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Verbal fluency as a predictor of autism spectrum disorder diagnosis and co-occurring attention-deficit/hyperactivity disorder symptoms

Xinzhou Tang[1] · Zihui Hua[2] · Jiayin Xing[3] · Li Yi[2,5] · Zhaozheng Ji[1] · Liyang Zhao[1] · Xing Su[1] · Tingni Yin[1] · Ran Wei[4] · Xue Li[1] · Jing Liu[1]

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Abstract

Verbal fluency tasks have been useful in characterizing the cognitive and language impairments in individuals with autism spectrum disorder (ASD). However, we have a limited understanding of verbal fluency in children and adolescents with comorbid ASD and attention-deficit/hyperactivity disorder (ADHD). The current study investigates whether the verbal fluency task can serve as an assistive diagnostic tool for predicting ASD and comorbid ASD and ADHD (ASD + ADHD) diagnoses and symptoms. Children and adolescents with ASD ($n=34$), ASD + ADHD ($n=26$), and typical development (TD; $n=65$) completed a semantic verbal fluency task and standardized cognitive assessments. Results indicated that both ASD and ASD + ADHD groups showed deficits in verbal fluency compared to the TD group, whereas no differences were found between ASD and ASD + ADHD groups. The number of correct word items participants produced during the verbal fluency task differentiated the ASD and ASD + ADHD groups from the TD group and predicted ADHD symptoms. The number of repetitive items and errors differentiated the ASD + ADHD group from the TD group and predicted ASD symptoms related to language and social and self-help. Moreover, the concurrent validity of verbal fluency measures varied according to developmental stages. Taken together, these findings provide new insights into the language and cognitive development of children and adolescents with ASD and ASD + ADHD. Further, the verbal fluency task may provide useful diagnostic information across different developmental stages and contribute to clinicians' ongoing efforts to develop more effective diagnostic tools and establish more accurate clinical profiles.

Keywords Verbal fluency · ASD · ADHD · School-aged children · Adolescents

Xinzhou Tang and Zihui Hua contributed equally.

Extended author information available on the last page of the article

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Introduction

Verbal fluency refers to the efficiency at which one retrieves concepts and sound forms from the mental lexicon and produces spontaneous verbal responses (Butman et al., 2000; Levelt et al., 1999). Verbal fluency tasks are commonly used in neuropsychological assessments to measure impairments in executive functioning (EF) and verbal abilities in related disorders, such as Alzheimer's disease (e.g., Appell et al., 1982; Hodges et al., 1992), amnesia (Weingartner et al., 1983), autism spectrum disorders (ASD; e.g., Ambery et al., 2006; Baxter et al., 2019; Begeer et al., 2014), and attention-deficit/hyperactivity disorder (ADHD; e.g., Abreu et al., 2013; Koziol & Stout, 1992; Marzocchi et al., 2008). Phonemic and semantic fluency tasks (Shao et al., 2014) are among the most widely used assessments of verbal fluency. Within a specified time limit, participants produce words based on a letter cue (e.g., "tell me all the words you can think of that begin with the letter S") or from a particular semantic category (e.g., "tell me all the animals you can think of"; Benton, 1968; Cipolotti & Warrington, 1995; Kenworthy et al., 2013; Lezak et al., 2012).

During verbal fluency tasks, participants are expected to search their mental lexicon stored in long-term memory and generate suitable words following the given rules at a relatively fast speed. Three widely used measures of verbal fluency are the numbers of correct, repetitive, and erroneous (e.g., naming dinosaurs despite being instructed to avoid naming such subcategories of animals) responses. EF skills such as working memory, inhibition, sustained attention, and overall monitoring and planning are also implicated (e.g., Pastor-Cerezuela et al., 2016). Therefore, individuals with impairments in language and EF skills (e.g., ASD and ADHD; see Craig et al., 2016 for a review) may show deficits in verbal fluency, and verbal fluency tasks may serve as assistive diagnostic and assessment tools for these disorders. The current study investigates verbal fluency deficits in children and adolescents with ASD and with comorbid ASD and ADHD (ASD + ADHD). We aim to achieve a better understanding of the cognitive and linguistic profiles of ASD and ASD + ADHD populations and explore the potential of verbal fluency tasks as an assistive index for differentiating these diagnostic groups from typically developing (TD) controls and predicting ASD and ADHD symptomology.

Verbal fluency in ASD

Individuals with ASD are characterized by difficulties with social communication and restrictive and repetitive behaviors (American Psychiatric Association, 2013) and tend to exhibit impaired verbal fluency (e.g., Boucher, 1988; Geurts & Vissers, 2012; Kleinhans et al., 2005). Specifically, relative to their TD counterparts, children (e.g., Geurts et al., 2004; Pastor-Cerezuela et al., 2016; Verté et al., 2005) and adults with ASD (e.g., Ambery et al., 2006; Baxter et al., 2019; Bramham et al., 2009) generated fewer correct word items and produced more repetitions (Bramham et al., 2009; Robinson et al., 2009; Spek et al., 2009; Turner, 1999) and errors (Inokuchi & Kamio, 2013; Turner, 1999). Extant research has attributed these ASD-related deficits in verbal fluency to impairments in language and EF (e.g., Friesen et al., 2015; Gonzalez-Barrero & Nadig, 2017). First, delayed and impaired language development in ASD, as indicated by lower verbal IQ compared to TD and other pervasive developmental disorders (Charman, Baron-Cohen, et al., 2003; Charman, Drew, et al., 2003; Mawhood et al., 2000; Thurm et al., 2007), may limit individuals' performance on verbal fluency tasks. For example, Ruff et al. (1997) found that word knowledge measured using the vocabulary subtest of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1981) was correlated with verbal fluency. Similarly, Pastor-Cerezuela et al. (2016) suggested that whereas age was the main predictor of verbal fluency in TD children, verbal IQ predicted verbal fluency in children with ASD. Moreover, neuroimaging studies also showed atypical responses in the left inferior frontal gyrus (LIFG, also referred to as "Broca's area") regions during verbal fluency tasks among adolescents (Kenworthy et al., 2013; Knaus et al., 2008) and adults with ASD (Beacher et al., 2012; Kenworthy et al., 2013). The LIFG regions support various language abilities, such as verbal fluency (Baldo & Shimamura, 1998; Thompson-Schill et al., 1998), sentence comprehension (Just et al., 2004; Kana et al., 2006), and language working memory (see Vigneau et al., 2006 for a meta-analysis). Hence, the atypical activation in the LIFG may have contributed to verbal fluency deficits in ASD.

