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ORIGINAL PAPER

Conversation During a Virtual Reality Task Reveals New Structural Language Profiles of Children with ASD, ADHD, and Comorbid Symptoms of Both

Cynthia Boo[1] · Nora Alpers-Leon[1] · Nancy McIntyre[2] · Peter Mundy[3,4] · Letitia Naigles[1]

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Abstract

Many studies have utilized standardized measures and storybook narratives to characterize language profiles of children with Autism Spectrum Disorder (ASD) and Attention Deficit/Hyperactivity Disorder (ADHD). They report that structural language of these children is on par with mental-age-matched typically developing (TD) peers. Few studies have looked at structural language profiles in conversational contexts. This study examines conversational speech produced in a virtual reality (VR) paradigm to investigate the strengths and weaknesses of structural language abilities of these children. The VR paradigm introduced varying social and cognitive demands across phases. Our results indicate that children from these diagnostic groups produced less complex structural language than TD children. Moreover, language complexity decreased in all groups across phases, suggesting a cross-etiology sensitivity to conversational contexts.

Keywords Autism spectrum disorder · Attention deficit/hyperactivity disorder · Comorbidity · Conversational context · Virtual reality paradigm

Autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD) are fairly commonly diagnosed neurodevelopmental disorders among school-aged children (Song et al., 2018; Zablotsky et al., 2019). ASD's diagnostic characteristics include impairments in social communication and interactions as well as atypical restricted and repetitive patterns of behavior (American Psychiatric Association, 2013); thus, individuals with ASD often experience difficulties with social-emotional reciprocity, nonverbal communicative behaviors, and developing, maintaining, and understanding relationships (Knott et al., 2006). ADHD is characterized by persistent symptoms of inattention (e.g., difficulties with details, holding attention and directions, or organizing tasks) and/or hyperactivity and impulsiveness (e.g., fidgeting, difficulties with remaining seated when expected, self-regulation, or talking excessively), manifested before the age of twelve that is inconsistent with developmental level and negatively impacts social and academic/occupational activities (American Psychiatric Association, 2013).

Although language impairments are not diagnostic criteria for either ASD or ADHD, age-appropriate receptive and expressive language is critical for successful social and academic development during the school years (McIntyre et al., 2017). A number of studies have compared language measures in school-aged children with ASD or ADHD with those of typically developing (TD) peers with such outcomes in mind. Findings from numerous studies utilizing standardized tests, and/or narratives elicited from wordless picture books, suggest that structural language (e.g. semantics and syntax) in these diagnostic groups is on par with mental-age-matched TD peers (e.g., Kim & Kaiser, 2000; Kuijper et al., 2017; Norbury et al., 2014); however, a small number of studies, in which language use is elicited in more

✉ Cynthia Boo
cynthia.boo@uconn.edu

1 Department of Psychological Sciences, University of Connecticut, 406 Babbidge Road., Unit 1020, Storrs, CT 06269-1020, USA

2 School of Communication Sciences and Disorders, University of Central Florida, 12805 Pegasus Drive, Orlando, FL 32816, USA

3 School of Education, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA

4 Department of Psychiatry and Behavioral Sciences, MIND Institute, Imaging Research Center, University of California, Davis, 2825 50th Street, Sacramento, CA 95817, USA

conversational contexts, have reported less complex language in children with ASD or ADHD compared with TD mental age-mates (Losh & Capps, 2003; Redmond, 2004). The current study extends these latter findings by analyzing the speech produced during a virtual reality (VR) task, in which children talk about their personal experiences to a classroom of human-like avatars under varying amounts of social-cognitive pressure (Jarrold et al., 2013). Moreover, fewer studies have examined the structural language use of children with ADHD in depth, with the assumption being that their language abilities are generally intact (Geurts & Embrechts, 2008; but also see Kujiper et al., 2021). However, in the relevant contexts of schooling and peer engagement, it is important to determine how well their language abilities are manifested. Therefore, another major goal of the current study is to examine children with ADHD's structural language abilities in closer detail.

Language in Standardized Testing Contexts

Researchers often utilize standardized measures to characterize children with ASD or ADHD's knowledge of simple and complex sentence structure, specific semantic relationships, and overall vocabulary. In general, when matched on variables such as age and non-verbal (NVIQ) and/or verbal IQ (VIQ), cognitively able children with ASD perform comparably to their TD peers on a number of standardized language tests, such as the Peabody Picture Vocabulary Test (PPVT-IV; Dunn & Dunn, 2007) and the Test for Reception of Grammar (TROG; Bishop, 2003; e.g., Kover et al., 2014; Paynter & Peterson, 2010). In other words, these children with ASD are capable of scoring as highly as their age-matched TD peers on standardized tests that measure lexical, semantic, and syntactic understanding. Likewise, when matched on NVIQ, children with ADHD have been found to perform comparably to their TD peers on similar standardized tests, showing intact semantic and syntactic abilities (e.g., Kim & Kaiser, 2000).

In contrast, researchers have consistently observed differences in *pragmatic* language abilities between children with ASD and/or ADHD and their TD peers. Pragmatic language represents language usage for social purposes (Prutting & Kittchner, 1987). Young et al. (2005) found that children with ASD performed significantly more poorly than their TD control group, scoring approximately 1.5 SD lower, on the Test of Pragmatic Language (TOPL; Phelps-Terasaki & Phelps-Gunn, 1992), despite being matched on VIQ. Thus, while many children with ASD and/or ADHD appear to show age-appropriate lexical, semantic, and syntactic use, their pragmatic language and their ability to respond in social contexts consistently emerges as at least somewhat impaired.

However, the usefulness of standardized tests may be limited when it comes to predicting language use in conversational contexts. For example, Wittke et al. (2017) have documented that some preschoolers with ASD, who scored at age-appropriate levels on standardized tests, nonetheless showed grammatical impairments during a semi-naturalistic interaction (see also Eigsti & Schuh, 2017). Thus, while standardized tests assess understanding or knowledge of a specific language structure or vocabulary, they often do not measure whether children use that structure or word in their natural speech, how often, or in which situations. Some researchers, then, have turned to elicited narratives as potential contexts for capturing language strengths and weaknesses in diagnostic populations.

