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ORIGINAL PAPER

Working Memory in Early-School-Age Children with Asperger's Syndrome

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Abstract Using a battery of working memory span tasks and n-back tasks, this study aimed to explore working memory functions in early-school-age children with Asperger's syndrome (AS). Twelve children with AS and 29 healthy children matched on age and IQ were recruited. Results showed: (a) children with AS performed better in digit and word recall tasks, but worse in block recall task and variant-visual-patterns test; (b) children with AS took longer time in most conditions of n-back tasks, and showed larger effects of task load. These findings indicated imbalance of working memory development in AS children: they had advantage in the phonological loop storing, but disadvantage in the visuospatial sketchpad storing, and partial deficit in central executive.

Keywords Asperger's syndrome · Executive function · Working memory · High functioning autism

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Introduction

Autism spectrum disorders (ASD) are a group of developmental disorders that are characterized by impairments in social interaction, verbal and non-verbal communications, as well as repetitive and restricted behaviors, interests and activities (American Psychiatric Association 1994; World Health Organization 1993). These deficits associated with ASD appear from early childhood, and persist in later life. One of the most influential theories of ASD is executive dysfunction theory (Hill 2004a; Hill and Frith 2003). Executive function is an umbrella term for abilities such as planning, working memory, impulse control, inhibition and shifting set, as well as initiation and monitoring of actions (Stuss and Knight 2002). A wide range of executive function deficits have been found in ASD (for reviews, see Hill 2004a, b; Pennington and Ozonoff 1996; Sanders et al. 2008), which may explain their social and non-social problems, such as repetitive behaviors and restricted interests in the daily life (Hill 2004a).

As an important component of executive function, working memory is a limited capacity system both to maintain information "on-line" over brief periods of time to support a temporal continuity of behavior, and to manipulate ideas internally to plan complex responses (Baddeley 1986, 2003). The results of studies on working memory in ASD were incongruent. Some studies found that ASD were impaired not only in visual spatial working memory (Goldberg et al. 2005; Happé et al. 2006; Joseph et al. 2005; Landa and Goldberg 2005; Luna et al. 2007; Reed 2002; Russell et al. 1996; Steele et al. 2007; Verté et al. 2006; Williams et al. 2005, 2006), but in verbal working memory (Gobig 2008; Russell et al. 1996); However, other studies didn't find that ASD had impairments in spatial working memory (Geurts et al. 2004;

Happé et al. 2006; Joseph et al. 2005; Nakahachi et al. 2006; Ozonoff and Strayer 2001), nor in verbal working memory (Lopez et al. 2005; Williams et al. 2005). Reasons for these inconsistent findings may lie in the fact that working memory performances are influenced by such factors as age, IQ, task, or heterogeneity of participants. Age was found to be significantly correlated with neuropsychological performances (Happé et al. 2006; Luna et al. 2007; Mayes and Calhoun 2003; Ozonoff and Strayer 2001), and the subjects in the studies were quite different, from children to adolescents to adults. IQ was revealed as another factor influencing working memory performances (Griffith et al. 1999; Mayes and Calhoun 2003; Ozonoff and Strayer 2001; Shaked and Yirmiya 2004). Besides demographic differences of the subjects, the tasks were divergent. For instance, for visual working memory, there were Cambridge neuropsychological test automated battery (CANTAB) spatial working memory task, block span, self-ordered pointing, finger windows, delayed response task etc.; for verbal working memory tasks, sentence span, counting span, letter-number sequencing, N-back for letters and so on were adopted. These tasks varied in difficulty and requirements and therefore would affect the working memory performance.

In addition, children with ASD were heterogeneous. Most ASD participants in working memory research were high functioning autism (HFA), who met the criteria for autism but had normal intellectual functioning. Asperger's syndrome (AS) was another subtype of ASD, which also had normal intellectual function, but had no history of speech and language delay. As was described in DSM-IV, AS had major deficits in social interaction, communication and behavior; it had neither clinically significant delay in cognitive development, adaptive behavior, nor history of speech and language delay, nor defects in curiosity about the environment (American Psychiatric Association 1994). Though there were some controversies about the differences between HFA and AS, for instance, some studies did not find difference between these two groups in neuropsychological profile or clinical variables (Krurita 1997; Manijiviona and Prior 1999; Miller and Ozonoff 2000) and suggested there was insufficient evidence to establish the validity of AS as a syndrome distinct from HFA (Macintosh and Dissanayake 2004). However, some studies found neuropsychological and communicative ability differences between them (Ehlers et al. 1997; Klin et al. 1995; Koyama et al. 2007), and suggested that AS had better verbal abilities and worse spatial skills in comparison with HFA (Klin et al. 1995; Kugler 1998; Tsatsanis 2004). Furthermore, recent neuroimaging studies showed AS had different patterns of brain abnormality compared to HFA (Kwon et al. 2004; McAlonan et al. 2009, 2008).

