADHD is diagnosed behaviorally from persistent, age-inappropriate inattention, impulsivity, and overactivity.[(2)] The main behavioral assessment techniques used to determine diagnosis of this disorder include parent and teacher rating scales and interviews, psychometric tests, and continuous performance tasks.[(3)] However, it is difficult to examine the covert shift of attention and the sustained attention based on the clinical observation and

From the Department of Rehabilitation Medicine, Chang Gung Memorial Hospital, Taipei; [1]Department of Occupational Therapy, Chang Gung University, Taoyuan; [2]Department of Industrial Engineering and Management, Chaoyang University of Technology, Taichung, Taiwan.

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Address for reprints: Dr. Chia-Ling Chen, Department of Rehabilitation Medicine, Chang Gung Memorial Hospital. 5 Fu-Shin St. Kweishan, Taoyuan 333, Taiwan, R.O.C. Tel.: 886-3-3281200 ext. 3846; Fax: 886-3-3277566; E-mail: a7634245@ms21.hinet.net

evaluation.

Attention can be assessed by several ways. The well-known Posner paradigm can assess visual spatial attention by presenting the participants with cues that direct attention to regions of the visual space within which an imperative stimulus may subsequently appear.[4] Some researchers have proposed a model of distributed neural system that consisted of an anterior and posterior attentional system to determine the covert shift of attention and sustained attention.[5-7] To orient to a particular spatial location by the covert shift of attention, one's attention must be (1) disengaged if it is currently focused, (2) moved to the new location, and (3) engaged at the new spatial location.[5-7] There are some studies about the attentional operations that revealed dissociable components linked to specific neural systems.[6] The parietal lobe acts to release the attention (disengage) from its current focus and signals the midbrain to move the spotlight of attention from its current location to the area of the cue. The thalamus selects the contents of the attended area and enhances (engages) those contents so they are given priority for processing by anterior areas (sustained attention) that will detect targets and generate responses.[8] Because the Posner paradigm could be used to differentiate a covert shift of attention including disengagement, movement and engagement operations from sustained attention, we used the Posner paradigm to examine the covert shift of attention and the sustained attention of the children with ADHD in this study.

Recently, there have been some studies about the attentional operations used to determine the sites/pathways of neuropathology of ADHD children. Swanson et al.[9] reported that the ADHD children had longer RTs for the targets presented on the right visual field (VF) than for those presented on the left VF (LVF) following an invalid cue with 800 msec delay, using exogenous cueing tasks. Their results suggested a dysfunction in the ability to sustain the engagement of attention upon a cued right VF (RVF) location. While Nigg et al.[10] found slower responses to uncued targets in the 100 msec delayed condition in the LVF than that in the RVF, when also utilizing exogenous cues. Carter et al.[11] utilized endogenous cueing tasks and their results were compatible with those of Swanson et al.[9] However, by using exogenous cue with 150 msec delays, Carter et al.[11] showed slower RTs in the LVF than in the RVF. More general right hemispheric dysfunctions were suggested due to the absence of asymmetry in the cost/benefit pattern.[12] The controversial results among these studies may be due to the differences in the measurements and tasks. Some studies used endogenous cueing tasks with the cues indicating the probable location of the target symbolically, while other studies used exogenous cueing tasks with the cues occurring at the probable location of the target.

In order to study the attentional deficits in children with ADHD in Taiwan, we used the Posner paradigm to compare covert shifts of attention and sustained attention in children with ADHD and healthy children.

METHODS

Participants

Twenty-one children with ADHD aged 6 to 9 years were recruited from our outpatient department in the summer of 1999. Another 20 age- and sex-matched healthy children were recruited in this study. All children included in the ADHD group had an onset of symptoms before 6 years of age, duration of problems for more than 6 months, and exceeded empirically established cutoffs for DSM-IV diagnostic criteria, with a cutoff of 6/9 symptoms of inattention or hyperactivity-impulsivity, separately.[13] Exclusionary criteria included developmental disabilities or evidence of other neurological disorders.

