RESEARCH ARTICLE

Online Processing of Subject–Verb–Object Order in a Diverse Sample of Mandarin-Exposed Preschool Children with Autism Spectrum Disorder

Yi (Esther) Su and Letitia R. Naigles

Grammatical comprehension remains a strength in English-exposed young children with autism spectrum disorder (ASD), yet limited research has investigated how preschool children with ASD process grammatical structures in real time, in any language. Using the eye-movement measures of Intermodal Preferential Looking, we assessed online processing of subject–verb–object (SVO) order in seventy 2- to 5-year-old children with ASD exposed to Mandarin Chinese across the spectrum, whose vocabulary production scores were dramatically delayed compared with the typical controls. With this Mandarin-exposed sample, we tested the extent to which children with ASD require (a) highly consistent input and/or (b) good discourse/pragmatics for acquiring grammatical structures. Children viewed side-by-side videos depicting reversible actions (e.g., a bird pushing a horse vs. a horse pushing a bird), and heard an audio matching only one of those actions; their eyegaze to each video was coded and analyzed. Both typically developing children and children with ASD demonstrated comprehension of SVO word order, suggesting that core grammatical structures such as basic word order may be preserved in children with ASD across languages despite radical differences in language environment, social/pragmatic abilities, and neurological organization. However, children with ASD were less efficient in online sentence processing than typical children, and the efficiency of their online sentence processing was related to their standardized language assessment scores. Of note is that across both Mandarin Chinese and English, some proportion of minimally verbal children with ASD exhibited SVO comprehension despite their profoundly impaired expressive language skills. ***Autism Res*** *2019, 12: 1829–1844.* © 2019 International Society for Autism Research, Wiley Periodicals, Inc.

Lay summary: Grammar is a strength in the language comprehension of young English learners with autism spectrum disorder (ASD). Eye-movement data from a diverse sample of Chinese preschoolers with ASD indicated similar grammatical strength of basic word order in Chinese (e.g., to understand sentences like "The bird is pushing the horse"). Moreover, children's proficiency of sentence processing was related to their language assessment scores. Across languages, such knowledge is even spared in some minimally verbal children with ASD.

Keywords: word order; grammar; online sentence processing; preschoolers; Mandarin Chinese

Introduction

Until the beginning of this century, language research concerning children with autism spectrum disorder (ASD) has largely focused on measures of language production, which have revealed pragmatic or communicative impairments, as well as some omissions of grammatical morphemes, among mostly school-age verbal children with ASD speaking English [Tager-Flusberg, 2001]. Using eye-movement measures such as those from the Intermodal Preferential Looking paradigm (IPL) [Naigles & Tovar, 2012], more recent studies among English-exposed 2- to 5-year-old children with ASD have revealed some underlying linguistic competences, including mastery of a number of grammatical structures (e.g., word order, wh-questions, and grammatical aspect) and exhibition of similar acquisition processes (e.g., comprehension preceding production) or mechanisms (e.g., syntactic bootstrapping) that are robust in typical language development. These findings testify to some fundamental similarities in the acquisition process of grammatical structures and mechanisms between children with ASD and typically developing (TD) children and suggest that the less frequent usage of the grammatical structures in spontaneous or elicited speech by children with ASD may result from their social disinterest in conversations rather than represent fundamental grammatical impairments [Naigles & Fein, 2017].

To expand this line of research, the current study investigates the extent to which preschool children with ASD

From the Child Language Lab, School of Foreign Languages, Central South University, Changsha, China (Y.S.); Department of Psychological Sciences, University of Connecticut, Mansfield, Connecticut (L.R.N.)
Received January 21, 2019; accepted for publication July 21, 2019
Address for correspondence and reprints: Yi (Esther) Su, Child Language Lab, School of Foreign Languages, Central South University, Changsha, Hunan 410083, China. E-mail: sy-esther@csu.edu.cn
Published online 11 August 2019 in Wiley Online Library (wileyonlinelibrary.com)
DOI: 10.1002/aur.2190