As for EF skills, ASD-related impairments in generativity, cognitive flexibility, and monitoring and planning (Bailey et al., 1996; Carmo et al., 2015; Harris, 1994) may also relate to deficits in verbal fluency. Carmo et al. (2015) found that high-functioning adults with ASD produced fewer words than verbal-IQ-matched TD controls only during the first half but not the second half of the task, which may be attributable to deficits in generativity, the ability to initiate and generate novel responses (Turner, 1999). Besides, special interest and a lack of cognitive flexibility in children with ASD may relate to their excessive responses within a particular subcategory in the semantic verbal fluency task (e.g., naming a large number of farm animals when asked to name animals; Crane et al., 2011). Further, deficits in monitoring and planning in ASD may result in difficulties in maintaining the stimulus–response rules of the task, hence leading to more repetitive or erroneous responses (Kenworthy et al., 2013; Turner, 1999). Neuroimaging studies further revealed that deficits in verbal fluency in ASD may be related to dysfunction of EF-related neural networks (i.e., the frontal-striatal-cerebellar loop) during word generation (Baxter et al., 2019; Kenworthy et al., 2013; Kleinhans et al., 2008). These regions were not only associated with EF (Robbins, 2007; Rubia et al., 2007; Wager & Smith, 2003; Wager et al., 2004), but also correlated with other common symptoms of ASD, such as repetitive behaviors and restricted interests (Kenworthy et al., 2013; Turner, 1999).

Verbal fluency in ADHD

ADHD, characterized by inattention, impulsivity, and hyperactivity, is the most common neurodevelopmental disorder in childhood, with a prevalence of approximately 5% (American Psychiatric Association, 2013). Whereas an extensive body of studies have shown verbal fluency deficits in ASD, findings characterizing such deficits in ADHD are less consistent. Compared to their TD counterparts, some studies found that individuals with ADHD generated a reduced number of correct words and an increased number of repetitions and errors during semantic verbal fluency tasks (Happé et al., 2006; Koziol & Stout, 1992; Marzocchi et al., 2008; Takács et al., 2014), while others found that individuals with ADHD generate comparable number of correct words, repetitions, and errors during those tasks (Abreu et al., 2013; Andreou & Trott, 2013; Hurks et al., 2004).

As to why individuals with ADHD may show verbal fluency deficits, Happé et al. (2006) suggested that impairments in response selection and inhibitory control among children with ADHD may contribute to the increased errors in verbal fluency tasks. Neuroimaging studies have lent preliminary support to this view by suggesting that errors in verbal fluency tasks may reflect dysfunction in focal orbitofrontal regions, the frontal components of the widely distributed and complex circuits involved in the executive control of attention (Goldman-Rakic, 1988; Loge et al., 1990).

Verbal fluency in comorbid ASD and ADHD

ADHD is among the most common comorbid disorders in individuals with ASD, with a comorbidity rate between 14 and 78% (Rommelse et al., 2011; van der Meer et al., 2012). Individuals with comorbid ASD and ADHD (ASD + ADHD henceforth) tend to have a lower IQ and more severe symptoms (e.g., greater attention deficits; Sinzig et al., 2008) compared to those with ADHD or ASD only. EF deficits in ASD and ADHD, such as impairments in flexibility, monitoring, attention, and inhibition, were also found in individuals with ASD + ADHD (see Craig et al., 2016 for a review). Moreover, ASD + ADHD comorbidity has been shown to result in heightened family stress and reduced treatment efficacy (Gadow et al., 2006; Hong et al., 2021; Reiersen & Todd, 2008). Therefore, to develop more effective diagnostic tools and intervention strategies, it is imperative to further understand the cognitive and linguistic profiles of ASD + ADHD comorbidity.

Taken together, verbal fluency disparities among TD, ASD, and ASD + ADHD groups call for closer scrutiny. Although verbal fluency in ASD and ADHD has been studied extensively, to our knowledge, previous studies have not distinguished between participants with ASD only and those with ASD + ADHD. Nor did previous studies focusing on verbal fluency in ASD report whether the participants underwent ADHD screening. This lack of attention to ASD + ADHD comorbidity and its implications limits our understanding of differential symptomology and diagnosis in comorbid populations. Hence, the current study aims to explore verbal fluency deficits in children and adolescents with ASD and ASD + ADHD.

The current study

This study investigates whether the verbal fluency task could serve as an assistive tool for diagnosing individuals with ASD and comorbid ASD + ADHD and assessing their symptom severity. Our study will not only further our understanding of the cognitive and language delays and impairments in ASD and comorbid ASD + ADHD, but also have important clinical implications for developing more efficient diagnostic and assessment tools (e.g., Santosh et al., 2006; Taurines et al., 2012). Commonly used rating scales of ADHD symptoms have shown decreased validity when used in individuals with ASD (Rau et al., 2020; Yerys et al., 2017). Considering that verbal fluency tasks are short in duration, easy to administer, and child-friendly, and that verbal fluency deficits are manifested in ASD and ADHD with different magnitude and mechanisms (e.g., Bramham et al., 2009; Geurts et al., 2004), verbal fluency tasks may serve as an assistive tool for the diagnosis and symptom assessment in ASD and comorbid ASD + ADHD in addition to the widely adopted scales. Moreover, ASD is an early onset disorder with distinct developmental trajectories, and preliminary evidence has suggested that the ASD-related deficits in verbal fluency may differ based on participants' age (Baxter et al., 2019; Stefanatos, 2008). Therefore, the current study extends prior literature by taking a developmental perspective and comparing school-aged children versus adolescents with regard to the correlations between verbal fluency and ASD/ASD + ADHD symptomology.

The present study addresses four research questions: a) Does verbal fluency differ among individuals with ASD, ASD + ADHD, and TD controls? b) Does verbal fluency predict ASD or ASD + ADHD diagnosis? c) Does verbal fluency relate to ASD and ADHD symptom severity, and if so, how? d) Do the associations between verbal fluency and diagnoses/symptomology vary according to developmental stage (i.e., school-aged children versus adolescents? To answer these questions, we will administer a semantic verbal fluency task on children and adolescents with ASD, ASD + ADHD, and on TD controls and compare their performance. Next, we will examine whether participants' verbal fluency predicts their diagnosis and symptom severity. We will then conduct age-based stratified analyses to examine the implication of developmental stage. Based on prior literature, we hypothesize that participants' performance on verbal fluency tasks may show group-based differences, predict ASD or ASD + ADHD diagnosis, and predict ASD and ADHD symptom severity.