A good rote memory was reported in AS (Myles and Simpson 2002; Wing 1981). And Ambery et al. (2006) found AS adults were not deficient in verbal memory measured by doors and people verbal memory index and wechsler memory scale-revised, but impaired in visual memory measured by doors and people visual memory index. However, there were few studies, therefore few inconsistent results on working memory in AS participants. Edgin and Pennington (2005) found AS children were intact in spatial working memory measured by CANTAB. While Morris et al. (1999), found AS adults were impaired in spatial working memory by using the executive golf task. The verbal working memory in AS has not been explicitly studied yet. So the present study aimed to explore working memory performance in AS children with a comprehensive battery of tests including both verbal and spatial working memory in a specific age range for the following reasons. First, AS might be considered to be a model of pure autism in the sense that it was unimpeded by the effects of learning difficulty common to other parts of the autism spectrum (Frith 2004). Second, working memory performance was correlated with age (Happé et al. 2006; Luna et al. 2007; Mayes and Calhoun 2003; Ozonoff and Strayer 2001); and Gathercole et al. (2004) found that the basic modular structure of working memory was present in children above 6 years old; moreover, children between 6 and 8 years were in their transfer from kindergarten to primary school, executive function could play an important role in their adaptation, thus the present study focused on AS children between 6 and 8 years old.

For working memory tasks, span tasks and n-back task were included. Span tasks were designed according to Pickering and Gathercole's (2001) working memory test battery (WMTB). This battery was developed on the basis of Baddeley's working memory model (1986) in which working memory mainly comprises three components: a central executive and two storage systems—the phonological loop and the visuospatial sketchpad. The WMTB contains three types of span tasks: verbal storage-only tasks measuring the phonological loop, complex memory span tasks capturing both the central executive (for processing) and the phonological loop (for storing), and visual or spatial storage tasks depending on the visuospatial sketchpad. Gathercole et al. (2004) investigated the structure of working memory and its development in 4–15 years old children with WMTB. They found that the development of working memory components in children showed a similar linear pattern, and the basic modular structure of working memory was existent in children above 6 years old.

As to the n-back task, we designed three types of materials (i.e., digits, geometric figures and locations). Since AS had better verbal abilities and worse spatial skills in comparison with HFA (Klin et al. 1995; Kugler 1998; Tsatsanis 2004); and compared with controls, HFA children were found to perform significantly poorer in verbal, but not in non-verbal self-ordered pointing test (Joseph et al. 2005), they suggested that children with HFA were deficient in the use of verbal mediation strategies to maintain and monitor goal-related information in working memory. Thus we would like to explore whether individuals with AS could use verbal mediation strategies when performing working memory tasks, and three types of materials were used in n-back (1-back and 2-back) tasks (digits, geometric figures and locations). Digits indicated the verbal condition; the geometric figures were easily named (e.g., red circle, green star), and the participants could use verbal cue in this task; but the locations were difficult to be named verbally.

Given that children with AS had good verbal ability and poor spatial skills, it was hypothesized that children with AS, in comparison with the control group matched on age and IQ, would (a) in working memory span tasks, show good verbal storage and do well in complex memory span tasks that taxes the phonological loop, but perform worse in visual or spatial storage tasks; (b) in n-back tasks, differ in performance in different conditions: they would do well in digit condition but worse in location condition; and if they could use verbal cue in the geometric figure condition, they would do as well as controls, but if they could not use verbal mediation strategies, they would show impairment. And we would like to test an additional hypothesis that (c) the working memory load (lag) may have a larger influence in performance for children with AS.