Narratives Elicited from Picture Books

Narratives are a form of discourse in which humans communicate experiences (Bruner, 1991); they are considered to be a universal form of language use (Stirling et al., 2014). In other words, every culture includes some sort of narrative discourse. Becoming a skilled narrator requires syntactic and morphological knowledge to mark temporal and causal relations, which are necessary in telling a cohesive story (Bliss et al., 1998), as well as pragmatic knowledge to convey story organization. Narrative mastery follows a fairly long developmental trajectory, with typically developing children (TD) attaining adult-like narrative production skills by the middle of their formal schooling years (Berman, 2015; Leadholm & Miller, 1992).

Investigations of the narrative abilities of children with ASD have generally highlighted their difficulties with the pragmatic conventions of storytelling. More specifically, many studies have documented the difficulties school-aged children with ASD have with producing key components of a narrative, such as a formal opening, setting, characters, an obstacle of some sort, a resolution, and an ending (e.g., Goldman, 2008; Hogan-Brown et al., 2013; Norbury et al., 2014; Suh et al., 2014). Assessed on these conventional narrative components, children with ASD are reported to produce impoverished narratives, often with fewer formal openings, mentions of settings, characters, obstacles, resolutions, and endings (Goldman, 2008; Norbury et al., 2014; Suh et al., 2014). Moreover, they have been found to produce more ambiguous pronouns than their TD peers (Suh et al., 2014; Novogrodsky & Edelson, 2016; Kuijper et al., 2015). For example, Novogrodsky and Edelson (2016) investigated ambiguous pronoun production in the context of storytelling. Pronouns were coded as ambiguous if there was no antecedent prior to the pronoun (i.e., "Once upon a time there was a frog and *he* said frog where are you."). Although grammatically correct, this type of ambiguous pronoun use shows a lack of pragmatic understanding, as not everyone will know who "he" refers to. Novogrodsky and Edelson (2016) found that children with ASD produced significantly more of these ambiguous pronouns than TD children. These findings are consistent with the pragmatic challenges that have been observed for children with ASD with standardized tests (e.g., Young et al., 2005).

Also consistent with standardized test findings, patterns of structural language in elicited narratives appear mental age-appropriate among children with ASD and/or ADHD. In one of the most widely used narrative tasks, telling a story from a wordless picture book, researchers have found that school-aged children with ASD produce narratives of similar length, as measured by number of utterances and clause-units, to their age- and language-matched TD peers (Fortea et al., 2018; Losh & Capps, 2003; Novogrodsky, 2013; Suh et al., 2014). In addition, these studies have reported that children with ASD are comparable to their age- and language-matched TD peers on measures of lexical diversity and syntactic complexity (Diehl et al., 2006; Losh & Capps, 2003; Novogrodsky, 2013; Rumpf et al., 2012; Suh et al., 2014). For example, lexical diversity can be measured by calculating type-token-ratio (number of different words divided by total number of words), with a larger ratio indicating a more varied vocabulary. Both Rumpf et al. (2012) and Suh et al. (2014) found no significant differences in lexical diversity between children with ASD and TD children based on their type-token-ratios. In addition, children with ASD, although often reported to have difficulties with pronouns (Luyster & Lord, 2009; Tager-Flusberg et al., 2005), have been found to produce subject pronouns at a comparable rate to their TD peers in such storybook tasks (Novogrodsky, 2013).

Similar patterns have been found when researchers compared children with ADHD to TD children on their performance on storybook narrative tasks. In general, when matched on age and overall IQ, children with ADHD produce storybook narratives that are comparable to their TD peers on measures of length and syntactic complexity (Fortea et al., 2018; Kuijper et al., 2017). For example, Kuijper et al. (2017) found that children with ADHD and a group of age-matched TD children did not differ in verbal productivity, as measured by counting the number of syntactic units and mean length of utterance (MLU). In addition, there were no differences in lexical diversity (Kuijper et al., 2017). However, the language abilities of children with ADHD have been less studied than those of children with ASD and there is a need for further investigation of their spontaneous and elicited language. The current study aims to contribute to this endeavor.

Overall, studies of storybook narrative telling/retelling have documented similar findings to those using standardized tests: when matched on mental age, children with ASD or ADHD perform similarly to TD peers on structural language components but demonstrate impairments with pragmatic language. However, we think the question is still open as to whether these contexts reveal all there is to know about structural language use in children with ASD or ADHD. For one thing, elicited storybook narratives involve a highly structured context with visual aids that indicate how the story should proceed; thus, children might experience smaller cognitive loads because they do not need to generate the content of the stories, themselves. In fact, one study has found that asking for a *personal* narrative (e.g., "What do you like to do on weekends?") yielded different findings for children with ASD (Losh & Capps, 2003). That is, they produced less grammatically complex and syntactically diverse utterances in their personal narratives compared with their storybook narratives, and deployed a more restricted range of complex syntactic devices in their personal narratives than TD children (Losh & Capps, 2003). Similarly, when King et al. (2013) prompted children with ASD and TD children matched on age and language abilities to recount specific events (i.e., "can you tell me about a time you went on holiday?"), the children with ASD produced fewer word tokens and word types and shorter MLUs than the TD children (King et al., 2013). Song et al. (2020) elicited 5-min conversations between school-aged children with ASD and a confederate by asking them "get-to-know-you" questions and found that children with ASD produced significantly fewer third-person pronouns (e.g., *they*) than their age-matched TD peers. This particular finding is reminiscent of findings that suggest that, early in development, children with ASD show difficulties with producing personal pronouns, particularly non-first-person pronouns (Kelty-Stephen et al., 2020).

Personal narratives may be more difficult to produce as they require children to remember a relevant event and decide how it should be presented, and *then* harness the linguistic resources to do so. Therefore, there is still much to be explored in regard to the structural language use of children with ASD or ADHD in contexts outside of narratives elicited from storybooks and other visual aids.