Method

Participants

We used G*Power 3.1.9.7 (Faul et al., 2007) to conduct the power analysis. Based on our ordinary least squares (OLS) regression models, obtaining a medium-to-large effect size ($f^2 = 0.3$, $\alpha = 0.05$) and a power ($1 - \beta$) of 0.80 requires a group size of $N = 62$. Sixty participants with ASD (age range = 6.1–17.4, $M = 10.67$, $SD = 2.89$) and 65 TD participants (age range = 6.2–17.2, $M = 11.72$, $SD = 2.68$) were enrolled in the current study. Participants' IQ was measured with the third or fourth edition of the Wechsler Intelligence Scale for Children, Chinese Revision (C-WISC-III or -IV; Gong & Cai, 1993; Zhang, 2009; we discuss score conversion between the two versions in the next section). All participants had an IQ above 70, had no known physical or neurological disorders other than ASD or ADHD and no history of substance abuse, and were psychotropic medication-naïve. We recruited the children with ASD and ASD + ADHD through the outpatient clinic of a local psychiatric hospital, and TD participants from the surrounding communities through online advertisements. Each ASD and comorbid ADHD diagnosis was established by two child and adolescent psychiatrists based on the Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM-IV; American Psychiatric Association, 2000). Comorbid ADHD diagnoses were confirmed based on the Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997). TD participants were also assessed by a child and adolescent psychiatrist to rule out possible ASD or ADHD diagnosis and other psychiatric disorders based on the K-SADS-PL. The present study has been approved by the Ethics Committee of the hospital. We received written consent from the participants and their parents or legal guardians.

We divided participants with ASD into two groups: those with or without ADHD comorbidity (ASD group and ASD + ADHD group, respectively) according to their clinical assessment and performance on the K-SADS-PL. Consistent with previous studies (e.g., Antshel et al., 2016; van der Meer et al., 2012), 26 (43%) children with ASD had a comorbidity of ADHD and the remaining 34 (57%) did not. Table 1 presents the demographic information and clinical characteristics of the three groups (ASD, ASD + ADHD, and TD). The groups were matched in gender and age, whereas the ASD group and the ASD + ADHD group had lower IQ than the TD group ($M = 100$, 101, and 111 respectively, $SD = 19.84$, 19.47, and 14.51, $p = 0.002$).

Material and procedures

Verbal fluency task

Chinese is a non-alphabetical language, so we chose the sematic verbal fluency task (also termed as the category fluency task; Turner, 1999) over the letter fluency task to accesses participants' ability to generate novel responses and inhibit incorrect responses. Participants were instructed to produce as many animal labels as possible in two minutes without repetition and were asked not to mention dinosaurs, parasites, microorganisms, or bacteria. An experimenter recorded the number of correct words (e.g., "cat"), repetitions (e.g., producing "cat" twice), and errors (e.g., "tyrannosaurus").

Autism Behavior Checklist

Parents of children with ASD or ASD + ADHD reported their child's current symptoms using the 57-item Autism Behavior Checklist (ABC; Krug et al., 1980). This checklist encompasses five domains: sensory, relating, body and object use, language, and social and self-help. Parents indicated whether their child showed a symptom or not. During data analyses, each item was assigned a score between 0

Table 1 Demographic Information and Clinical Characteristics of ASD, ASD + ADHD and TD groups

	Group						Post hoc of ASD versus ASD + ADHD	
	ASD (n = 34)	ASD + ADHD (n = 26)	TD (n = 65)	F/χ^2	p	Post hoc comparison	t/χ^2	p
Gender (M: F)	29:5	22:4	43:22	5.95	.051	–	0.005	.942
Age	10.5 (2.70)	10.9 (3.15)	11.7 (2.68)	2.42	.09	–	–0.626	.534
FIQ	100 (19.84)	101 (19.47)	111 (14.51)	6.42	.002**	ASD < TD, ASD + ADHD < TD	–0.243	.809
VIQ/VCI	107 (19.29)	107 (18.50)	114 (19.90)	2.30	.104	–	0.024	.981
PIQ/PRI	97.3 (20.00)	99.5 (19.72)	108 (14.15)	4.73	.01*	ASD < TD	–0.430	.669
ADHD-RS-IV IA	13.26 (5.67)	15.7 (5.33)	7.6 (4.31)	30.8	< .001**	ASD > TD, ASD + ADHD > TD	–1.701	.095
ADHD-RS-IV HI	9.3 (5.63)	11.3 (6.04)	4.7 (4.50)	18.84	< .001**	ASD > TD, ASD + ADHD > TD	–1.299	.200
ADHD-RS-IV total	22.6 (10.21)	27.0 (9.32)	12.3 (8.23)	30.34	< .001**	ASD > TD, ASD + ADHD > TD	–1.743	.087
ABC Sensory	3.97 (4.17)	5.46 (5.81)	0.9 (2.93)	14.55	< .001**	ASD > TD, ASD + ADHD > TD	–1.108	.274
ABC Relating	6.38 (5.13)	8.88 (6.25)	0.78 (2.09)	42.62	< .001*	ASD > TD, ASD + ADHD > TD	–1.658	.104
ABC Body and Object Use	3.18 (4.56)	5.81 (6.47)	0.8 (3.10)	12.58	< .001*	ASD > TD, ASD + ADHD > TD	–1.764	.085
ABC Language	4.00 (5.68)	6.42 (4.83)	0.75 (2.71)	19.09	< .001**	ASD > TD, ASD + ADHD > TD	–1.784	.080
ABC Social and Self-Help	6.68 (4.35)	9.00 (4.86)	1.5 (3.58)	37.69	< .001**	ASD > TD, ASD + ADHD > TD	–1.921	.060
ABC total	24.2 (17.34)	35.6 (22.11)	4.77 (12.29)	39.17	< .001**	TD < ASD < ASD + ADHD	–2.163	.036*

Standard deviations were in parentheses. VIQ = verbal IQ of C-WISC-III; PIQ = performance IQ of C-WISC-III; VCI = verbal comprehension index of C-WISC-IV; PRI = perceptual reasoning index of C-WISC-IV; FIQ = full-scale IQ of C-WISC-III or C-WISC-IV; ADHD-RS-IV = Chinese ADHD Rating Scale–IV; ADHD-RS-IV IA = Inattention subscale of ADHD-RS-IV; ADHD-RS-IV HI = Hyperactivity-Impulsivity subscale of ADHD-RS-IV; ABC = Autism Behavior Checklist

* $p < .05$. ** $p < .01$

and 4 based on its loading on the checklist. The highest possible total score is 158, and children who received a total score of 31 and above were considered potentially autistic (Yang et al., 1993). The Cronbach α of the ABC in the current sample was 0.89 (Heo et al., 2015).