learning a typologically different language from English may demonstrate similar grammatical strengths. Specifically, we investigate the online processing of subject–verb–object (SVO) word order in Mandarin Chinese, a language which allows variant word orders and frequent omissions of argument noun phrases (NPs). For example, the Mandarin sentence *Xiao3niao3 tui1le3 xiao3ma3*, "The bird pushed the horse," can be uttered with a bare verb as in *Tui1le3* "Pushed"; these bare-verb utterances appear frequently in Mandarin input [Lee & Naigles, 2005]. Crucially, argument drop is produced during a set of discourse conditions that guarantee the referents of the dropped arguments are recoverable from the context [Allen, 2007]. However, whether or not the dropped arguments can be successfully recovered by the listener also depends to a large extent on the listener's pragmatic/discourse skills. If the speaker believes that a common ground about which specific entities are being talked about has been established (e.g., perhaps a bird and a horse already been referenced), *Tui1le3* "Pushed" can be produced. But if the listener has failed to establish this common ground with the speaker, then the listener will have difficulty recovering the omitted arguments, which consequently leads to difficulty comprehending the sentence and makes this sentence a non-useful data point for learning the relevant SVO constructions in Mandarin Chinese. Importantly, one way to establish such common ground is via joint attention [Allen, 2007]. Thus, for children with ASD who have difficulties establishing and maintaining joint attention [Baron-Cohen, Baldwin, & Crowson, 1997; Mundy, Sigman, & Kasari, 1990], failure to comprehend a sentence like *Tui1le3* "Pushed" and failure to use this utterance as a useful data point for learning the SVO constructions seem likely to occur.

In this respect, Mandarin Chinese is an extremely important language to examine within the study of language acquisition in ASD, because it requires learners to exploit their pragmatic/discourse skills to recover any omitted arguments from the context, en route to understanding argument-drop sentences, and acquiring relevant linguistic structures such as SVO order. The most common language studied thus far is English, which is a strict SVO language that does not allow argument drop and so does not impose such discourse-pragmatic requirements on learners. Thus, by investigating Mandarin-exposed children with ASD, we may obtain a better understanding of the nature of grammatical acquisition in ASD. For example, the extent to which basic SVO order knowledge is impaired or preserved in Mandarin-exposed preschoolers with ASD can shed light on the extent to which children with ASD require (a) highly consistent input and/or (b) good discourse/pragmatics in acquiring grammatical structures. In addition, we tested children with ASD whose vocabulary production levels were dramatically delayed compared with TD peers to investigate the extent to which vocabulary and grammar develop together versus separately in this population [Naigles & Chin, 2015; Naigles, Kelty, Jaffery, & Fein, 2011; Su, Naigles, & Su, 2018]. Furthermore, by using the sensitive eye-movement measures of the IPL paradigm, we break new ground in delineating how a diverse sample of preschool Mandarin-exposed children with ASD process SVO structures in real time and in examining the factors relating to the efficiency of their online grammatical processing.

Word Order and Its Acquisition in TD Children and Preschool Children with ASD

Word order is an essential property that constitutes the basic syntactic structure of a language. Before producing their first word combinations, TD children have already demonstrated word order knowledge in sentence comprehension. Initial IPL experiments by Hirsh-Pasek and Golinkoff [1996] revealed that 17-month-old infants learning English noticed the order of the NPs in sentences like "Big Bird is washing Cookie Monster," by interpreting the subject NP before the verb "wash" as the agent (e.g., the washer) and the object NP after "wash" as the patient (e.g., the one being washed). Recent IPL experiments confirmed that 1-year olds learning English and 2- or 3-year olds learning Turkish or Mandarin Chinese had basic word order knowledge in their target languages [Candan et al., 2012]. For example, while tested with simple transitive sentences like *Xiao3niao3 zai4 tui1 xiao3ma3*, "The bird is pushing the horse," Mandarin-speaking 34-month olds significantly shifted their attention toward the matching scene during the test trials relative to control trials (especially during the first half of the test trials). The Mandarin-speaking 34-month olds also showed faster latencies than the 24-month olds, who did not shift significantly toward the match during the test trials and took longer to find the matching scene in real time. In addition, using novel verbs rather than familiar verbs, studies have attested to abstract representations of word order in 19- to 21-month olds learning languages such as English, French, and Hindi–Urdu [Guasti, 2016]. TD children's association between the agent and patient roles with the Subject–Object over the Object–Subject order reflects their early sensitivity to the form-meaning mapping of word order structures, that is, the mapping between the position of the words in the sentences and their thematic roles, across languages [Franck, Millotte, Posada, & Rizzi, 2013]. This in turn suggests that word order is a core syntactic construction in human language [Fromkin, Rodman, & Hyams, 2014].