Method

Participants

Twelve children with AS (11 boys and 1 girl), with a mean age of 7.46 years (ranged between 6.25 and 8.42 years) participated in the study. All of them were recruited from outpatients in the child developmental behavior center, the Third Affiliated Hospital of Sun Yat-Sen University. Clinical diagnoses were made by experienced pediatric clinicians in this field strictly according to DSM-IV (APA 1994) for Asperger's disorder, including interview with parents and children, clinical records consultation, behavioral observation, and extensive physical examinations, and neurological examination in particular. None of the AS children had a history of speech or language delay; and other varieties of pervasive developmental disorder or schizophrenia were excluded. Ten of them went to public school (four in the first grade and six in the second grade). The other two had been in school, but left school because of such behavioral problems as violation of classroom rules, difficulty in interacting with other children, etc. They were taught by their parents at home. These children were taken to the Center mainly due to their behavioral problems in school. However, most of them had good academic records. Eight of them were reported by their parents to have good memory in the daily observation.

Table 1 Age and intelligence test data in the AS and controls

	AS (n=12) *M* (SD)	Controls (n=29) *M* (SD)	*F*	*p*
Age(years)	7.46(0.84)	7.37(0.48)	0.21	0.652
Brief-FIQ	100.03(17.13)	108.31(14.08)	2.40	0.129
Boys:girls	11:1	24:6		0.651

Gender ratio used Fisher's exact test

The control group consisted of 29 healthy children (23 boys and 6 girls) matched on age and IQ, with a mean age of 7.37 years (ranged from 6.25 to 8.33 years). They were recruited from a public primary school in the same city. Fourteen of them were in the first grade, and 15 were in the second grade. None of them had obvious behavioral problems or a history of relevant disease.

A brief version of wechsler intelligence scale for children (Chinese Revised) (C-WISC; Gong and Cai 1993) including information, sorting, digit span, picture filling, and block design subtests were used to estimate IQ. The correlation of this brief version and the full scale was 0.918 (Gong and Cai 1993). The brief IQ of all participants was over 70. Participants in the two groups did not differ significantly in age, brief IQ, and gender ratio (see Table 1).

Measures

Working Memory Span Tasks

Six working memory span tasks were designed according to Pickering and Gathercole's WMTB (2001; Gathercole et al. 2004). They were two verbal storage-only tasks (digit recall and word list recall) examining the phonological loop, two complex memory span tasks (backward digit recall and counting recall) involving both the function of central executive (for processing) and that of phonological loop (for storing), and two visuospatial storage tasks (block recall and variant-visual-pattern test) measuring the visuospatial sketchpad. The variant-visual-pattern test was designed from the visual pattern test (Gathercole et al. 2004).

Digit Recall

This test involved the presentation of spoken sequences of digits in which the children were asked to recall in correct serial order. Lists constructed randomly and with replacement from the digits ranging from 1 to 9 were spoken by the experimenter at the rate of one digit per second. Following two practice trials (three digits), four lists were presented at each length. List length was increased by one at a time. Testing commenced with three-digit lists and continued until three lists of a particular length were recalled incorrectly. The number of lists correctly recalled (total score) and the longest length passed (memory span) were recorded. The following span tasks also recorded these two indexes.

Word Recall

This test involved the presentation of spoken sequences of words in which the children were asked to recall in correct serial order. All words were two-character nouns from the textbook of the first grade, and no stimuli were repeated. Lists were spoken by the experimenter at the rate of one word per second. Following two practice trials (two words), two lists were presented at each length. List length was increased by one at a time. Testing commenced with two-word lists and continued until both lists of a particular length were recalled incorrectly.

Backward Digit Recall

The procedure and recording rule were identical to digit recall except that participants were required to recall the sequence of spoken digits in a reverse order. List length began with two.

Counting Recall

In this test, the participants were required to count the number of dots presented in a series of arrays (saying the total number aloud) and to recall subsequently the dot tallies in the order that the arrays were presented. The arrays of dots were presented to children on the computer within a square, each contained either two, three, four, five, six or seven green dots. Test trials began with a single array of dots and increased by one further array following the digit span procedure outlined above. There were two trials in each length, testing continued until both lists of a particular length were recalled incorrectly.

Block Recall

In this test, the children viewed nine wooden cubes located randomly on a board. The experimenter taped a sequence of blocks, and the child's task was to repeat the sequence in the same order. Testing began with a single block tap and increased by one additional block following the digit span procedure outlined above. There were two trials in each length, testing continued until both lists of a particular length were recalled incorrectly.