The Chinese ADHD Rating Scale-IV

The 18-item Chinese ADHD Rating Scale–IV (ADHD-RS-IV; Su et al., 2015) gauges inattention and hyperactivity-impulsivity symptoms described in DSM-IV (American Psychiatric Association, 2000) and consists of two subscales, namely Inattention and Hyperactivity-Impulsivity. Each item asked parents to rate children's symptom severity on a scale of 0 (never or rarely) to 3 (very often). The ADHD-RS-IV has shown high reliability and validity in Chinese samples (Su et al., 2015). The Cronbach α of the ADHD-RS-IV in the current sample was 0.83 (Heo et al., 2015).

Chinese Wechsler Intelligence Scale for Children

Due to timing constraints of participant enrollment, 10 participants (3 with ASD, 6 with ASD + ADHD, and 1 TD) were assessed using the C-WISC-III (Gong & Cai, 1993) and the remaining 115 were assessed using C-WISC-IV (Zhang, 2009). Both versions were validated and norm-referenced in Chinese samples. C-WISC-III measures verbal IQ (VIQ) and performance IQ (PIQ). C-WISC-IV includes four dimensions: verbal comprehension index (VCI), perceptual reasoning index (PRI), working memory index (WMI), and processing speed index (PSI). Notably, VCI in C-WISC-IV corresponds to VIQ in C-WISC-III, and PRI in C-WISC-IV corresponds to PIQ in C-WISC-III. Hence, the full-scale IQ (FIQ) assessed using both editions can be directly converted across versions (Wechsler, 2008). According to DSM-5, an IQ below 70 is typically considered as a sign of intellectual disability (American Psychiatric Association, 2013). Given that a condition of intellectual disability may significantly interfere with task performance, the current study only included individuals with an IQ of 70 and above.

Results

Group differences in verbal fluency

We first compared participants' performance on the verbal fluency task across groups (ASD, ASD + ADHD, and TD). We conducted a series of planned one-way ANCOVA comparisons of three verbal fluency indices commonly used in literature (e.g., Borkowska, 2015; Dunn et al., 1996; Hurks et al., 2004), namely the number of correct items ("correct number" henceforth), the number of errors ("error number"), and the number of repetitive responses ("repetition number"). Age and verbal IQs (either VIQ or VCI) were included as covariates. One participant was missing the VIQ score and was hence removed from all analyses pertaining to VIQ, resulting in a total of 33 participants in the ASD group and a final sample of $N = 124$.

The groups differed in error numbers and repetition numbers, $F(2,119) = 5.43$, $p = 0.006$ and $F(2,119) = 3.64$, $p = 0.029$, respectively. As shown in Fig. 1, post-hoc Tukey's honest significant difference tests showed that the error number of the ASD + ADHD group ($M = 0.62$, $SD = 1.10$) was significantly higher than the TD group ($M = 0.12$, $SD = 0.33$), $p = 0.002$, and that the repetition number of the ASD + ADHD group ($M = 1.65$, $SD = 3.15$) was also higher than the TD group ($M = 0.54$, $SD = 0.87$), $p = 0.026$. No group differences were found in the error number or the repetition number between ASD and ASD + ADHD groups or between ASD and TD groups. Group differences in the correct number were marginal, $F(2,119) = 2.98$, $p = 0.055$. Post-hoc comparisons indicated that the TD group ($M = 26.94$, $SD = 8.18$) had higher correct number than the ASD group ($M = 20.64$, $SD = 8.80$), $p < 0.001$, and the ASD + ADHD group ($M = 22.38$, $SD = 8.90$), $p = 0.019$. No group difference of the correct number was found between ASD and ASD + ADHD groups.

Verbal fluency as a predictor of group membership

Having shown group differences in verbal fluency, we then examined whether verbal fluency (i.e., correct, error, and repetition numbers) could predict group membership (ASD, ASD + ADHD, TD) using multinomial logistic regressions (MLR). We used TD as the reference group, which yielded comparisons of ASD versus TD and of ASD + ADHD versus TD. We then conducted a second MLR with ASD as the reference group, generating comparisons of ASD versus ASD + ADHD. Data from all 125 participants were included in the MLRs.

Overall, MLRs (statistics are reported in Table 2) suggested that the correct number, error number, and repetition number each individually predicted group membership, $ps < .05$. Specifically, results first indicated that the correct number significantly differentiated the ASD group from the TD group, $p < 0.001$. The odds ratio (OR) for

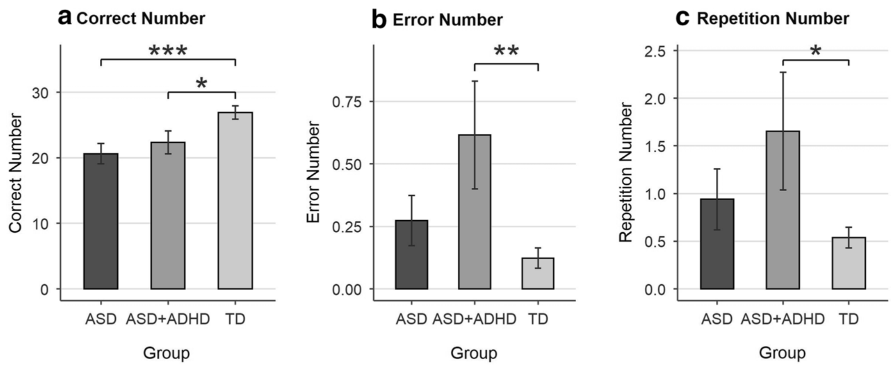

Fig. 1 Group Differences in Verbal Fluency Measurements *Note* Error bars indicate standard errors.* $p < .05$. ** $p < .01$. *** $p < .001$

Table 2 Parameter Estimates, Odds Ratios, and Confidence Limits for the MLR Analyses

Predictor	ASD versus TD[a]					ASD[a] versus ASD + ADHD					ASD + ADHD versus TD[a]				
	β (*SE*)	*OR*	95% CI *OR*		p^b	β (*SE*)	*OR*	95% CI *OR*		p^b	β (*SE*)	*OR*	95% CI *OR*		p^b
			Lower	Upper				Lower	Upper				Lower	Upper	
Intercept	1.591 (0.724)	–	–	–	.028*	-1.226 (0.799)	–	–	–	.125	0.365 (0.816)	–	–	–	.655
Correct number	-0.110 (0.031)	0.896	0.843	0.952	< .001***	0.030 (0.035)	1.031	0.966	1.101	.386	–0.079 (0.033)	0.924	0.865	0.986	.018*
Error number	0.612 (0.521)	1.844	0.664	5.121	.240	0.534 (0.385)	1.705	0.619	4.697	.165	1.146 (0.517)	3.145	1.142	8.663	.027*
Repetition number	0.318 (0.181)	1.374	0.963	1.961	.080	0.063 (0.127)	1.065	0.750	1.512	.620	0.381 (0.179)	1.463	1.030	2.078	.033*