Language in Conversational Contexts

Only a few studies have recorded and analyzed children with ASD or ADHD's language in conversational contexts, and none have scrutinized the structural aspects in detail. For example, Nadig et al. (2010) elicited conversations between high-functioning children with ASD (HFA) and an adult research assistant by asking them to talk about their interests, hobbies, and other generic topics. The focus of this study's analyses was not structural language, so they only reported no significant differences in number of utterances and lexical diversity between the HFA children and a group of TD children matched on age, gender, language, and NVIQ; no syntactic analyses were undertaken (see also Bang et al., 2013). Similarly, Redmond (2004) collected 30-min conversational samples of school-aged children with ADHD during free-play with an adult examiner with age-appropriate toys, such as hospital and camping sets. The adult examiner contributed personal anecdotes involving hospital or camping experiences and probed for similar personal narratives from the child. Again, structural language was not the focus of the analyses, and Redmond (2004) only reported that the ADHD group produced more false starts, fillers, repetitions, and revisions than their age matched group of TD children.

The Current Study

In the current study, we extend the conversational speech research of Nadig et al. (2010), Bang et al., (2013), and Redmond (2004), in three ways. First, we use a similar interview format to elicit conversational speech, and analyze this speech rigorously for number of utterances, MLU, and lexical measures, including noun types and tokens, verb types and tokens, pronoun types and tokens, and discourse marker types and tokens (some of which are also fillers, e.g., *um, uh, like;* see Clark & Fox Tree, 2002, Schiffrin, 2001). Second, we employ virtual reality (VR) technology to increase ecological validity (Jarrold et al., 2013). Our VR setup was created to mimic a classroom setting, which is a setting familiar to school-aged children, and includes human-like avatars that simulate classmates (for more details see Jarrold et al., 2013). In addition, the VR classroom introduces what might be considered a more socially and cognitively demanding component, as the children move through phases in which they are asked to fixate on the avatars. The focus of Jarrold et al. (2013) analyses was the social attention of children with ASD, and not their language; however, their speech in this task was recorded, and the current study analyzes these recordings. Finally, we compare the structural language profiles of children with ASD, children with ADHD, and a group of children with comorbid symptoms of ASD and ADHD to their TD peers, addressing the scarcity of research scrutinizing the language abilities of children with ADHD. Our hypotheses are as follows:

Group Differences in Language Measures

First, we expected the children's language during the VR task to differ by group, with the ASD and Comorbid groups showing less complex structural language in this conversational context than the TD group. As previously mentioned, there are mixed findings in regard to the language abilities of children with ASD in a conversational context. While Losh and Capps (2003) have identified the task of producing personal narratives as being more challenging than retelling a story for children with ASD, Nadig et al. (2010) did not find any general language differences between children with ASD and TD children in their conversational speech task, although they did not thoroughly investigate their structural language. Thus, we hypothesized these group differences would emerge because we believe a detailed analysis will indeed reveal the challenges of this conversational context for children with ASD, including those with comorbid diagnoses of ASD and ADHD.

Currently, not enough is known about the structural language abilities of children with ADHD. Therefore, we could not make a motivated hypothesis about the performance of the ADHD group in this context.

Phase Differences

We expected the children's language to vary across the phases, with the least complex structural language coinciding with when the avatars must be fixated. In addition, we expected to see a group by phase interaction, with the ASD groups showing bigger effects than the non-ASD groups, due to the perceived social nature of the context.

Methods

Participants

This study was conducted in compliance with the UC Davis, M.I.N.D. Institute Institutional Review Board. Participants were recruited via the subject system tracking (STS). The participants in the study were selected from a larger study of information processing during joint attention conducted at the UC Davis, M.I.N.D. Institute. Twenty-one 8- to 16-year-old verbally-fluent children with community diagnoses of ASD (VF-ASD) were recruited. All diagnoses were made prior to the study by community mental health professionals using DSM-IV criteria. Diagnostic status was confirmed at the time of study enrollment using the Autism Diagnostic Observation Schedule-2 (ADOS-2; Lord et al., 2012). Similarly, twenty-four children with community diagnoses of ADHD were recruited. Symptoms were confirmed at the time of the study using the Conners-3 (Conners, 2008). Thirty-one children in the Comorbid group met diagnostic criteria for both ASD and ADHD. Children in the TD group ($n = 22$) did not meet diagnostic criteria for either disorder. None of the children in these groups had co-occurring intellectual disabilities ($FSIQ \geq 75$).

Table 1 presents demographic information on all 98 participants. Overall, the VF-ASD, ADHD, Comorbid, and TD groups did not differ in mean age. The VF-ASD,

Table 1 Demographic information and standardized test scores

	VF-ASD (n = 21)	ADHD (n = 24)	Comorbid (n = 31)	TD (n = 22)	*F*	Tukey's post hoc
Age	11.6 (2.2)	11.9 (2.5)	12.0 (2.3)	12.5 (2.3)	0.493	
Sex ratio (M:F)	17:4	21:3	28:3	14:8		
FSIQ	99.71 (16.1)	96.29 (16.1)	96.77 (17.2)	115.45 (12.6)	7.640*	VF-ASD, ADHD, Comorbid < TD
VIQ	96.19 (14.1)	97.42 (14.1)	96.16 (17.1)	110.86 (13.7)	5.181+	VF-ASD, ADHD, Comorbid < TD
NVIQ	103.62 (18.9)	95.96 (18.8)	98.42 (17.6)	116.14 (14.3)	6.123*	VF-ASD, ADHD, Comorbid < TD
ADOS	9.3 (3.3)	4.5 (3.9)	10.8 (3.2)	–	21.718*	ADHD < VF-ASD; ADHD < Comorbid
Conners-3 (combined)	60.6 (7.0)	72.8 (12.6)	79.9 (7.0)	47.4 (10.0)	58.742*	VF-ASD < ADHD, Comorbid; VF-ASD > TD; ADHD < Comorbid; ADHD > TD

*$p < 0.001$; +$p = 0.015$

ADHD, and Comorbid groups differed on average raw ADOS scores; both the VF-ASD and Comorbid groups had significantly higher ADOS scores than the ADHD group, $p < 0.001$. In addition, the ADHD and Comorbid groups had significantly higher Conners-3 scores than the VF-ASD and TD groups, $p < 0.001$.