Do children with ASD follow the typical pattern in acquiring basic word order structures? Most of the existing studies have focused on English-exposed children with ASD, showing that they demonstrate an intact, albeit delayed, comprehension of SVO order in English [Naigles et al., 2011; Paul, Fischer, & Cohen, 1988; Swensen, Kelley, Fein, & Naigles, 2007; Tager-Flusberg, 1981]. Using the IPL paradigm, Swensen et al. [2007] assessed SVO knowledge in 10 English-exposed boys with ASD who averaged 33.4 ± 4.06 months (range = 27–41 months) and 13 TD children who averaged 20.9 ± 0.49 months (range = 20–21-months), matched on the MacArthur–Bates Communicative Developmental Inventory (MCDI) [Fenson et al., 1993] vocabulary scores (ASD: 94.9 ± 2.96; TD: 123.59 ± 108.15, $P > 0.05$). Both groups of children listened to simple active sentences in SVO order paired with two visual scenes, only one of which matched the sentence (e.g., to distinguish between "the girl tickling the boy" and "the boy tickling the girl"). Six familiar verbs (i.e., *ride*, *kiss*, *hug*, *push*, *tickle*, and *wash*) and actions were introduced. Eye-movement data revealed that both the ASD and TD groups looked longer at the match during the test than the control trials, without significant group differences. Noteworthy, neither group of children consistently produced sentences in SVO order in spontaneous speech. Besides, when they were divided into one-word speakers and multiword speakers, the latter group did not show an advantage of mastering SVO order over the former group nor were significant correlations found between children's degree of SVO comprehension and their percentage of total utterances of multiple words. Thus, children with ASD's SVO comprehension appears to precede their production, similar to typical development.

In a follow-up IPL study by Naigles et al. [2011], 17 children with ASD aged 32.86 ± 3.45 months showed equivalent levels of comprehension of SVO order as younger TD children averaged 20.59 ± 1.73 months, who were matched on MCDI vocabulary production scores at Visit 1 (ASD: 94.11 ± 111.33; TD: 118.77 ± 114.35, $P > 0.05$). Eight months later at Visit 2, the 41-month-old children with ASD were even able to map novel verbs in SVO transitive frames (e.g., "The bunny is gorping the duck") onto novel causative actions rather than noncausative actions, similar to 29-month-old TD children. Hence, these children with ASD were able to abstract grammatical patterns by engaging in syntactic bootstrapping, that is, using the sentence frames in which words appear to make conjectures about the meanings of those words, which is one of the core acquisition processes in typical development [Arunachalam & Waxman, 2010; Gleitman, 1990; Naigles, 1990]. Note also that at Visit 2, the children with ASD's overall vocabulary production scores were significantly lower than those of TD children (ASD: 283.6 ± 238.01; TD: 503.61 ± 153.2, $P < 0.01$), which indicates that children with ASD may only require a fairly low threshold level of vocabulary production ability to abstract the transitive sentence frame.