Variant-Visual-Patterns Test

The test required the participants to view two-dimensional grids for 10 s. Some of the grids were filled with grey circles, with both the matrix (numbers of grids) and number of circles varying. The number of circles began with 2 and increase 1 at a time. The number of the grids in the matrix changed from 4 (2*2), 6 (2*3), 9 (3*3), 12 (3*4), 16 (4*4), to 20 (4*5). In all conditions the number of the circles was no larger than half the number of grids. An empty grid was then presented in which the participant had to mark the filled squares in the studied pattern. There were two trials in each length (number of circles), testing continued until both lists of a particular length were recalled incorrectly.

N-back Tasks

The n-back task was one of the most commonly used tests of working memory (Baddeley 2003). In this task a continuous stream of items was viewed and the participant decided whether the current item matches the stimulus presented a designated number of stimuli back, where working memory load could be manipulated by changing the n (e.g., 1, 2, or 3). In this study, we adopted 1-back and 2-back.

The materials used in n-back were divided into three types: digit, geometric figure, and location. In the digit n-back task (D-n-back), the digits 1, 2, 3, and 4 were presented in a fixed pseudorandom order, one at a time, at the center of the screen. In 1-back condition, participants would respond by pressing the green key ("J") when the current digit matched the letter immediately preceding it, otherwise they would press the red key ("F"). A trial began with a 500 ms fixation (with a black "+" in the center of the white screen), after that, the stimuli appeared and remained on the screen until response was made. Participants were required to respond as quickly and accurately as possible. After a practice block, when the participants were sure that they understood the instructions, the formal experiment begun. There were 20 trails in practice and 30 trials in the test session. Half of these trials were with the correct response by pressing the green key and the other half the red key. In the 2-back condition, participants would respond by pressing the green key ("J") when the current digit matched the digit that was viewed two digits back, otherwise they would press the red key ("F"). Considering the higher difficulty of 2-back task, experimenter illustrated the instructions by drawing on the paper in addition to verbal explanation. After the participants understood the requirements, the practice began. Other requirements and settings were identical to 1-back.

In the geometric figure n-back task (F-n-back), red circle, green star, blue triangle, and yellow square were used as stimuli, all these stimuli were easily named by color or shape. The other settings were the same as digit n-back task.

In the location n-back task (L-n-back), a red circle would be presented at four possible locations: 45, 135, 225, and 315° from twelve O'clock, defined using coordinates of an invisible circle with a diameter of 20 cm (yielding an overall visual angle of 30°), these four locations were not easily encoded verbally. Participants were asked to judge whether the location of the current circle matched the location of circle immediately preceding it (1-back) or two circles back (2-back). Other settings were the same as digit n-back task.

The n-back tasks were programmed using the E-prime 1.0 (Schneider et al. 2002), the accuracy and reaction time were recorded.

Procedure

Children with AS participated the tests in the hospital, control group finished the tests in their school. Tests were conducted in quiet rooms. During the tests, computer tests and paper-and-pencil tests were conducted alternately to attract the participants' attention and interest. The n-back tasks were performed in the following fixed order in order to be easily understood by children: digit condition, figure condition, and then location condition. The experimenter asked the participant frequently whether they need a rest. Each child spent approximately 1.5–2 h completing the whole tests. During the tests, the experimenter encouraged the children orally.

All the tests were performed by the same experimenter. The study was approved by the IRB of the Department of Psychology, Sun Yat-Sen University. Written informed consent was filled by parents before testing begun. Before the test, the children were told that they would complete some tasks by playing some games.

Results

C-WISC Subtests

Five C-WISC subtests were used to estimate IQ of the participants, only one subtest was found to be significantly different between two groups, the AS group performed poorer than control group in block design task [F(1, 39) = 11.21, p=0.002]. The results suggested children with AS might be impaired in visual-spatial perception and visual-motor integration (see Table 2).