The groups differed on Full Scale IQ (FSIQ) ($F(3, 94) = 7.640$, $p < 0.001$), Verbal IQ (VIQ) ($F(3, 94) = 5.181$, $p = 0.002$), and Non-Verbal IQ (NVIQ) ($F(3, 94) = 6.123$, $p = 0.001$). Tukey post hoc tests indicated that the mean FSIQ, VIQ, and NVIQ scores for the VF-ASD, ADHD, and Comorbid groups were significantly lower than those of the TD group.

Standardized Tests

Autism Diagnostic Observation Schedule-2 (ADOS-2; Lord et al., 2012)

The ADOS-2 is a semi-structured, standardized assessment of ASD status. An examiner interacts with the participant using a series of tasks to identify and quantify behaviors that are consistent with DSM-V criteria for autism.

Conners-3 (Conners, 2008)

The Conners-3 is a parent report measure of ADHD symptoms. The instrument is designed to assess cognitive, behavioral, and emotional problems associated with ADHD among children and adolescents between the ages of 6 and 18.

Wechsler Abbreviated Scale of Intelligence 2 Ed. (WASI-II; Wechsler, 2011)

Full Scale, Verbal, and Non-Verbal IQ scores were obtained via the WASI-II. The tests included two verbal subscales (Expressive Vocabulary and Similarities) and two non-verbal subscales (Block Design and Matrix Reasoning).

Procedures

The participants experienced a virtual reality (VR) classroom through a headset they wore. The VR classroom integrated head positioning and virtual avatar technology to measure social attention (Jarrold et al., 2013). The public speaking task was delivered via an eMagin Z800 3DVisor head mounted display. A research assistant sat behind the participants and acted as a "teacher", introducing the participants to the virtual avatars, or "students", in the classroom using a microphone that fed into the participant's headset. Participants were given a 1990s warm-up period to get acquainted with the classroom.

Participants experienced three phases, as originally labeled: a non-social phase, a social phase, and a higher-demand phase; in each phase, they were asked questions by the research assistant. Each phase lasted 3 min. During the non-social phase, participants viewed targets that resembled lollipop figures that were similar in size to the human figures; during the social phase, the targets became human figure avatars, introduced as students in the class, and during the higher-demand phase, each avatar student was programmed to fade over the course of 6 s to 70% transparency if the participant did not fixate on it. The avatars would become opaque again once they were fixated on by the participant. At the beginning of each phase participants were prompted to look at and talk to all the targets or people in the room.

The questions posed across all three phases were factual, self-referenced questions concerning topics such as participants' typical daily routines, favorite foods, recent vacations, etc. Thus, the majority of the questions can be thought of as prompts for personal narratives (Stirling et al., 2014). If the participant provided a brief response to the questions, the research assistant would ask follow-up questions to maintain continuous verbal responses during each 3-min trial. The complete list of questions is presented in Table 2. Each participant received a slightly different number of questions in each phase, depending on the length of their responses and how cooperative each participant was during the VR paradigm. On average, each participant received a total of 24 out of the 38 possible questions, with approximately 6–8 questions per phase. To control for differences in the specific questions asked, and the number of questions each participant received per phase, the analyses here were conducted on participant responses for the subset of questions that were consistently answered by each participant in the same phase. The list of the 18 questions that every participant received is presented in Table 3.

Audio recordings were collected during each trial. Each audio recording was transcribed by multiple assistants into CHAT (MacWhinney, 2000) and checked by the second author. Any differences among transcribers were resolved

Table 2 Complete list of questions asked during the VR paradigm

Talk a little about yourself, like say your name, age, and anything else
Describe your family and who lives with you
What is a normal day like for you, from waking up to bedtime?
What are some of your favorite foods?
Where are some of your favorite places to eat out?
What did you do on your last birthday? What do you hope to do for your next birthday? Are there any particular gifts you hope to get?
Talk about a favorite vacation you have had
Where is a place you would like to go on vacation?
What is your favorite holiday of the year? What do you like about it?
What will you be doing (did you do) over the [insert closest school holiday]?
Talk about any pets you have now or had when you were younger
If you could have any animal as a pet, what would it be?
If you could have three wishes, what would they be?
What are some of your favorite TV shows? Talk about one of your favorite episodes or characters
Talk about any hobbies you have; things you like to do when not at school
Tell about any computer or video games you like to play
What music do you like listening to?
Talk about your favorite movie and what happens in that movie
Describe your perfect day, what would happen if you could choose what to do
Describe a good friend or a friend from when you were younger
Talk about school, about things you do there and are learning
What do you usually do at recess?
What do you want to be when you grow-up (do when you finish school)?
If you could have a super-secret power, what would it be?
Do you have a [insert type of relative] who you know? Talk about him/her
What's your favorite book? What do you like about it?
Have you ever been on a plane? Where did you go? Have you ridden a train? Who were you with? Have you been on a boat? What was it like?
Have you ever gone to the beach? Talk about it Have you ever been to the mountains? What do you remember about it?
Have you ever been horseback-riding? What was it like?

Table 3 List of questions that each participant heard in a given phase

Non-social	Social	Higher-demand
Talk a little about yourself, like say your name, age, and anything else	Talk about a favorite vacation you have had	Talk about any hobbies you have; things you like to do when not at school
Describe your family and who lives with you	Where is a place you would like to go on vacation?	Tell about any computer or video games you like to play
What is a normal day like for you, from waking up to bedtime?	What is your favorite holiday of the year? What do you like about it?	What music do you like listening to?
What are some of your favorite foods?	Talk about any pets you have now or had when you were younger	Describe your perfect day, what would happen if you could choose what to do
Where are some of your favorite places to eat out?	If you could have any animal as a pet, what would it be?	Describe a good friend or a friend from when you were younger
What did you do on your last birthday?	If you could have three wishes, what would they be?	What's your favorite book? What do you like about it?

by replaying the audios in joint discussion until consensus was reached.