Importantly, early comprehension of SVO order as well as their ability to abstract the transitive sentence frame of English-exposed children with ASD may be facilitated by the high frequency of the canonical SVO structure in English [Naigles et al., 2011]. Examinations of child-directed speech among TD children have confirmed that the position of NPs in English transitive sentences consistently manifests SVO order (accounting for about 80% of the utterances), with rare NP omissions [Naigles & Hoff-Ginsberg, 1995]. In contrast, although the canonical word order in Mandarin Chinese is also SVO, it allows variant word orders (e.g., SOV and OSV) and frequent NP ellipsis (e.g., V, SV, and OV). Hence, Mandarin input to toddlers is quite different, with transitive verbs appearing with postverbal NPs only 39% of the time [Lee & Naigles, 2005]. Recall that Mandarin speakers can simply say "*Tui1le3*/Pushed" without mentioning the subject or the object, as long as the referents are in the context and the listener is able to use pragmatic cues to identify the referents. However, because one diagnostic feature of children with ASD is their pervasive deficit in reading pragmatic context and in linking referents to the real world through joint attention [Baron-Cohen et al., 1997; Mundy et al., 1990], Mandarin-exposed children with ASD may thus have difficulties recovering the omitted arguments in sentences like "*Tui1le3*/Pushed," let alone identifying their corresponding thematic roles. Thus, these frequent argument-drop sentences may be uninformative for Mandarin-exposed children with ASD's acquisition of the form-meaning mapping of SVO structures. Hence, if the primary cause of grammatical impairments in children with ASD is their inattention to the requisite linguistic structures as well as the social-pragmatic deficits defining children with ASD [Lord & Paul, 1997; Tager-Flusberg, 1997], then the varied word orders and especially argument drop of Mandarin Chinese may hamper Mandarin-exposed children with ASD in acquiring SVO order.

Thus far, only one (offline) study [Zhou, Crain, Gao, & Jia, 2017] has tested SVO knowledge in Mandarin-speaking children, including 4- and 5-year olds with high functioning autism (HFA), whose verbal IQ scores were higher than 90 and mean length of utterances (MLU) averaged 4.87 ± 1.34 and 5.89 ± 1.36, respectively. The children with HFA correctly chose pictures corresponding to sentences in SVO order (e.g., *Tu4zi3 ju3-le3 xiao3mao1*, "The rabbit lifted the cat") above 98% of the time, indicating little difficulty with interpreting SVO structures at this age and level of functioning. However, this study included neither a broader group of children with more diverse functioning nor children with ASD who were closer to the beginning of acquisition. Moreover, the yes–no nature of the picture-pointing task precluded any comparisons of SVO processing within or between groups. The present study investigates whether a diverse sample of 2- to 5-year-old Mandarin-exposed children with ASD, who are younger, lower verbal and lower functioning than those who participated in Zhou et al. [2017]

may possess similar grammatical strengths. Moreover, we break new ground in delineating the patterns and predictors of online processing of SVO sentences in Mandarin-exposed preschool children with ASD.

Online Sentence Processing in Preschool Children with ASD

Within the past two decades, research has begun to explore how preschool children with ASD process grammatical structures in real time. A number of IPL studies have assessed whether children with ASD can demonstrate grammatical comprehension using eye gaze; moreover, two IPL studies have evaluated the speed of English-exposed preschool children's looking at the match. Naigles et al. [2011] reported that children with ASD engaged in an SVO order task had shorter latencies to the matching scene than to the nonmatching scene after hearing the test audio. In addition, Naigles et al. [2011] compared the children's speed 8 months later during (test) trials matching sentences and scenes to (control) trials when the scenes are presented without directing sentences (hence requiring less processing of the audio and visual scenes) and reported that both ASD and TD groups looked more slowly to the match during test than control trials, although this difference in latency was only significant for the TD children. However, Tovar, Fein, and Naigles [2015] reported that while processing aspect markers (*–ing*, *–ed* suffixes), children with ASD's latency of first look to the match was significantly shorter than to the nonmatch, testifying to their ability to quickly identify the matching scene based on the audio stimuli; this study lacked a TD control group. Thus, although looking patterns in previous IPL studies indicate accuracy (i.e., longer looking to the match) for English-exposed preschool children with ASD, we have limited knowledge about the efficiency of on-line grammatical processing in children with ASD, compared with TD children.