$N = 125$. MLR = multinomial logistic regression. CI = confidence interval

[a] Reference group in the multinomial logistic regression. [b] *P* value from a Wald test statistic

*$p < .05$. **$p < .01$. ***$p < .001$

the correct number was 0.896, indicating that on average, a one-unit decrease in a participant's correct number was associated with a 1.12 times greater likelihood of falling into the ASD group relative to the TD group. The error number and the repetition number did not differentiate ASD from TD, *p*s > 0.05. Moreover, the correct number, error number, and repetition number each differentiated the ASD + ADHD group from the TD group, *p*s = 0.018, 0.027, and 0.033, respectively. Specifically, when the correct number decreased by one unit, participants had 1.082 times greater likelihood of being in the ASD + ADHD group relative to the TD group, $OR = 0.924$. As a participant's error number increased by one unit, they had 3.145 times greater likelihood of being in the ASD + ADHD group compared with the TD group, $OR = 3.145$. A one-unit increase in participant's repetition number was associated with 1.463 times greater likelihood of being in the ASD + ADHD group relative to the TD group, $OR = 1.463$. Last, results from ASD versus ASD + ADHD comparisons (with ASD group as the reference group) showed that none of the verbal fluency measurements differentiated the ASD group from the ASD + ADHD group.

Verbal fluency as a predictor of ASD and ADHD symptom severity

Next, we used OLS regressions to examine relations between participants' verbal fluency and the severity of ASD (as measured by the ABC) and ADHD symptoms (ADHD-RS-IV scores; $N = 125$; for full statistics from regression analyses, see Table 3). The OLS regressions allowed us to consider multiple potential correlates of ASD and ADHD symptomology simultaneously, and our data met OLS modeling assumptions. We found that verbal fluency related to the ABC Language scores. Specifically, repetition number was associated with ABC Language score, $\beta = 0.559$, $p = 0.018$, and the correct number marginally related to ABC Language score, $\beta = -0.089$, $p = 0.066$. Moreover, the ABC Social and Self-Help scores were associated with the correct number, $\beta = -0.110$, $p = 0.040$, and marginally associated with repetition number, $\beta = 0.505$, $p = 0.052$. The ABC total score and other subscales were unrelated to verbal fluency.

As for correlates of ADHD severity, the ADHD-RS-IV total score, ADHD-RS-IV Inattention score (ADHD-RS-IV IA), and ADHD-RS-IV Hyperactivity-Impulsivity score (ADHD-RS-IV HI) were all related to verbal fluency. Specifically, the correct number was a significant predictor across all three ADHD-related regression models, $\beta = -0.318$, $p = 0.004$ (ADHD-RS-IV total score as the outcome variable), $\beta = -0.158$, $p = 0.010$ (ADHD-RS-IV IA as outcome), and $\beta = -0.160$, $p = 0.008$ (ADHD-RS-IV HI as outcome). Repetition number marginally related to ADHD-RS-IV HI and ADHD-RS-IV total score, $\beta = 0.538$, $p = 0.063$ and $\beta = 0.956$, $p = 0.074$ respectively. Error numbers were unassociated with ADHD symptom scores. See Table 4 for full results from regression analyses.

Concurrent validity of verbal fluency by age groups

Lastly, we used age-based stratified analyses to examine whether the association between verbal fluency and group membership and symptom severity varied across age groups. Participants ($N = 125$) were divided into two groups:

Table 3 Ordinary Least Squares Regressions Predicting ASD Symptoms Measured Using ABC Scores

Dependent variables	Independent variables	β	95% CI of β		*SE*	*t*	*p*
			Lower	Upper			
ABC Sensory	Correct number	–0.019	–0.111	0.072	0.046	–0.421	.675
	Error number	0.774	–0.481	2.030	0.634	1.221	.225
	Repetition number	0.115	–0.330	0.560	0.225	0.511	.610
ABC Relating	Correct number	–0.028	–0.140	0.083	0.056	–0.504	.615
	Error number	–0.424	–1.955	1.107	0.773	–0.548	.584
	Repetition number	0.386	–0.156	0.928	0.274	1.410	.161
ABC Body and Object Use	Correct number	–0.019	–0.118	0.081	0.050	–0.374	.709
	Error number	–0.291	–1.656	1.074	0.689	–0.422	.674
	Repetition number	0.161	–0.322	0.645	0.244	0.661	.510
ABC Language	Correct number	–0.089	–0.185	0.006	0.048	–1.857	.066
	Error number	0.400	–0.905	1.705	0.659	0.607	.545
	Repetition number	0.559	0.097	1.021	0.233	2.395	.018*
ABC Social and Self-Help	Correct number	–0.110	–0.215	–0.005	0.053	–2.076	.040*
	Error number	–0.352	–1.788	1.083	0.725	–0.486	.628
	Repetition number	0.505	–0.004	1.013	0.257	1.965	.052
ABC total	Correct number	–0.266	–0.688	0.156	0.213	–1.248	.215
	Error number	0.107	–5.675	5.888	2.920	0.037	.971
	Repetition number	1.726	–0.322	3.773	1.034	1.669	.098

Note. ABC = Autism Behavior Checklist. CI = confidence interval

* $p < .05$

Table 4 Ordinary Least Squares Regressions for Predicting ADHD Symptoms Measured by ADHD-RS-IV

Dependent variables	Independent variables	β	95% CI of β		*SE*	*t*	*p*
			Lower	Upper			
ADHD-RS-IV total	Correct number	–0.318	–0.535	–0.101	0.109	–2.907	.004**
	Error number	1.887	–1.080	4.853	1.499	1.259	.210
	Repetition number	0.956	–0.095	2.007	0.531	1.802	.074
ADHD-RS-IV IA	Correct number	–0.158	–0.277	–0.039	0.060	–2.633	.010**
	Error number	1.268	–0.362	2.899	0.824	1.540	.126
	Repetition number	0.418	–0.160	0.995	0.292	1.432	.155
ADHD-RS-IV HI	Correct number	–0.160	–0.277	–0.043	0.059	–2.703	.008**
	Error number	0.618	–0.984	2.221	0.809	0.764	.446
	Repetition number	0.538	–0.028	1.106	0.287	1.879	.063

ADHD-RS-IV = Chinese ADHD Rating Scale–IV; ADHD-RS-IV IA = Inattention subscale of ADHD-RS-IV; ADHD-RS-IV HI = Hyperactivity-Impulsivity subscale of ADHD-RS-IV; CI = confidence interval