Coding, Measures, and Analysis Plan

CLAN algorithms were used to extract number of utterances, mean length of utterances (MLU), noun types and tokens, verb types and tokens, pronoun types and tokens, and discourse marker types and tokens. In addition to calculating pronoun types and tokens, supplementary analyses were undertaken to determine the number of 1st-person and 3rd-person personal pronouns produced by each group. Furthermore, additional analyses were conducted to identify ambiguous pronouns (i.e., with no clear antecedent) produced by each child per group.

For all types and tokens, counts were computed, and ANOVAs were planned to investigate group and phase differences. Tukey post hoc analyses would then indicate which group(s)/phases were different. In addition, because NVIQ scores significantly differed by group, NVIQ was utilized as a covariate in subsequent ANCOVAs.

Results

Group Comparisons in Language Measures

Table 4 presents the language measures by group, collapsed across all phases. The number of utterances significantly differed among groups, $F(3, 96) = 3.783$, $p = 0.013$, $\eta_p^2 = 0.109$. A post hoc comparison using the Tukey HSD test revealed

Table 4 Number of utterances, MLU, noun types & tokens, verb types & tokens, pronoun types & tokens, and discourse marker (DM) types & tokens (M, SD) for participants averaged across all three phases

	VF-ASD (n = 21)	ADHD (n = 24)	Comorbid (n = 31)	TD (n = 22)	F	p	η_p^2
Number of utterances	$13.9^{a,b}$ (2.5)	15.0^{a} (5.4)	11.7^{b} (2.7)	$12.9^{a,b}$ (3.9)	3.783	**0.013**	0.106
MLU	10.3^{a} (3.8)	$11.4^{a,c}$ (6.1)	$13.5^{a,c}$ (6.3)	$15.9^{b,c}$ (7.6)	3.599	**0.016**	0.104
Noun types	$15.7^{a,c}$ (5.1)	15.1^{a} (5.3)	$17.0^{a,c}$ (4.9)	$20.0^{b,c}$ (7.4)	3.263	**0.025**	0.095
Noun tokens	$19.3^{a,c}$ (6.8)	19.3^{a} (7.4)	$21.8^{a,c}$ (7.4)	$25.9^{b,c}$ (8.8)	2.897	**0.039**	0.085
Verb types	8.8^{a} (2.9)	8.4^{a} (2.6)	9.1^{a} (2.1)	11.3^{b} (3.9)	4.709	**0.004**	0.132
Verb tokens	14.8 (5.6)	15.2 (6.1)	16.0 (5.6)	19.5 (8.2)	2.498	0.065	0.054
Pronoun types	2.1^{a} (0.7)	2.0^{a} (0.6)	2.0^{a} (0.5)	2.6^{b} (0.7)	4.748	**0.004**	0.133
Pronoun tokens	12.5^{a} (5.4)	$13.1^{a,b}$ (6.3)	$13.7^{a,b}$ (5.8)	$17.6^{a,b}$ (9.0)	2.593	**0.057**	0.077
1st-Person pronoun tokens	11.0 (4.9)	11.6 (5.8)	12.4 (5.3)	14.0 (5.4)	1.212	0.310	0.058
3rd-person pronoun tokens	1.5^{a} (0.3)	$2.5^{a,b}$ (0.2)	1.3^{a} (0.2)	3.6^{b} (0.4)	2.517	**0.043**	0.174
Ratio of children who produced ambiguous pronouns (%)	2:21 (9.5%)	1:24 (4.2%)	1:31 (3.2%)	1:22 (4.5%)	–	–	–
DM types	2.3 (0.9)	2.5 (0.7)	2.3 (1.2)	2.5 (1.0)	1.356	0.261	0.039
DM tokens	$8.9^{a,c}$ (6.5)	$9.2^{a,c}$ (6.0)	7.2^{a} (5.9)	$12.3^{b,c}$ (7.6)	2.644	**0.055**	0.079

$p < 0.05$ values are in bold

Superscripts of same letter indicate no significant difference, superscripts of different letters indicate significant difference that the ADHD group produced significantly more utterances than the Comorbid group ($p = 0.009$). In addition, MLU significantly differed among groups, $F(3, 96) = 3.599$, $p = 0.016$, $\eta_p^2 = 0.104$. A post hoc comparison revealed that the VF-ASD group produced significantly shorter MLUs than the TD group ($p = 0.018$).

Noun types ($F(3, 96) = 3.263$, $p = 0.025$, $\eta_p^2 = 0.095$) and noun tokens ($F(3, 96) = 2.897$, $p = 0.039$, $\eta_p^2 = 0.085$) also significantly differed among the groups. A post hoc comparison revealed that the ADHD group produced significantly fewer noun types than the TD group ($p = 0.025$). In addition, the ADHD group produced marginally significantly fewer noun tokens than the TD group ($p = 0.053$). Verb types also significantly differed among the groups ($F(3, 96) = 4.709$, $p = 0.004$, $\eta_p^2 = 0.132$), with the VF-ASD ($p = 0.022$), ADHD ($p = 0.005$), and Comorbid ($p = 0.035$) producing fewer verb types than the TD group.

Pronoun types significantly differed among the groups ($F(3, 96) = 4.748$, $p = 0.004$, $\eta_p^2 = 0.133$), with the VF-ASD ($p = 0.032$), ADHD ($p = 0.010$), and Comorbid ($p = 0.007$) producing fewer pronoun types than the TD group. Pronoun tokens marginally differed among groups ($F(3, 96) = 2.593$, $p = 0.057$, $\eta_p^2 = 0.077$), with the VF-ASD group producing marginally significantly fewer pronoun tokens than the TD group ($p = 0.068$). Furthermore, all groups produced significantly fewer third-person personal pronouns than first-person personal pronouns ($ps < 0.001$), with no significant group differences in first-person pronoun production ($p = 0.310$). However, significant group differences emerged in third-person pronoun frequency, $F(3, 94) = 2.517$, $p = 0.043$, $\eta_p^2 = 0.174$. Post hoc comparisons revealed that the VF-ASD ($p = 0.018$) and Comorbid ($p = 0.002$) groups produced significantly fewer third-person pronouns than the TD group. Ambiguous pronouns, on the other hand, did not significantly differ across groups and were, in fact, attested at very low rates, with only 1 to 2 children per group producing ambiguous pronouns (Table 4).