Additionally, recent eye-tracking studies have reported that high-functioning children with ASD manifested incremental semantic or syntactic processing in interpreting linguistic stimuli, but such processing was less developed for children with ASD than TD age mates [Bavin et al., 2014; Bavin, Prendergast, Kidd, Baker, & Dissanayake, 2016; Zhou, Ma, Zhan, & Ma, 2018; Zhou, Zhan, & Ma, 2019]. For instance, 5-year-old Mandarin-speaking high-functioning children with ASD appeared to use a verb's semantics to predict its upcoming object NPs, similar to TD 4-year olds matched on MLU and verbal IQ [Zhou et al., 2019]. When tested with the sentence *Kang1kang1 yao4 qu4 chi1/zhao3 di4-shang4-de3 dan4gao1*, "Kangkang is going to eat/find the cake on the floor," both groups of children had more fixations on the target area (e.g., cake), upon hearing the "bias" verb *chi1* "eat" than the "neutral" verb *zhao3* "find." Moreover, 5-year olds with ASD exhibited these verb-based anticipatory eye movements as efficiently and rapidly as TD 4-year olds, that is, they were able to fixate more on the target area after the onset of the verb and before the onset of the object NP. However, the 5-year olds with ASD exhibited fewer looks to the target area when compared with age-matched TD children. Although informative, these eye-tracking studies have targeted only high-functioning children with ASD older than 5 years and have focused on processing of lexical-semantics over grammatical structures; thus, the need to include more diverse samples, and to focus on grammatical constructions in young Mandarin-exposed children with ASD, remains.

Individual Differences of Grammatical Processing within the ASD Group

Thus far, we have considered group-wide effects of online language processing in children with ASD; however, the previous studies with English-exposed children with ASD have also revealed that online language processing of preschool children with ASD may be affected by multiple individual factors [Bavin & Baker, 2017; Naigles & Fein, 2017]. For example, children with ASD's vocabulary size as measured by the MCDI has correlated positively with their performance on syntactic bootstrapping and wh-questions tasks [Goodwin, Fein, & Naigles, 2012; Naigles et al., 2011]. Heightened autism severity scores have been negatively associated with preschool children with ASD's understanding of wh-questions [Goodwin et al., 2012] and efficiency of visual-language integration [Bavin et al., 2014; Bavin et al., 2016] but not their understanding of grammatical aspect [Tovar et al., 2015]. Children with ASD's age or attention may also be associated with their processing abilities, albeit with inconsistent findings across studies [Bavin & Baker, 2017].

Moreover, because previous IPL studies among English-exposed children with ASD included those whose expressive language scores were at the floor level, it is likely that some proportion of minimally verbal children demonstrated reliable grammatical comprehension abilities [Naigles & Fein, 2017]. When Tek, Mesite, Fein, and Naigles [2014] divided this sample of English-exposed children with ASD into high-verbal and low-verbal groups based on a median split of their vocabulary production scores, most of the low-verbal children (mean MCDI vocabulary production scores = 12.00 ± 28.41, range = 0–86) still demonstrated successful comprehension of SVO order, wh-questions, and grammatical aspect in the IPL tasks. Moreover, Tovar et al. [2015] illustrated the range of production abilities associated with good comprehension of grammatical aspect via scatterplots, suggesting that although faster and better comprehension of the *-ing* suffix among 22 English-exposed preschool children with ASD was significantly correlated with their spontaneous production skills, four children with ASD who produced very few grammatical aspect tokens nonetheless exhibited longer looking at the match or faster looking to the match, indicating that comprehension of the *-ing* morpheme may not solely belong to children with ASD with better production skills. More pertinent to the current study, as mentioned above, Swensen et al. [2007] reported that 10 English-exposed boys whose vocabulary production scores averaged 94.9 ± 2.96 demonstrated comprehension of SVO order well before production, that is, only 1 boy produced any SVO constructions at all. Moreover, the five minimally verbal boys (the one-word speakers) showed equivalent comprehension of SVO order as the five boys who produced some multiword combinations.

Summary and Prospectus

To recap, to date, we still lack cross-linguistic examination of how young children with ASD learning different languages acquire basic word order in their target language. In addition, we have no knowledge about online grammatical processing in preschool children with ASD exposed to languages other than English. This study will examine the online processing of SVO structures in a diverse sample of 2- to 5-year-old Mandarin-exposed children with ASD who manifest a wide range of vocabulary production scores and autistic symptomatology and who are also younger, lower verbal, and lower functioning than those who participated in Zhou et al. [2017]. Investigation of the acquisition of SVO order in a diverse sample of Mandarin-exposed children with ASD has the potential to contribute to a deeper understanding of the nature of grammatical acquisition of children with ASD, for example, whether acquisition of the core grammatical structures like word order in ASD depends on a high frequency of the relevant structures in the input as well as the child's pragmatic/discourse skills.