Procedure

The Posner et al.[14] visual-spatial cueing tasks were implemented on the Neuroscan system using the MEL programming language (Micro Experimenter Laboratory Software, Psychology Software Tools, Pittsburgh, Penn). Two white boxes (1^o¡ 1^o of visual angle) were presented on a black background of the computer screen. They were presented at about 5^o of visual angle from a central fixation cross ($.6^o$¡ $.6^o$ of visual angle), and this display remained on for the entire experiment. Each trial began with a cue event which was the brightening of one of the two peripheral boxes, followed by a target which consisted of a white asterisk ($.5^o$¡ $.5^o$ of visual angle) inside one of the boxes. Measures were made under normal room illumination. A detection response was required. Participants were instructed to press the space bar on the computer keyboard with the index finger of the dominant hand when the target stimulus was presented and detected. If the stimulus appeared within the location indicated by the cue (e.g. cue points to the left and stimulus appears in the left visual hemispace) the trial was considered to be 'valid'. If the stimulus appears in a location that was not indicated by the cue (e.g. cue points to the left but stimulus appears in the right visual hemispace), the trial was considered to be 'invalid'. The participants were informed that, most of the time, the target would be preceded by a valid cue (300-msec brightening of one box, caused by appearance of a double white line around the box), but that they should not respond to the cue. They were also instructed to maintain center fixation. In the healthy adult and child participants, the valid cue oriented attention to the target's presentation and decreased RT (benefits), whereas the invalid cue orients attention away from the target's presentation and increased RT (costs). A trained technician sat directly behind each child in the experimental room to monitor and maintain participants' motivation and attention to the task. The technician rated each child's effort on the task as 'good', 'fair', 'poor' or 'session not valid'. Any rating below a 'good' prompted a makeup examination of that block which is consisted of 60 trials. Trials on which participants made eye movements were not excluded from the analysis. All of the children were given a practice session on the task before the experimental trials. The practice sessions also served as training for the technician. RT was measured from the onset of the target to the onset of the key press. An error was recorded if the RT was less than 100 msec, and it was assumed to be an anticipation error or false alarm. If no RT occurred by 1500 msec after the target presentation, it was assumed to be an omission error. The target remained present until a response was made or for a maximum of 3 seconds. After the response, the target (asterisk) disappeared from the screen, and the two boxes remained on the screen for a 1000 msec intertrial interval. Each child participated in one or more sessions of approximately 240 trials each. The total number of trials collected from each person and the number of sessions were dictated by their general condition. Four blocks of 60 trials were presented. On 16 of the 240 trials, no cue was presented; this defined the neutral condition. On 224 of the 240 trials, a cue was presented before the target. On 176 of the cued trials, the target appeared in the cued location; this defined the valid cue condition. On 48 of the cued trials, the target appeared in the uncued location; this defined the invalid cue condition. Half of the targets were presented in the RVF and half in the LVF. On half of the cued trials, the target was presented 100 msec after the onset of the cue; on the other half, the target was presented 800 msec after the onset of the cue. On the neutral trials, the target was presented 1100 msec or 1800 msec after the previous response (i.e., 100 msec or 800 msec plus the 1000-msec intertrial interval) in order to match the temporal characteristics of the 100-msec and 800-msec cue-target intervals in the valid and invalid cueing conditions. The 100-msec delay condition allowed for the assessment of orienting and alerting prior to eye movement. The 800-msec condition allowed for the assessment of how well attention to a target location was maintained.[15] The different types of trials were presented randomly in the four blocks.

Analysis

For each of the 12 within-subject conditions [defined by the factorial combination of levels of cue (neutral, valid and invalid), VF (LVF and RVF) and delay (100 msec and 800 msec)], a mean RT was calculated based on the correct reactions for each participant. These means were based on the correct reactions from 44 valid cue presentations, 12 invalid cue presentations and four neutral presentations in each of the four blocks. A four-way analysis of variance (ANOVA) was performed using one between-subject factor (group) and three within-subject factors (cue, VF, and delay). Because the main effect could not be interpreted without the knowledge of interactions among the terms,[16] we therefore followed analytic procedures recommended by Fisher,[16] which required a significant omnibus test to precede the simpler comparisons. The higher-order interactions were analyzed before the lower-order interactions, and the interaction effects were analyzed before the main effects. When interactions were significant, they were further analyzed as interaction contrasts at levels of the final factor. When interactions were non-significant, the main effects were analyzed. To avoid misinterpreting results due to an undetected higher-order interaction,[16] we completely decomposed the factorial matrix to describe the data fully. However, to simplify the presentation of results, we omitted the presentation of non-significant effects. We specified when reported findings were the result of post-hoc planned comparisons (in which case appropriate corrections for multiple comparisons were noted if relevant) rather than the data decomposition strategy. Post-hot comparisons were performed using the Newman-Keuls procedure (a-level = 0.05). Analyses were preceded by the appropriate tests of the assumption of normal data distribution using the Kolmogorov-Smirnov test. In addition, the presumption was not rejected.