Finally, discourse marker tokens marginally significantly differed among the groups ($F(3, 96) = 2.644$, $p = 0.054$, $\eta_p^2 = 0.079$), with the Comorbid group producing significantly fewer discourse marker tokens than the TD group ($p = 0.031$). No significant group differences emerged for verb tokens ($p = 0.064$) or discourse marker types ($p = 0.261$).

Because NVIQ significantly differed by group (see Table 1), analyses were conducted using NVIQ as a covariate in additional ANCOVAs. Previously observed group differences for noun types ($p = 0.123$), noun tokens ($p = 0.150$), pronoun tokens ($p = 0.308$), including third-person pronoun tokens ($p = 0.331$), and discourse marker tokens ($p = 0.225$) no longer emerged when controlling for NVIQ. In addition, group differences in production of verb tokens ($p = 0.280$) and discourse marker types ($p = 0.464$) remained non-significant. However, significant group differences were maintained for the remaining structural language measures. The average number of utterances still significantly differed among groups, $F(3, 92) = 3.684$, $p = 0.015$, $\eta_p^2 = 0.107$. A post hoc comparison revealed that the ADHD group still produced significantly more utterances than the Comorbid group ($p = 0.011$). In addition, MLU still significantly differed among groups, $F(3, 92) = 2.607$, $p = 0.049$, $\eta_p^2 = 0.135$, with the VF-ASD group producing significantly shorter MLUs than the TD group ($p = 0.041$). Verb types also still significantly differed among groups, $F(3, 92) = 2.679$, $p = 0.046$, $\eta_p^2 = 0.164$, with the ADHD group producing significantly fewer verb types than the TD group ($p = 0.047$). Finally, pronoun types also still significantly differed among groups, $F(3, 92) = 3.059$, $p = 0.032$, $\eta_p^2 = 0.145$, with the Comorbid group producing significantly fewer pronoun types than the TD group ($p = 0.039$).

Phases Differences

Individual mixed-design ANOVAs with within-subject factors of phase (non-social, social, and higher-demand) and dependent variables of the previously mentioned language measures, including utterances, MLU, noun types and tokens, verb types and tokens, pronoun types and tokens, and discourse marker types and tokens, were conducted. There were no significant group differences, nor any significant group by phase interactions. The following results, then, are for the entire sample analyzed together. Table 5 presents the language measures by phase.

The mixed-design ANOVA revealed a significant effect of phase on pronoun types, $F(2, 188) = 37.864$, $p < 0.001$, $\eta_p^2 = 0.287$. Participants produced *fewer* pronoun types during the non-social phase than the social phase, but *more* pronoun types during both the non-social and social phases than the higher-demand phase ($ps < 0.001$). In addition, there was a significant effect of phase on discourse marker types, $F(2, 188) = 10.776$, $p < 0.001$, $\eta_p^2 = 0.103$. Overall, participants produced *more* discourse marker types during the non-social ($p < 0.001$) and social ($p = 0.006$) phases than the higher-demand phase.

For each of the remaining language measures, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated and therefore a Greenhouse–Geisser correction was used. A significant effect of phase emerged for number of utterances, $F(1.698, 159.574) = 65.016$, $p < 0.001$, $\eta_p^2 = 0.409$. Overall, participants produced *more* utterances during the non-social and social phases than the higher-demand phase ($ps < 0.001$). There was also a significant effect of phase on MLU ($F(1.754, 164.909$, $p = 0.017$, $\eta_p^2 = 0.043$), with participants producing *longer* MLUs

Table 5 Phase effects on language measures (M, SD) across groups

	Non-social	Social	Higher-demand	F	p	η_p^2	Post-hoc
Utterances	16.4[a] (0.8)	15.9[a] (0.5)	7.9[b] (0.4)	65.016	< 0.001	0.409	NS, S > HD
MLU	13.4[a,b] (0.9)	13.4[a] (0.8)	11.4[b] (0.6)	4.193	0.017	0.043	S > HD
Noun types	23.9[a] (1.2)	17.7[b] (0.7)	9.2[c] (0.7)	74.217	< 0.001	0.441	NS > S, HD; S > HD
Noun tokens	30.7[a] (2.0)	22.3[b] (1.0)	11.7[c] (0.8)	53.902	< 0.001	0.364	NS > S, HD; S > HD
Verb types	11.3[a] (0.6)	10.7[b] (0.5)	6.4[c] (0.4)	35.495	< 0.001	0.274	NS > S, HD; S > HD
Verb tokens	19.6[a] (1.3)	19.5[b] (0.9)	10.1[c] (0.6)	33.136	< 0.001	0.261	NS > S, HD; S > HD
Pronoun types	2.1[a] (0.1)	2.8[b] (0.1)	1.6[c] (0.1)	37.864	< 0.001	0.287	NS < S; NS, S > HD
Pronoun tokens	18.1[a] (1.3)	17.4[a] (1.0)	7.2[b] (0.5)	51.405	< 0.001	0.354	NS, S > HD
1st-person pronoun tokens	14.3[a] (1.1)	12.8[a] (0.8)	5.8[b] (0.7)	54.467	< 0.001	0.367	NS, S > HD
3rd-person pronoun tokens	3.8[a] (0.4)	4.6[a] (0.2)	1.4[b] (0.3)	21.780	< 0.001	0.188	NS > HD
DM types	2.8[a] (0.1)	2.6[a] (0.1)	2.1[b] (0.1)	10.776	< 0.001	0.103	NS, S > HD
DM tokens	11.7[a] (1.1)	9.6[a] (0.7)	6.8[b] (0.6)	13.891	< 0.001	0.129	NS, S > HD

Superscripts of same letter mean no significant difference, superscripts of different letters mean significant difference

NS non-social, *S* social, *HD* higher-demand phases

during the social phase than the higher-demand phase ($p = 0.049$).