** $p < .01$

school-aged children (age < 12 years; $n = 68$) and adolescents (age ≥ 12 years; $n = 57$; see Table 5 for demographic information). Following similar MLR procedures reported above, we examined associations between verbal fluency and group membership (ASD, ASD + ADHD, or TD) within each age group. Overall, within the school-aged group, only correct number related to group membership, $p < 0.001$, whereas within the adolescent group, only error number was associated with group membership, $p = 0.046$. As shown in Table 6, within the school-aged children group, the correct number differentiated the ASD group from the TD group, $OR = 0.844$, $p = 0.002$, as well as the ASD + ADHD group from the TD group, $OR = 0.838$, $p = 0.003$, indicating that when the correct number of a school-aged child participant decreased by one unit, they had 1.185 times greater likelihood of being in the ASD group relative to the TD group, and 1.193 times greater likelihood of being in the ASD + ADHD group relative to the TD group. Within the adolescent group, however, it was the error number that differentiated the ASD + ADHD group from the TD group, $OR = 6.554$, $p = 0.025$, indicating that a one-unit increase in an adolescent participant's error number was associated with 6.554 times greater likelihood of being in the ASD + ADHD group relative to the TD group, and the ASD and TD groups were not significantly differentiated. Neither were the ASD and ASD + ADHD groups differentiated by verbal fluency in either school-aged children or adolescent group.

We then conducted within-age-group OLS regressions to test whether and how correlations between verbal fluency measures and ASD (ABC scores) and ADHD symptom severity (ADHD-RS-IV scores) varied. As shown in Table 7, in the school-aged group, the correct number was related to ABC Relating score, $\beta = -0.193$, $p = 0.018$ and ABC Social and Self-Help score, $\beta = -0.190$, $p = 0.049$. Nevertheless, in the adolescent group, repetition numbers correlated with ABC Language score, $\beta = 0.416$, $p = 0.027$ and ABC Social and Self-help score, $\beta = 0.489$, $p = 0.022$. In terms of ADHD symptoms, in the school-aged group, the three verbal fluency measurements were non-significant correlates, whereas in the adolescent group, repetition number was related to ADHD-RS-IV total score,

Table 5 Demographic Information of Two Age Groups

	School-aged children ($n = 68$)	Adolescents ($n = 57$)	t/ χ^2	p
Gender (M:F)	53:15	41:16	0.601	.438
Age	9.12 (1.67)	13.72 (1.61)	–15.664	< .001
Age range	6.11–11.90	12.00–17.40	–	–
IQ[a]	104.28 (17.09)	107.81 (18.63)	–1.090	.278
VIQ/VCI[a]	109.48 (17.67)	111.88 (21.87)	–0.664	.508
Diagnose makeup	21 ASD, 15 ASD + ADHD, 32 TD	13 ASD, 11 ASD + ADHD, 33 TD	1.557	.459

VIQ = verbal IQ of C-WISC-III; VCI = verbal comprehension index of C-WISC-IV

[a] One participant from the school-aged children group was removed from the comparison due to missing IQ score

Table 6 MLR Analyses for Two Age Groups

Predictor	ASD versus TD[a]					ASD[a] versus ASD + ADHD					ASD + ADHD versus TD[a]				
	β (*SE*)	*OR*	95% CI *OR*		p^b	β (*SE*)	*OR*	95% CI *OR*		p^b	β (*SE*)	*OR*	95% CI *OR*		p^b
			Lower	Upper				Lower	Upper				Lower	Upper	
School-aged children (n = 68)															
Intercept	2.999 (1.130)	–	–	–	.008**	–0.541 (0.995)	—	–	–	.586	2.458 (1.230)	–	–	–	.046*
Correct number	–0.170 (0.054)	0.844	0.760	0.937	.002**	–0.007 (0.054)	0.993	0.894	1.104	.902	–0.176 (0.060)	0.838	0.746	0.943	.003**
Error number	–0.012 (0.702)	0.988	0.250	3.909	.986	0.629 (0.564)	1.875	0.620	5.669	.265	0.617 (0.668)	1.853	0.501	6.861	.356
Repetition number	0.193 (0.386)	1.213	0.569	2.585	.617	0.142 (0.363)	1.153	0.566	2.350	.695	0.336 (0.393)	1.399	0.647	3.023	.393
Adolescents (n = 57)															
Intercept	0.100 (1.352)	–	–	–	.941	–2.629 (1.748)	–	–	–	.133	–2.530 (1.619)	–	–	–	.118
Correct number	–0.061 (0.048)	0.941	0.856	1.034	.207	0.077 (0.058)	1.080	0.964	1.209	.184	0.016 (0.051)	1.016	0.920	1.122	.753
Error number	1.378 (0.808)	3.966	0.813	19.341	.088	0.502 (0.715)	1.652	0.407	6.713	.483	1.880 (0.838)	6.554	1.267	33.894	.025*
Repetition number	0.351 (0.230)	1.421	0.906	2.229	.126	0.034 (0.136)	1.035	0.793	1.351	.801	0.385 (0.229)	1.470	0.939	2.301	.092

MLR = multinomial logistic regression; CI = confidence interval

[a] Reference group in the multinomial logistic regression. [b] *P* value from a Wald test statistic

* $p < .05$. ** $p < .01$

Table 7 Multiple Linear Regressions for Predicting ASD Symptoms for Two Age Groups