We have chosen to use the eye-movement method of IPL because it is a sensitive measure for detecting early online language processing abilities in children with ASD [Naigles & Tovar, 2012]. Importantly, the IPL setup reduces social-pragmatic demands by projecting the linguistic audio from a central speaker without direct interaction with the experimenters; therefore, it assesses the syntactic knowledge of children with ASD without requiring social interaction. Moreover, the average video task lasts for only 3–5 min, thus minimizing effects of children with ASD's short attention spans. In addition, because the implicit measure of IPL does not require an overt spoken response, it can reveal knowledge of basic grammar in even minimally verbal children whose language levels suffer from floor effects via standard assessments [Naigles & Fein, 2017].

We will investigate and compare both the accuracy and speed of real-time sentence processing in Mandarin-exposed preschool children with ASD and TD children. Then, we will identify factors that might affect individual differences in the efficiency of such processing, which will be important to inform subsequent early language intervention in children with ASD. Consistent with the general conclusion of English-exposed children with ASD's strengths of basic grammatical structures in the IPL experiments [Naigles & Fein, 2017], we hypothesize that Mandarin-exposed children with ASD's linguistic development will generally follow the same course as typical development; thus, they are expected to demonstrate sensitivity to SVO order structures as seen in younger TD children. However, because Mandarin Chinese is not a strict SVO language as English and because we have recruited a diverse sample of Mandarin-exposed children with ASD, whose vocabulary production scores were dramatically lower than those of the typical participants, it is also possible that our Mandarin-exposed children with ASD may demonstrate much higher heterogeneity of grammatical knowledge of SVO order than the English-exposed children with ASD. Moreover, following previous language processing studies in preschool children with ASD, we hypothesize that children with ASD may be less efficient in real-time sentence processing than TD children. We also predict that individual factors such as children with ASD's vocabulary size may be related to their proficiency of sentence processing. Finally, as with English-exposed children with ASD, it is possible that some proportion of minimally verbal Mandarin-exposed children with ASD in the current study may nonetheless demonstrate reliable processing of basic SVO structures.

Methods

Participants

Seventy Mandarin-exposed children with ASD (mean age = 49.57 ± 10.65 months; 61 males and 9 females) and 52 TD children (mean age = 33.25 ± 4.86 months; 22 males and 30 females) were included in the final sample. Our diagnostic groups were not matched on gender, with the ASD group reflecting the predominance of males in this population, whereas the TD group consisted mostly of girls; however, no gender effects were observed for either group [see also Swensen et al., 2007]. To confirm that this gender imbalance did not confound possible diagnostic group effects, we also conducted group comparisons with a subset of the TD group that matched the ASD group in gender (see the Supporting Information Table S1 and Supporting Information S1 for more detail). The children with ASD were recruited from the Second Xiangya Hospital of Central South University (CSU) and three autism training centers (Aimier, Xingyuan, and Aimeng) in Changsha, China. The diagnoses were ascertained by experienced child psychiatrists on the basis of the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM IV-TR)

[American Psychiatric Association, 2000]. The DSM IV-TR-based diagnoses were supplemented with the parent rating scale of the Chinese autism behavior checklist (ABC) [Yang, Huang, Jia, & Chen, 1993]. All children with ASD had ABC scores above the cutoff score of 31 (mean score = 64.14 ± 22.94, range = 32–151), but none of the TD children had ABC scores of ≥31 (mean score = 13.35 ± 8.53, range = 0–29). The TD group was recruited from three mainstream kindergartens including the CSU main campus kindergarten, the CSU railway campus kindergarten, and the Blue Sky Art kindergarten, as well as word of mouth. All parents of the child participants signed consent forms for participation, which were approved by the Medical Ethics Committee of the Second Xiangya Hospital, CSU.