Simple linear regression analysis using age and RT as two variables was performed for the healthy children and children with ADHD to analyze the relationship between them. The total number of errors (anticipation plus omitted errors) in the two groups were determined and compared using the *t* test. The statistical analysis was conducted using the SPSS (SPSS Inc., Chicago, IL) for Windows.

RESULTS

Demographic data are summarized in Table 1. The groups showed no significant difference in age, gender or handedness.

The mean RT of the 12 conditions defined by levels of delay, cue and VF are presented in Tables 2 and 3 separately for the healthy and ADHD groups. The cueing effects must be interpreted in light of the significant three-way interaction of cue ¡ delay ¡ group [F(2,38)= 4.317; $p = 0.02$]. Post hoc tests revealed significant differences between the valid and invalid cueing conditions in both 100-msec ($p = 0.031$) and 800-msec delayed conditions ($p = 0.020$) for the healthy participants. For the ADHD participants, significant differences were found between the valid and invalid cueing conditions for the 800-msec delay ($p < 0.001$). For the 100 msec delay, significant differences were found not only between the valid and invalid conditions ($p < 0.001$) but also between invalid and neutral cueing conditions ($p = 0.016$). A significant VF ¡ cue [F(2,38)=6.367; $p = 0.004$] interaction emerged due to significant VF differences in the invalid cue condition. However, there were no significant VF differences in the valid cue condition. Post hoc paired *t* tests revealed that the performance of the ADHD children showed that the lateral difference in RT was significant in the 100-msec invalid cue condition ($p = 0.045$) only (RT_{RVF}: 883 msec> RT_{LVF}: 830 msec). There were no significant differences (RT_{RVF}: 791 msec > RT_{LVF}: 759 msec) for the 800-msec invalid condition ($p = 0.233$) or for the healthy participants. Inspection of the main effects revealed that, averaged across the levels of other conditions, the valid cue condition resulted in faster RTs than the invalid or neutral conditions, and RTs were faster at

Table 1. Demographic Data of ADHD and Healthy Children

Variable	ADHD	Healthy
Age (years)	6.1 ¡ 1.1	6.7 ¡ 1.5
Body height (cm)	115.5 ¡ 9.1	115.1 ¡ 9.3
Body weight (kg)	21.5 ¡ 4.8	20.8 ¡ 4.2
Gender (F:M)	4:17	8:12
Handedness (R:L)	20:1	19:1

Abbreviation: ADHD: attention deficit hyperactivity disorder.

Table 2. Reaction Time (msec) of ADHD and Healthy Children in 800 msec Delay Condition

		Cue		
Participant	Visual field	Valid	Invalid	Neutral
ADHD	Right	660 ¡ 100	790 ¡ 110	730 ¡ 110
	Left	670 ¡ 110	760 ¡ 130	720 ¡ 120
Healthy	Right	590 ¡ 120	670 ¡ 120	620 ¡ 120
	Left	590 ¡ 110	670 ¡ 140	620 ¡ 120

Abbreviation: ADHD: attention deficit hyperactivity disorder. Data are expressed as mean ¡ standard deviation.

Table 3. Reaction Time (msec) of ADHD and Healthy Children in 100 msec Delay Condition

		Cue		
Participant	Visual field	Valid	Invalid	Neutral
ADHD	Right	730 ¡ 120	880 ¡ 130	790 ¡ 120
	Left	740 ¡ 110	830 ¡ 130	780 ¡ 120
Healthy	Right	630 ¡ 100	740 ¡ 130	660 ¡ 120
	Left	640 ¡ 110	690 ¡ 110	660 ¡ 120

Abbreviation: ADHD: attention deficit hyperactivity disorder. Data are expressed as mean ¡ standard deviation.

Table 4. Pearson Correlation Coefficient between Reaction Time and Age

			Cue		
Delay	Subject	Visual field	Valid	Invalid	Neutral
800 msec	ADHD	Right	-0.372	-0.205	-0.151
		Left	-0.347	-0.465*	-0.333
	Healthy	Right	-0.794**	-0.429	-0.677*
		Left	-0.421	-0.339	-0.326
100 msec	ADHD	Right	-0.440*	-0.258	-0.314
		Left	-0.333	-0.519*	-0.343
	Healthy	Right	-0.631**	-0.554**	-0.620**
		Left	-0.630**	-0.587**	-0.571**

Abbreviation: ADHD: attention deficit hyperactivity disorder.
*: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level.

the 800-msec (RT=680 msec) than at the 100-msec delay conditions (RT=730 msec). The ADHD participants showed longer RT (RT=760 msec) than the comparison group (RT=650 msec) (group main effect, F=12.103; $p = 0.001$).