Table 2 Comparison of C-WISC subscales between AS and controls

Subscales	AS (n=12) M (SD)	Controls (n=29) M (SD)	F	p
Information (I)	10.00 (3.62)	11.24 (3.31)	1.13	0.294
Sorting (So)	11.08 (4.38)	12.62 (3.53)	1.40	0.243
Digit span (D)	12.92 (3.80)	11.52 (2.40)	2.03	0.163
Picture filling (PC)	7.75 (2.22)	8.45 (2.46)	0.77	0.401
Block design (BD)	8.42 (2.78)	11.97 (3.20)	**11.21****	**0.002**
Brief-FIQ	100.03 (17.13)	108.31 (14.08)	2.40	0.129

** $p < 0.01$

Working Memory Span Tasks

One-way analyses of variance (ANOVA; see Table 3) showed that in digit and word recall tasks, children with AS performed significantly better on both span [digit recall, $F(1,39) = 9.15$, $p = 0.004$; word recall, $F(1,39) = 5.25$, $p = 0.027$] and score [digit recall, $F(1,39) = 11.79$, $p = 0.001$; word recall, $F(1,39) = 5.93$, $p = 0.020$], indicating that children with AS were better in phonological loop. They did as well as controls in backward digit recall [span, $F(1,39) = 0.02$, $p = 0.889$; score, $F(1,39) = 0.01$, $p = 0.931$] and counting recall [span, $F(1,39) = 0.37$, $p = 0.545$; score, $F(1,39) = 0.13$, $p = 0.931$], indicating that in the complex span tasks, they did not show central executive impairment. However, children with AS performed worse in block recall task [span, $F(1,39) = 2.07$, $p = 0.158$; score, $F(1,39) = 7.03$, $p = 0.01$] and variant-visual-patterns test [VVPT; span, $F(1,39) = 2.03$, $p = 0.162$; score, $F(1,39) = 5.53$, $p = 0.024$], their scores in the two tasks were significantly poorer than controls. The results indicated that children with AS had some impairment in visuospatial sketchpad.

Correlation analysis revealed that IQ and working memory performance were correlated in a similar pattern in AS group and control group, so we reported correlations in all participants here, IQ was significantly correlated with digit span score ($r = 0.318$, $p = 0.043$), back digit recall span ($r = 0.495$, $p = 0.001$), back digit recall score ($r = 0.380$, $p = 0.014$), counting recall span ($r = 0.513$, $p = 0.001$), counting recall score ($r = 0.375$, $p = 0.016$), VVPT span ($r = 0.449$, $p = 0.003$), and VVPT score ($r = 0.459$, $p = 0.003$). Other correlations were non-significant. Considering that IQ may influence working memory performance, we controlled for IQ as a covariant

Table 3 Comparison of WM span tasks between AS and controls

	AS (n = 12) M (SD)	Controls (n = 29) M (SD)	F	p	Cohen's d
Digit recall span	8.33 (1.23)	7.28 (0.92)	**9.15****	**0.004**	0.97
Digit recall score	21.83 (4.73)	17.52 (3.15)	**11.79****	**0.001**	1.07
Word recall span	4.67 (1.07)	4.07 (0.59)	**5.25***	**0.027**	0.69
Word recall score	8.42 (1.73)	7.28 (1.19)	**5.93***	**0.020**	0.77
Back digit recall span	3.92 (1.16)	3.97 (0.94)	0.02	0.889	−0.05
Back digit recall score	9.00 (3.98)	9.10 (3.26)	0.01	0.931	−0.03
Counting recall span	5.17 (2.25)	5.48 (1.09)	0.37	0.545	−0.18
Counting recall score	9.33 (4.38)	8.97 (2.16)	0.13	0.719	0.10
Spatial recall span	4.67 (0.78)	5.03 (0.73)	2.07	0.158	−0.48
Spatial recall score	8.00 (1.76)	9.28 (1.19)	**7.30****	**0.010**	−0.85
VVPT span	5.25 (1.42)	5.83 (1.07)	2.03	0.162	−0.46
VVPT score	6.92 (2.61)	8.62 (1.88)	**5.53***	**0.024**	−0.75

* $p < 0.05$, ** $p < 0.01$. According to Cohen's criteria (Cohen 1988), Cohen's d larger than 0.5 indicates medium effect size, larger than 0.8 indicates large effect size

and then compared children with AS and control's WM performance, the results were similar to previous analysis.

N-back Tasks

Four children with AS and 8 children in the control group did not finish 2-back tasks because of task difficulty, thus the analysis of the n-back tasks included 8 children with AS and 21 controls. These children did not differ in age, IQ and gender ($ps > 0.05$).