In addition, there was a significant effect of phase on noun types ($F(1.652, 155.322, p < 0.001, \eta_p^2 = 0.441)$, with participants producing *more* noun types in the non-social phase than the social and higher-demand phases ($p < 0.001$) and *more* noun types in the social phase than the higher-demand phase ($p < 0.001$). Similarly, there was a significant effect of phase on noun tokens ($F(1.496, 140.628, p < 0.001, \eta_p^2 = 0.364)$, with participants producing *more* noun tokens in the non-social phase than the social and higher-demand phases ($p < 0.001$) and *more* noun tokens in the social phase than the higher-demand phase ($p < 0.001$).

There was also a significant effect of phase on verb types, $F(1.881, 176.842, p < 0.001, \eta_p^2 = 0.274$. Overall, participants produced *more* verb types in the non-social phase than the social phase ($p < 0.001$) and *more* verb types in the social phase than the higher-demand phase ($p < 0.001$). In addition, there was a significant effect of phase on verb tokens ($F(1.757, 165.199, p < 0.001, \eta_p^2 = 0.261)$, with participants producing *more* verb tokens in the non-social phase than the social phase ($p < 0.001$) and *more* verb tokens in the social phase than the higher-demand phase ($p < 0.001$).

There was a significant effect of phase on pronoun tokens ($F(1.829, 171.899, p < 0.001, \eta_p^2 = 0.354)$, with participants producing *more* pronoun tokens during the non-social and social phases than the higher-demand phase (ps < 0.001). Finally, there was a significant effect of phase on discourse marker tokens, $F(1.705, 160.294) = 13.891$, $p < 0.001$, $\eta_p^2 = 0.129$. Overall, participants produced *more* discourse marker tokens during the non-social and social phases than the higher-demand phase (ps < 0.001).

Discussion

The goal of this study was to compare the structural language profiles of school-aged verbally-fluent children with ASD, children with ADHD, and children with comorbid symptoms of ASD and ADHD to their TD peers, during a personal narrative elicitation task. Our first findings were at the group level. Overall, our first hypothesis was confirmed as the children in the VF-ASD group produced shorter MLUs and fewer verb types, pronoun types, and pronoun tokens than the TD group. In addition, children in the other two diagnostic groups (ADHD and Comorbid) also produced less complex structural language, as measured by noun, verb, pronoun, and discourse marker types and tokens, than their TD peers. These effects held even after controlling for NVIQ, with the strongest group effects observed with number of utterances, MLU, verb types, and pronoun types, and moderate group effects observed with the remaining language measures. Our second finding was that producing personal narratives under social-cognitive demands resulted in less complex structural language in all four groups, with no group by phase interactions observed.

Even when accounting for general cognitive abilities, children in the VF-ASD group produced significantly shorter

MLUs than the TD children. This finding is not particularly striking, as other studies have found similar results in other contexts (e.g., narratives elicited from picture books, see Kuijper et al., 2017; personal narratives, see King et al., 2013), although there are also findings in the other direction (e.g., Nadig et al., 2010; Suh et al., 2014)). It is possible that other studies did not observe differences in MLU between their ASD and TD control groups due to the nature of their tasks, some of which (e.g., story retelling, see Fortea et al., 2018) may be less challenging for children of this age range.

More surprisingly, children in the ADHD group produced significantly fewer verb types than those in the TD group. Contrary to the current assumption that children with ADHD do not have difficulties with structural language use (Geurts & Embrechts, 2008), our finding suggests otherwise, particularly in this conversational context. In our sample, the children with ADHD, on average, produced a less diverse set of verbs. For example, one child with ADHD only produced seven distinct verbs across all three phases (*eat, go, have, know, like, open,* and *want*), whereas a NVIQ-matched TD child produced a total of sixteen distinct verbs across all three phases (*climb, do, explore, get, go, have, keep, know, like, live, play, ride, see, take, use,* and *want*). Thus, this result may be a product of children with ADHD reusing the same verbs throughout the 9-min task and is consistent with their difficulties with managing their attention (Hawkins et al., 2016). Similarly, researchers have identified difficulties with verbal recall as a symptom of ADHD (e.g., Andersen et al., 2013), which may play a role in the repetitive usage of the same verbs throughout this task.

In addition, children in the Comorbid group produced significantly fewer pronoun types than the TD group. For example, one child from the Comorbid group only produced the pronoun *I* throughout all three phases, whereas a NVIQ-matched child from the VF-ASD group produced *I, she,* and *we* throughout all three phases and a NVIQ-matched child from the TD group produced *I, he, she, they,* and *we.* Furthermore, the ASD groups produced significantly fewer third-person pronouns than the TD group. These findings are consistent with the challenges with pronoun usage that others have found with children with ASD (e.g. Kelty-Stephen et al., 2020; Novogrodsky, 2013; Tager-Flusberg et al., 2005). More specifically, these findings support Kelty-Stephen et al.'s (2020) report that preschool-aged children with ASD produced relatively fewer third-person pronouns. The finding that the Comorbid group was particularly subject to restricted pronoun usage suggests that having an additional diagnosis of ADHD may exacerbate difficulties with pronouns for children with ASD. One explanation for this difficulty with producing pronouns involves children's challenges adapting to their listener's perspective (Tager-Flusberg, 2004), which may be due to deficits with Theory of Mind (Tager-Flusberg, 2004; Kuijper et al., 2021). In addition, other findings suggest that the use of pronouns is a constituent of pragmatic language and as children with ASD show consistent pragmatic language impairments, they show impairments with pronoun usage as well (Hamann, 2011). Thus, in school-aged children with ASD, an additional diagnosis or symptomology of ADHD should be assessed, as this appears to play a role on pronoun production in a conversational context.