The Pearson product-moment correlation coefficients between age and RT in the healthy children and children with ADHD are shown in Table 4. For the healthy children in the 100-msec delay condition, there was significantly negative correlation between age and RT which was not found consistently in the 800 msec delay condition. This correlation was only significant in children with ADHD in limited conditions. However, there was still a negative trend between RT and age in children with ADHD.

There were significant differences in total the number of errors made by the participants when compared with the two groups ($p = 0.03$). The ADHD children made more mistakes than the healthy children. Total error rates (anticipations, omission) were low for both groups (3.7% for healthy participants and 10.1% for ADHD participants).

DISCUSSION

In this study, the RTs in both the 100-msec and 800-msec delay conditions were slower in the children with ADHD than for the healthy children. These results suggest that ADHD children have generalized dysfunction not only in covert shift of attention but also in sustained attention. Covert orienting refers to the direction of spatial attention apart from actual eye movement,[6] overcoming the confound of immature oculomotor development in children. When the cue-target interval (or stimulus-onset asynchrony) is less than about 350 msec for children,[17] the participant does not have time for an eye movement, thus, only 'covert' or automatic, early stage attention processing is thought to be involved. The covert shift of attention could be assessed by RT performed in the 100-msec delay condition and sustained attention could be assessed by RT performed in the 800-msec delay condition. However, when sustained attention is assessed under the condition that the participants do not make eye movement, the result still was considered "covert" attention. The anterior attentional system may relate to the function of sustained attention and the posterior attentional system may relate to the function of covert shift of attention.[18,19] Both the parietal lobe (as part of the posterior attentional system) and the frontal lobe (as part of the anterior attentional system) played an important role in visual-spatial attention.[20] Therefore, our findings suggest that ADHD children have generalized visual-spatial attentional deficits that involve the anterior and posterior attentional system.

In this study, there were lateral differences in RTs (RVF > LVF) under invalid cue conditions with the 100-msec delay in the ADHD children that were not found in the healthy children. General dysfunction in the covert shift of attention could not explain the asymmetric performance in the invalid cue condition, so there must be asymmetric deficits in the disengage operation. Swanson et al. reported that if RT was lengthened only in the short cue-target intervals after an invalid cue, the disengage operation was assumed to be impaired because attention was presumed to have been moved and engaged elsewhere after the invalid cue.[9] Because the ADHD children had poor ability to disengage their attention from the invalid cue occurring in LVF, their RT in the RVF under invalid cue condition was slower. This asymmetrical deficit in the disengage function was also observed in patients with left parietal brain injury[15] and schizophrenia.[14] Furthermore, different anatomical areas of the brain have been hypothesized as the loci for the three elementary operations of attention.[4,7] Posner[5] supported that the neural network for directing visual-spatial attention involved areas of the parietal lobe (for the disengage operation), midbrain (for the move operation), and thalamus (for the engage operation). Therefore, our findings suggest that the ADHD children had asymmetrical deficits in the disengagement operation, which impaired more in the left parietal lobes.

Our findings are different from those of previous studies as mentioned before. The reasons are multifactorial. First, there was negative correlation between age and RT. That is, the RT decreased as the children became older. Therefore, the differences between healthy participants and children with ADHD in RT may change as age increases. The reason the healthy children had significantly negative correlation mostly in 100-msec delay condition remains to be determined. It may be that the sustained attention was still immature at the age they were tested. In contrast, there was no consistently significant correlation between RT and age in the children with ADHD. This may be due to the variation of disease severity among the children with ADHD. The mean age of the ADHD children in our study (6 years) was younger than that of other studies (9 years).[9] In addition, the mean RT in this study (590-710 msec for healthy children and 660-880 msec for children with ADHD) was longer than in previous studies (500-679 msec for healthy children and 569-728 msec for children with ADHD),[9] although the total error rates in our study (10.1%) were similar to the previous studies (9.88%).[10] Second, we did not discard the trials which eye saccade occurred in our data analysis. Most studies stated that both endogenous and exogenous cueing effects occurred regardless of whether or not participants made saccades.[5,21,22] Some researchers reported that motor movement (e.g. eye saccade) may influence responses[1,17] with longer cue-target interval (>350 msec). In contrast to the usual adult performance in the attentional strategy,[5,22,23] children were unable to maintain near-perfect fixation. Therefore, the eye movement should be analyzed in further, especially in the 800-msec delay condition. Third, using the different predictive value for cue, our results differed from the results of Carter et al.[11] Valid and invalid trials were equiprobable in Carter's study.