Accuracy

A 2*3*2 repeated measure ANOVA was conducted to explore the effects of group (AS, controls; between-subject variable), material (digit, geometric figure, location; within-subject variable), and lag (1-back, 2-back; within-subject variable) on accuracy. Descriptive data were presented in Table 4 and Fig. 1. The main effect of lag was significant, $F(1,27) = 78.60$, $p < 0.001$, the accuracy in 2-back condition was lower than 1-back condition; the main effect of material was significant, $F(2,54) = 3.172$, $p = 0.05$. Further analysis showed that the accuracy in figure condition was higher than location condition ($p = 0.002$). The main effect of group was not significant [$F(1,27) = 0.214$, $p = 0.648$] and none of the interactions were significant (F ranged from 0.20 to 0.88).

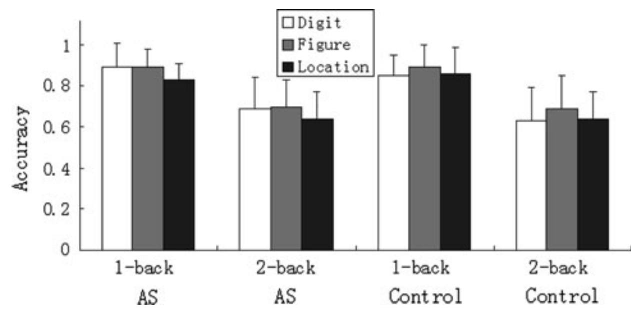

Fig. 1 Accuracy of N-back task in AS and Controls

Reaction Time

A repeated measure ANOVA was conducted on reaction time (RT). The results (see Table 5) showed that the main effect of group was significant [$F(1,27) = 20.38$, $p < 0.001$], children with AS needed longer time to respond. The main effect of lag was significant [$F(1,27) = 36.75$, $p < 0.001$], the RT in 2-back condition was longer. The main effect of material was significant [$F(2,54) = 9.50$, $p < 0.001$], the RT in figure condition was shorter than digit and location condition ($ps < 0.05$). The interactions between lag and group [$F(1,27) = 7.47$, $p = 0.011$], between material and group [$F(2,54) = 3.90$, $p = 0.026$], between lag and material [$F(2,54) = 6.93$, $p = 0.002$], and three-way interaction among lag, material and group [$F(2,54) = 3.338$, $p = 0.043$] were significant.

Table 4 Accuracy of n-back in AS and Controls

	AS (n = 8)		Controls (n = 21)		Cohen's d	
	1-back M (SD)	2-back M (SD)	1-back M (SD)	2-back M (SD)	1-back	2-back
Digit	0.89 (0.12)	0.69 (0.15)	0.85 (0.10)	0.63 (0.16)	0.36	0.39
Figure	0.89 (0.09)	0.70 (0.13)	0.89 (0.11)	0.69 (0.16)	0	0.07
Location	0.83 (0.08)	0.64 (0.13)	0.86 (0.13)	0.64 (0.13)	−0.28	0

Table 5 Reaction time in n-back of AS and Controls (ms)

	AS ($n = 8$)		Controls ($n = 21$)		Cohen's d	
	1-back *M* (SD)	2-back *M* (SD)	1-back *M* (SD)	2-back *M* (SD)	1-back	2-back
Digit	2,236 (560)	5,451 (2578)	1,654 (456)	2,774 (1806)	1.14	1.35
Figure	2,042 (417)	3,444 (1940)	1,548 (399)	2,308 (817)	1.21	0.76
Location	2,345 (1047)	4,932 (2616)	1,624 (406)	2,469 (1076)	0.91	1.23

To explore the meaning of interactions, we compared the RT of AS with controls in all conditions, independent-sample *t*-tests showed that AS group took longer time in almost all conditions [$t(27) = 4.12 \sim 2.72$, $ps < 0.05$] except in Fig. 2 -back condition [$t(27) = 1.602$, $p = 0.148$]; we also compared the RT difference between 1-back and 2-back in three materials (2-back RT minus 1-back RT). The results showed that the RT difference of the AS group was significantly longer than that of the control group in digit and location conditions [digit: $t(27) = 2.53$, $p = 0.035$, location: $t\ (27) = 2.21$, $p = 0.036$], but not in figure condition [$t(27) = 0.824$, $p = 0.435$], these might indicate that the effects of task difficulty was larger for children with AS than for controls except in figure condition. In addition, we compared RT between conditions within each group. In the AS group, paired-sample t-tests showed that in 1-back condition, the RT in three materials was not different [$t\ (7) = 0.026$–0.826, $p = 0.436$–0.803], and so was in the control group [$t\ (20) = 0.291$–1.237, $p = 0.23$–0.774]; however, in 2-back condition, the AS group took longer time to make response in digit condition in comparison with figure condition ($p < 0.05$). And the same trend in location condition in comparison with figure condition ($p = 0.067$) was found. In the control group, only a significant difference was found between figure and digit condition, with digit condition taking longer RT ($p < 0.01$; See Fig. 2).