Dependent variables	Independent variables	β	95% CI of β		*SE*	*t*	*p*
			Lower	Upper			
School-aged children (n = 68)							
ABC Sensory	Correct number	–0.065	–0.211	0.081	0.073	–0.892	.376
	Error number	0.783	–0.782	2.347	0.783	0.999	.321
	Repetition number	0.479	–0.756	1.715	0.618	0.775	.441
ABC Relating	Correct number	–0.193	–0.352	–0.034	0.079	–2.432	.018*
	Error number	–0.928	–2.632	0.775	0.853	–1.089	.280
	Repetition number	1.191	–0.154	2.536	0.673	1.769	.082
ABC Body and Object Use	Correct number	–0.050	–0.234	0.135	0.092	–0.537	.593
	Error number	–0.417	–2.396	1.563	0.991	–0.420	.676
	Repetition number	–0.110	–1.673	1.453	0.782	–0.141	.889
ABC Language	Correct number	–0.124	–0.300	0.052	0.088	–1.406	.164
	Error number	–0.092	–1.985	1.801	0.947	–0.097	.923
	Repetition number	1.475	–0.020	2.969	0.748	1.971	.053
ABC Social and Self-Help	Correct number	–0.190	–0.378	–0.001	0.094	–2.009	.049*
	Error number	–0.508	–2.534	1.518	1.014	–0.501	.618
	Repetition number	0.372	–1.227	1.972	0.801	0.465	.644
ABC total	Correct number	–0.622	–1.348	0.104	0.363	–1.710	.092
	Error number	–1.163	–8.959	6.634	3.903	–0.298	.767
	Repetition number	3.408	–2.748	9.563	3.081	1.106	.273
Adolescents (n = 57)							
ABC Sensory	Correct number	0.052	–0.099	0.203	0.075	0.692	.492
	Error number	0.478	–1.967	2.922	1.219	0.392	.697
	Repetition number	0.054	–0.443	0.552	0.248	0.220	.827
ABC Relating	Correct number	0.140	–0.056	0.336	0.098	1.434	.157
	Error number	0.113	–3.069	3.294	1.586	0.071	.943
	Repetition number	0.194	–0.453	0.841	0.323	0.600	.551
ABC Body and Object Use	Correct number	0.112	–0.007	0.230	0.059	1.893	.064
	Error number	0.610	–1.312	2.532	0.958	0.637	.527
	Repetition number	0.184	–0.207	0.574	0.195	0.942	.351
ABC Language	Correct number	0.026	–0.085	0.137	0.055	0.465	.644
	Error number	0.988	–0.814	2.790	0.898	1.100	.276
	Repetition number	0.416	0.049	0.782	0.183	2.275	.027*
ABC Social and Self-Help	Correct number	0.086	–0.040	0.212	0.063	1.366	.178
	Error number	0.547	–1.497	2.591	1.019	0.537	.594
	Repetition number	0.489	0.073	0.905	0.207	2.360	.022*
ABC Total	Correct number	0.416	–0.170	1.002	0.292	1.422	.161
	Error number	2.736	–6.771	12.242	4.740	0.577	.566
	Repetition number	1.336	–0.597	3.270	0.964	1.386	.171

ABC = Autism Behavior Checklist. CI = confidence interval

* $p < .05$

β = 1.073, $p = 0.022$ and ADHD-RS-IV HI, β = 0.736, $p < 0.001$, and error number was associated with ADHD-RS-IV IA, β = 3.384, $p = 0.018$ (See Table 8).

Discussion

The current study examined group-level differences in verbal fluency among children and adolescents with ASD, ASD + ADHD, and TD controls, and investigated whether verbal fluency measures predicted group membership and symptom severity. Overall, the results indicate that: (a) both ASD and ASD + ADHD groups exhibited lower verbal fluency than the TD group; (b) verbal fluency measures effectively differentiated the ASD group from the TD group as well as the ASD + ADHD group from the TD group, such that impaired performance indicated a greater probability of ASD and ASD + ADHD diagnosis; (c) verbal fluency performance correlated with ASD- and ADHD-related symptoms; and (d) the concurrent validity of verbal

Table 8 Ordinary Least Squares Regressions for Predicting ADHD Symptoms for Two Age Groups

Dependent variables	Independent variables	β	95% CI of β		*SE*	*t*	*p*
			Lower	Upper			
School-aged children (n = 68)							
ADHD-RS-IV total	Correct number	−0.305	−0.682	0.072	0.189	−1.618	.111
	Error number	1.639	−2.408	5.686	2.026	0.809	.421
	Repetition number	0.179	−3.016	3.374	1.600	0.112	.911
ADHD-RS-IV IA	Correct number	−0.179	−0.382	0.025	0.102	−1.755	.084
	Error number	0.438	−1.748	2.624	1.094	0.400	.690
	Repetition number	0.721	−1.005	2.447	0.864	0.835	.407
ADHD-RS-IV HI	Correct number	−0.126	−0.329	0.076	0.102	−1.245	.218
	Error number	1.201	−0.977	3.379	1.090	1.102	.275
	Repetition number	−0.542	−2.262	1.178	0.861	−0.630	.531
Adolescents (n = 57)							
ADHD-RS-IV total	Correct number	0.020	−0.255	0.296	0.137	0.148	.883
	Error number	4.347	−0.124	8.818	2.229	1.950	.057
	Repetition number	1.073	0.164	1.983	0.453	2.368	.022*
ADHD-RS-IV IA	Correct number	−0.040	−0.212	0.132	0.086	−0.466	.643
	Error number	3.384	0.599	6.170	1.389	2.437	.018*
	Repetition number	0.338	−0.229	0.904	0.282	1.196	.237
ADHD-RS-IV HI	Correct number	0.060	−0.065	0.186	0.063	0.963	.340
	Error number	0.963	−1.074	3.000	1.016	0.948	.347
	Repetition number	0.736	0.321	1.150	0.207	3.562	< .001***

ADHD-RS-IV = Chinese ADHD Rating Scale–IV; ADHD-RS-IV IA = Inattention subscale of ADHD-RS-IV; ADHD-RS-IV HI = Hyperactivity-Impulsivity subscale of ADHD-RS-IV; CI = confidence interval

* $p < .05$. *** $p < .001$

fluency scores varied by developmental stage (i.e., school-aged children versus adolescents).

First, we examined group differences in three verbal fluency indices. Overall, we found that controlling for age and verbal IQ, both ASD and ASD + ADHD groups produced fewer correct words than the TD group, which may be attributable to ASD-related deficits in EF (e.g., Corbett et al., 2009; Dunn et al., 1996; Geurts et al., 2004; Pastor-Cerezuela et al., 2016; Turner, 1999), including reduced flexibility and impaired generativity (e.g., Kenworthy et al., 2013; Memari et al., 2013). Vocabulary deficits in ASD (e.g., Charman, Baron-Cohen, et al., 2003; Charman, Drew, et al., 2003; Pastor-Cerezuela et al., 2016), such as reduced receptive and expressive vocabulary, may also have interfered with participants' production of word items within a predetermined semantic category under time constraints. ADHD-related EF deficits such as inattention and reduced inhibitory control (e.g., Barkley, 1998; Pennington & Ozonoff, 1996) may also contribute to the decreased correct number in the ASD + ADHD group, as argued in previous studies (e.g., Corbett et al., 2009; Geurts et al., 2004). Additionally, the ASD + ADHD group produced more errors and repetitions than the TD group, whereas the ASD group did not differ from the TD controls in errors and repetitions. Echoing previous research (Hurks et al., 2004; Tucha et al., 2005), these findings suggest that ADHD symptomology may have given rise to erroneous and repetitive responses. For example, auditory attention plays a critical role in verbal fluency performance (Ruff et al., 1997), and hence EF deficits and impaired attention skills related to ADHD may have hindered the ASD + ADHD participants' attention to experimenters' verbal instructions, which may in turn lead to increased repetitions and errors. Moreover, deficits in inhibition and ADHD-related impulsivity may have rendered the inhibition of errors and repetitions more challenging to participants with ASD + ADHD. Indeed, inhibitory control at an earlier age has been shown to predict later verbal fluency (Berlin et al., 2004), lending preliminary support to this hypothesized mechanism.