Using the same exogeneous cue, the lateral differences occurred in the same VF but in the different delay conditions (100-msec delay in our study and 800-msec delay in the study of Swanson et al.[9]). Age may play an important role in the differences. As mentioned before, the mean age of the ADHD children in our study (6 years) was younger than that in their studies (9 years).[9] It is not clearly understood whether the lateral differences found in the children with ADHD remained the same as they get older. The sustained attention in younger children with ADHD as we recruited in our study may be not fully matured yet. Therefore, the severe prolonged RT in response to bilateral VF stimulation in 800-msec delay condition makes the lateral difference insignificant. As the children with ADHD get older, the sustained attention should become more matured to make the differences, if it really exists, significant. The covert shift of attention in100-msec delay condition may be relatively more matured as compared with the sustained attention in children with ADHD that we recruited in our study. Therefore, the lateral differences are already significant. As they grow up, the relatively more impaired side catches up with the contralateral side and the significant differences disappears.

There were no significant differences in RT between the neutral and the other conditions in this study. It is ill-justified to use the 'neutral' value as a reference point for the calculation of cost/benefit measures. The participants could be jumping attention from one to the other visual hemifield, splitting attention between the hemifield, or adopting some other attentional management strategy because of ambiguous nature of the neutral type of the cueing.[12]

In conclusion, the RTs in both the 100-msec and 800-msec delay conditions were slower and there was lateral difference in RT (RVF > LVF) under the 100-msec invalid cue condition in the ADHD children. These findings suggest that ADHD children have generalized dysfunction in covert shift of attention and sustained attention, and there are asymmetrical deficits in the disengage functions, especially impaired more in the left posterior attentional system. Further studies should focus on whether the performance in RTs using Posner's paradigm changes as children with ADHD get older.

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注意力欠缺過動兒之視覺空間注意力研究

陳仲堯　陳嘉玲　吳菁宜[1]　陳協慶[2]　鄧復旦　黃美涓

背 景： 注意力欠缺過動兒的主要特徵之一是注意力不能集中。然而，對於過動兒之視覺空間注意力之缺損到目前爲止仍無定論。本篇研究乃是利用 Neuroscan 這套系統來研究過動兒之視覺空間注意力 (visual spatial attention)，其中包括了大腦後側所負責的隱藏性注意力系統 (covert shift of attention) 及大腦前側所負責的持續性注意力系統 (sustained attentional system) 之研究。

方 法： 本實驗乃利用Neuroscan system，分成三種不同的條件共十二種情況：(1)提示的正確與否(分成正確，錯誤和沒有提示)；(2)延遲 (delay) (分成100 msec和800 msec延遲)；(3)左右側 (左側及右側)，在每一種情況下分別測量其反應時間(reaction time, RT)，實驗分成過動兒及正常小孩兩組。

結 果： 我們發現過動兒的平均反應時間 (RT=760 msec) 比正常小孩 (RT=650 msec) 還要慢 ($p=0.001$)。所有小孩在 800 msec 延遲情況下的反應時間 (RT=680 msec) 都比100 msec 延遲情況 (RT=730 msec) 的還要快 ($p<0.001$)。過動兒在100 msec延遲，錯誤提示的情況下，其右側視野的反應時間 (RT=880 msec) 比左側視野的反應時間 (RT=830 msec) 還要長 ($p=0.045$)，這在正常小孩並沒有發現。

結 論： 我們發現過動兒之隱藏性注意力及持續性注意力系統均較正常小孩差，而且過動兒之左側額葉所負責之注意力功能比起右側爲差。

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關鍵字： 注意力欠缺過動兒，小孩，反應時間，注意力。

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fl`¤œ' ƒL¥»‡B¡G‡fl„¯<´´ fiv¡A“ł' < ' ´ | •_ •< ¡Cfi ¶Ø¿⁄ 333 t⁄s¶m·_¿‡ 5 „¡C Tel.: (03)3281200´ 3846; Fax: (03)3277566; E-mail: a7634245@ms21.hinet.net