Ultimately, these challenges with aspects of structural language might feed into lower academic achievement and poorer educational and vocational outcomes. Oral and written language skills (i.e., listening, speaking, reading, and writing) have been shown to be separable but highly related skills (Berninger & Abbott, 2010). Difficulties in oral structural language skills are linked to reading and writing impairments in children and adolescents with ASD (Brown et al., 2013; McIntyre et al., 2017; Zajic et al., 2020), ADHD (Helland et al., 2016; Purvis & Tannock, 1997), and specific language impairment (Graham et al., 2020). These literacy skills underpin access to, and engagement with, the core school curriculum, and as children move from elementary into secondary school settings strong reading and writing skills become even more critical.

Effects of Phase Changes on Language

Also as predicted, children generally decreased in many aspects of their language use when talking under higher demands. In general, children from all four groups spoke less and produced fewer lexical items (noun types and tokens, verb types and tokens, pronoun types and tokens, and discourse marker tokens) during the higher-demand phase than the non-social phase. Under our first assumption, that the VR phases were solely presenting an increased social load, we had hypothesized that children from the VF-ASD and the Comorbid groups would manifest the most dramatic changes in their language output as the phases became more socially demanding. However, we observed this phase effect for all of the groups, including the TD group. For example, one child from the VF-ASD group provided considerable detail in response to this question during the non-social phase: what are some of your favorite foods? The child listed a number of their favorite foods. However, when asked a question of a similar caliber during the higher-demand phase (Talk about any hobbies you have; things you like to do when not at school), the child provided a much shorter list (see Table 6). A child from the TD group responded similarly: In response to the favorite foods question, the TD child responded with a list of what they like: different types of fruits, cake, toast, etc. However, in response to the question about their hobbies, the child responded with only one item (see Table 6).

Table 6 Example responses from non-social and higher-demand phases

VF-ASD child	TD child
Non-social phase INV: What are some of your favorite foods? CHI: One of my, well, some of my favorite foods are, uh, French fries, chicken nuggets, hamburgers, hm…and uh, I uh, pizza, and uh, goldfish. And that's pretty much, uh, all I can remember right now	Non-social phase INV: What are some of your favorite foods? CHI: I like…I like fruit. I like strawberries and blueberries, and I like chocolate cake and, um, I like toast, um, with honey and butter on it
Higher-demand phase INV: Can you tell me about any hobbies you have or things you like to do when you're not at school? CHI: video games, make things out of clay, that stuff	Higher-demand phase INV: Can you talk about any hobbies you have; things you like to do when you're not at school CHI: When I'm not at school, I like to write

INV investigator/research assistant, *CHI* child participant

This led us to consider the possibility that the phases presented in the VR paradigm are not only socially demanding, but perhaps also cognitively demanding. The higher-demand phase, especially, may encompass a heavier cognitive load, because children were asked to fixate on the avatars because they would otherwise fade. Supporting this speculation is the fact that, when we re-conducted the phase comparisons covarying for NVIQ, the phase effects that we previously observed no longer remained significant. Previous studies have identified that the presence of cognitive load can disrupt global coherence of language, especially among individuals with ASD (Engelhardt et al., 2017; Fitch et al., 2015; Rogalski et al., 2010). Thus, this may provide an explanation as to why all of the groups showed this pattern of decreased language use during the higher-demand phase in comparison to the non-social phase.

Limitations

Limitations to this study include the fact that the phases in the VR task were not counterbalanced. Therefore, we are unable to distinguish the degree to which the cognitive load observed in the final phase can be solely attributed to having to attend to the VR avatars while also producing personal narratives, and/or to fatigue while completing this 9-min task. Moreover, a higher-demand non-social phase was not included; therefore, we are unable to parse between whether the task induces purely social or cognitive demands, or a mix of both.

In addition, our Comorbid group was formed post-hoc, with the ASD diagnosis determined from DSM-IV criteria and the ADHD diagnosis determined from Conners score. Therefore, these participants may not meet criteria for having both ASD and ADHD based on today's standards of the DSM-V, and the findings described here may not generalize to current ASD-ADHD comorbid children and adolescents.

A final limitation of this conversational context is that it may not afford the illumination of all pragmatic challenges that these children have. For example, the structuring of the questions that probe for third-person others (e.g., "Describe a good friend or a friend from when you were younger.") may have decreased the opportunity for ambiguous pronoun production, which has been commonly observed in samples of children with ASD (e.g., Novogrodsky, 2013; Overweg et al., 2018). Recall, we only found 1 to 2 children per group that produced ambiguous pronouns (e.g., INV: "where is a place you would like to go on vacation?" CHI: "uh, I don't care where *we* go.") yielded only 1–2 such tokens in each group. Thus, we did not observe any significant group differences in ambiguous pronoun production rate. However, this finding is consistent with Kuijper et al. (2021) who assessed ambiguous pronouns in an experimental context and found that school-aged children with ASD showed challenges with interpretation, but not necessarily production. Nevertheless, the specific questions asked in the current study may have contributed to the lack of ambiguous pronouns found.

Future Directions and Conclusion

The results of this study suggest that the task matters when analyzing language produced by children with ASD, ADHD, and/or comorbid symptoms of both. Future studies should thus take the contexts of language use into account (and explore new/additional contexts, such as disputes) when examining the language profiles of children with ASD and ADHD, as these profiles may change with different contexts. In addition, there is a need for more studies that analyze the language abilities of children with ADHD.

In conclusion, our diagnostic groups showed less complex structural language compared to their TD peers in this conversational context. This finding corroborates existing reports of children with ASD and children with ADHD producing less complex language in contexts that require them to produce personal narratives (Losh & Capps, 2003; Redmond, 2004); however, our task does so in a more ecologically valid manner by using a VR setup that mimicked a classroom setting. Furthermore, the VR task used in this study appeared to demonstrate an effect of social cognitive load on language usage for all of the children, not just the diagnostic groups. The findings of this study also contribute to the scarcity of research that scrutinizes the language abilities of children with ADHD, as well as children with comorbid symptoms of ASD and ADHD. As our findings suggest, children with ADHD struggle with structural language in a discourse pragmatic context in ways similar to their ASD peers.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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