We then investigated whether verbal fluency predicted group membership. In line with our findings on group-level differences, regression analyses further revealed that the correct number differentiated the ASD group from the TD group as well as the ASD + ADHD group from the TD group, such that a lower correct number indicated a greater probability of ASD and ASD + ADHD diagnosis. Error and repetition numbers only differentiated the ASD + ADHD group from the TD group (but not ASD from TD), with higher error and repetition numbers associated with a greater probability of ASD + ADHD diagnoses. These results demonstrated the potential of verbal fluency as an assistive tool in diagnosing ASD and comorbid ADHD, in that a relatively lower correct number may indicate higher likelihood of ASD, and higher error and repetition numbers in addition to a lower correct number may raise the need for ADHD screening. Although none of the verbal fluency indices significantly differentiated between the ASD and ASD + ADHD groups, these indices did underscore differential manifestations of verbal fluency deficits between the two groups, which extended our understanding of the clinical, cognitive, and linguistic profiles of ASD + ADHD populations.

Next, we further explored the relations between verbal fluency and ASD and ADHD symptom severity in order to fully capture the varying levels of functioning and diverse manifestations of impairments (Volkmar et al., 2009; Whalen et al., 2002). Repetition and correct numbers respectively related to ABC language scores (e.g., a lack of speech, sound/phrase repetition, echoed speech) and social and self-help scores (e.g., poor self-care abilities, inappropriate social behaviors), but not overall ASD symptomology (ABC total score). Additionally, the correct number related to ADHD-related inattention and hyperactivity-impulsivity, and thus also correlated with overall ADHD symptom severity. Taken together, these findings not only shed new light on how various verbal fluency indices differentially correlate with diagnostic status and symptom severity and but also generate important clinical implications. While repetitions may be useful in indicating the risk of co-occurring ADHD diagnosis, the correct number may serve as a more effective index of ADHD-related impairments.

Lastly, the age-based stratified analyses showed that the concurrent validity of verbal fluency varied according to developmental stages. Among school-aged children (age 6–12), the correct number differentiated the ASD and the ASD + ADHD groups from the TD group and related to ASD-related impairments in relating (e.g., poor relationship development, lack of social interactions) and social and self-help. In adolescents (age 12–18), however, the error number differentiated the ASD + ADHD group from the TD group, and the repetition number was associated with ASD-related impairments in language and social and self-help as well as with ADHD symptoms (inattention and hyperactivity-impulsivity). These findings imply that the cognitive and linguistic impairments hindering ASD and ASD + ADHD groups' performance on verbal fluency tasks may vary according to developmental stages. Among school-aged children, decreased correct number may be attributable to delayed language development in ASD (e.g., reduced verbal intelligence and vocabulary size; Matson & Neal, 2010; Pastor-Cerezuela et al., 2016). In adolescents, however, deficits in EF resulting from both ASD and ADHD may be a major cognitive constraint, giving rise to increased errors and repetitions. Admittedly, the current study does not provide direct evidence supporting these hypothesized mechanisms, and future research is needed to test whether EF and language modulate ASD- and ADHD-related deficits in verbal fluency across developmental stages. Nevertheless, findings from the stratified analyses highlighted that aligning diagnostic tools with individuals' developmental stages, symptomology, and comorbidity is essential to capturing more accurate clinical profiles.

The current study presents important limitations and raises interesting questions for future investigations. First, the three verbal fluency indices we used did not systematically differentiate the ASD group from the ASD + ADHD group. Hence, these indices may not be sensitive enough to distinguish two groups with overlapping clinical profiles. Future studies can explore more fine-grained indices of verbal fluency. For example, excessive word clustering (i.e., generating words within the same subcategory, such as naming only farm animals when asked to name animals) and difficulty in switching (i.e., compromised ability to shift to a new subcategory, such as switching from farm animals to pets) were found in ASD, whereas deficits in switching were found in ADHD (Andreou & Trott, 2013; Begeer et al., 2014; Carmo et al., 2015). Hence, further analysis of the semantic contents produced may help generate more nuanced verbal fluency measures. Second, although we hypothesized that EF and language skills may modulate the verbal fluency deficits in ASD and ASD + ADHD based on prior research (Henry & Crawford, 2004; Henry et al., 2015; Whiteside et al., 2016), and that the potential role of EF and language skills may vary by age, the current study does not directly examine these hypothesized mechanisms. Future studies should investigate the role of EF and language skills in supporting verbal fluency, especially among individuals with comorbid ASD and ADHD. Whether and how the roles of EF and language skills differ across ages and developmental stages also call for further research. Third, we used two editions of C-WISC to measure IQ due to practical constraints. Although the verbal IQ measures from the two editions are directly comparable, consistency in measurement would have further added to the validity of our findings. Lastly, in recent years, machine learning approaches have been widely used in auxiliary diagnosis studies of cognitive deficits (e.g., Liu et al., 2016). The current study is exploratory in nature and likely underpowered for such techniques, but future studies with an expanded sample size can adopt machine learning approaches to further shed light on the diagnostic validity of verbal fluency measures.

In conclusion, the present study demonstrated that children and adolescents' performance on a semantic verbal fluency task was robustly associated with their diagnostic status and symptom severity. These findings not only provide new insights into the cognitive and linguistic profiles of children and adolescents with ASD and comorbid ASD + ADHD, but also have important implications for clinical practices. Used in conjunction with behavior checklists and clinical interviews, the easily administered, child-friendly verbal fluency task may have the potential to assist clinicians in diagnosing ASD and comorbid ADHD as well as establishing more elaborate clinical profiles.

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Declarations

Conflict of interest The authors declare no financial interests or potential conflicts of interest.

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Authors and Affiliations

Xinzhou Tang[1] · Zihui Hua[2] · Jiayin Xing[3] · Li Yi[2,5] · Zhaozheng Ji[1] · Liyang Zhao[1] · Xing Su[1] · Tingni Yin[1] · Ran Wei[4] · Xue Li[1] · Jing Liu[1]

✉ Ran Wei
ran.wei@childrens.harvard.edu

✉ Xue Li
lixue@bjmu.edu.cn

✉ Jing Liu
ljyuch@bjmu.edu.cn

[1] National Clinical Research Center for Mental Disorders (Peking University Sixth Hospital), Peking University Sixth Hospital/Institute of Mental Health, Beijing, China

[2] School of Psychological and Cognitive Sciences & Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, China

[3] Roxelyn and Richard Pepper Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL 60208, USA

[4] Division of Developmental Medicine, Boston Children's Hospital, Harvard Medical School, Brookline, MA 02445, USA

[5] IDG/McGovern Institute for Brain Research at PKU, Peking University, Beijing, China