In all participants, IQ was correlated with digit 1-back accuracy ($r = 0.341$, $p = 0.034$), digit 1-back RT ($r = -0.341$, $p = 0.034$), Fig. 1 -back accuracy ($r = 0.374$, $p = 0.021$), location 1-back accuracy ($r = 0.319$, $p = 0.048$). When including IQ as a covariant in the analysis of n-back accuracy and RT, the results were the same as in previous analysis. Furthermore, we performed condition-wise correlations between speed and accuracy for each group to examine potential speed-accuracy trade-off. Results showed that all the correlations were non-significant in both groups ($ps > 0.05$), indicating that the participants did not show speed-accuracy trade-off.

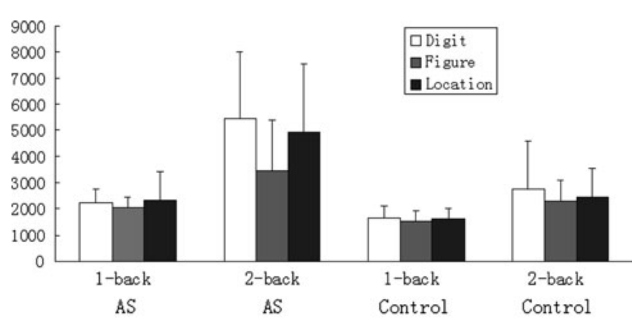

Fig. 2 Reaction time of N-back task in AS and Controls

Discussion

The present study adopted a battery of working memory span tasks and n-back tasks to assess working memory in early-school-age children with AS. In the working memory span tasks, compared with the controls matched on age and IQ, children with AS performed better in the simple verbal span tasks (only need storing; i.e., digit recall and word recall), intact in complex verbal span task (require both processing and storing; i.e., backward digit recall and counting recall), but worse in visual/spatial storage span task (i.e., scores of block recall and VVPT). These results mainly supported our first hypothesis, and suggested that children with AS developed differentially on distinct working memory components. Results of n-back tasks were partly consistent with our hypothesis: AS group attained similar accuracy as control group in all conditions, but they needed longer time to respond, and the effect of working memory load (lag) was larger in AS group in digit and location condition but not in geometric figure condition. These results indicated that Children with AS had partial deficit in central executive, and the verbal cue might be used as strategy when performing working memory tasks.

Children with AS performed significantly better than controls in digit and word recall tasks on both spans and scores, which only taxed verbal storage. This suggested that children with AS are advantaged in the phonological loop. These results were consistent with the viewpoint that AS had good rote memory (Myles and Simpson 2002; Wing 1981). However, their performance in spatial storage tasks were poor, their scores in block recall and VVPT were significantly lower than those of the controls, though the block recall span and VVPT span were smaller but not significant. These findings were consistent with previous studies. For example, Ambery et al. (2006) found AS adults were impaired in visual memory; and Morris suggested that AS patients may have general deficits in representing visual and spatial information (Morris et al. 1999). But it was inconsistent with Edgin and Pennington's (2005) findings that the AS children did as well as the normal controls in CANTAB spatial working memory, probably because the position of the boxes did not change in each set in CANTAB, and the position might serve as a verbal cue. The dissociation between verbal and spatial storage of working memory in AS in our study was consistent with the former reports that they had higher verbal IQ than performance IQ (Hayashi et al. 2008; Klin et al. 1995; Koyama et al. 2007). In the present study, difference between verbal IQ and performance IQ in AS could not be compared because we did not include all subtests of C-WISC. However, we found that children with AS performed significantly worse in block design, a subtest of performance IQ.

In the two complex working memory span tasks (i.e., backward digit recall and counting recall) that involved central executive processing, children with AS did as well as controls. This might indicate that the function of central executive of children with AS is intact. However, these two tasks were verbal working memory tasks. The reason why children with AS performed well in these tasks could be due to their advantage in the phonological loop. The span tasks could not examine the effect of reaction time of working memory performance. For n-back tasks, the accuracy and reaction time could be investigated at the same time. Results showed that though accuracy did not differ between groups, reaction time was significantly different in most conditions. Children with AS took significantly more time to make responses, and task difficulty (i.e., lag) showed larger influence on AS group (in geometric figure condition the results were same but non-significant).

Though the effect of material was similar to the two groups in accuracy, it was different in reaction time. The reaction time in digit 2-back was longer than that in Fig. 2 -back, this tendency was the same in both groups. That might be a practice effect because figure condition was always performed after digit condition (it is a limitation of this study). However, only children with AS needed longer time to respond in location 2-back (spatial working memory task) than in Fig. 2 -back, this suggested that AS children might be impaired in spatial processing, for the figures were easier to remember, all figures could be named easily by using either the shape or the color as verbal cues. It was also consistent with the fact that both groups had more accurate performance in figure condition than in location condition.

The results that the performance of AS participants in Fig. 2 -back did not significantly differ from controls indicated that AS participants used verbal mediation strategy to complete the working memory task. This was consistent with a recent elaborate study by Sahyoun et al. (2009). They investigated the cognitive differences in pictorial reasoning between HFA and AS adolescents and adults, with three conditions designed to differentially engage linguistic mediation and visuospatial processing (visuospatial, *V*; semantic, *S*; visuospatial + semantic, $V + S$). Their results showed that both HFA and AS groups demonstrated accuracy similar to the controls. But they showed response time difference: AS performed similarly to the controls, they performed fastest on $V + S$ condition, whereas HFA performed equally fast on *V* and $V + S$ condition, and slowest on S condition. So the authors suggested that HFA participants appeared to favor visuospatial over linguistic mediation, whereas AS individuals recruited both verbal mediation and fluid reasoning resources. The fact that HFA could not use verbal strategy was also found in Joseph et al.'s study (2005) where HFA children performed worse in verbal self-ordered pointing test than controls. However, that children with AS used verbal strategy in figure n-back was only inferred from the results, further study adopting a task explicitly test the verbal strategy would be helpful to clarify this issue.

The n-back tasks results suggested that the central executive of children with AS was partially impaired, they needed longer time to respond. In another part of this collaborative study, these children with AS did not show significant difference in reaction time of computerized sustained attention tasks in comparison with the controls (Cui et al. 2008), thus the difference in reaction time of n-back in the present study was not due to their psychomotor problems. However, whether it was due to the difference in speed of information processing between groups need further study. The result that none of the condition-wise correlations between speed and accuracy was significant in either group indicated they did not have speed-accuracy trade-offs in this study. A rough comparison of performance between verbal and spatial working memory tasks in controls found that the performances in two conditions were comparable, thus children with AS were better in verbal tasks but impaired in visual-spatial tasks in comparison with controls could not be attributed to task difficulty difference of verbal and visual-spatial WM. However, the relative task difficulty between verbal and spatial working memory may not be compared directly, the possibility that the AS children's different impairment pattern in verbal and spatial working memory may be more a matter of differences in task difficulty than in modality differences could not be ruled out completely.

There are several limitations in the present study: First, the sample size of children with AS was small, and this may have obscured some of the findings. More AS individuals should be recruited later. Second, we only explored the working memory function in children with AS of early school ages. However, working memory will develop with age, so it will be helpful to recruit AS participants from a broader age range. Third, the present study did not include a HFA group and could not tell the difference between HFA and AS. Further studies exploring working memory capacities in ASD, including different groups (e.g., HFA, AS, control) with elaborately designed tasks and materials will be of great value which may help to tell the precise difference of cognitive function among the subtypes of ASD. Notwithstanding these limitations, the present study provided the first comprehensive study of working memory in children with AS and obtained informative results.

To summarize, the present study found that early-school-age children with AS had asymmetric development in different components of working memory: they had advantage in the phonological loop storing (performed better in verbal short-term memory tasks than the control group), but they were impaired in the visuospatial sketchpad storing (performed worse in visual-spatial short-term memory tasks); and they showed a partial deficit in the central executive processing (did as well as the control group in the complex working memory span tasks and n-back accuracy, but took longer reaction time in the n-back tasks).

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