Table 1 presents descriptive data of the participants' age, their vocabulary production scores on the Putonghua Communicative Development Inventories (PCDI) [Tardif, Fletcher, Zhang, & Liang, 2008], mean length of the three longest utterances (MLU3) [Fenson et al., 1993] calculated by averaging the total number of words of each participant's three longest utterances from "the three longest utterances the child has said recently" item of the PCDI, and the parent rating scores on the total and five subscales of the ABC. The TD group was comparable to the 33.8-month-old Mandarin children showing reliable comprehension of SVO in Candan et al. [2012], $t(61) = 0.77$, $P = 0.44$, $d = 0.16$, but they were significantly younger than the ASD group, $t(102) = 11.34$, $P < 0.001$, $d = 1.97$. The vocabulary production score of the ASD group was equivalent to that of 19-month-old TD Mandarin learners in the PCDI normative study, 237.27 ± 233.06 versus 226 ± 203, $t(103) = 0.24$, $P = 0.80$, $d = 0.04$, and was significantly lower than the TD group, $t(111) = 12.31$, $P < 0.001$, $d = 2.23$. The MLU3 of the ASD group was also significantly lower than that of the TD group, $t(86) = 10.33$, $P < 0.001$, $d = 2.08$. Not surprisingly, the ASD group had significantly higher ABC scores of autistic behaviors than the TD group on the total scale, $t(95) = 16.53$, $P < 0.001$, $d = 2.94$, and the five subscales of Sensory, $t(97) = 10.23$, $P < 0.001$, $d = 1.82$, Relating, $t(102) = 14.81$, $P < 0.001$, $d = 2.67$, Body and Object Use, $t(102) = 4.79$, $P < 0.001$, $d = 0.87$, Language, $t(104) = 16.06$, $P < 0.001$, $d = 2.92$, Social and Self-help, $t(102) = 10.58$, $P < 0.001$, $d = 2.01$.

Materials

Standardized test measures. *ABC* [Krug, Arick, & Almond, 1980; Chinese version: Yang et al., 1993] was administered to assess the child's autistic behaviors. The parent rating scale of the ABC is one of the most widely used autism screening tools in China [Sun et al., 2013]. Individuals with a total score of 62 or more have a high probability of being autistic, and the cutoff score of 31 distinguishes between children who are likely and unlikely to be autistic. *PCDI: Words and Sentences* [Tardif et al., 2008] provided a measure of the child's language production abilities in Mandarin Chinese via parental report. CDI measures (e.g., MCDI and PCDI) have been widely used in language assessments of 1- to 7-year olds with ASD learning different languages [e.g., Charman, Drew, Baird, & Baird, 2003; Su et al., 2018].

IPL setup. The IPL paradigm [Naigles & Tovar, 2012] involves showing children two videos side by side, while playing child-directed speech that corresponds to only one of the videos. The child's direction and duration of gaze were recorded and coded for indications of his/her understanding. An Apple laptop was used to project the stimuli onto a portable 150 cm × 120 cm screen via an LCD projector. The computer was connected to an external speaker, placed out of sight behind the screen. A digital camcorder for filming the child's face was placed on a small tripod in front of the screen, just below the center.

IPL stimuli. Table 2 presents the layout and trial durations for the word order video [Candan et al., 2012]. The pretest trials (labeled "P") introduced and labeled the costumed bird and horse. Trials 1 and 2 presented a familiar action (e.g., pushing) with Agent A and Patient B on one

Table 1. Mean and SD and Range of Group Scores on Standardized Tests

		PCDI		ABC					
Group	Age in months	Total vocabulary production	MLU3	Total	Sensory	Relating	Body/ object use	Language	Social/ self-help
TD (n = 52)									
Mean	33.25	665.05	5.87	13.35	1.18	2.18	4.95	2.43	4.22
SD	4.86	137.89	1.62	8.53	2.11	3.08	3.94	2.77	3.70
Range	20–38	101–799	2.00–9.67	0–29	0–10	0–13	0–14	0–10	0–12
ASD (n = 70)									
Mean	49.57	237.27	1.96	64.14	8.61	16.29	10.83	15.57	13.25
SD	10.65	233.06	2.10	22.94	5.36	6.81	8.77	5.74	5.16
Range	28–69	0–766	0–6.50	32–151	0–26	4–35	0–38	5–30	1–25

Note. ABC, autism behavior checklist; ASD, autism spectrum disorder; MLU3, mean length of three longest utterances; PCDI, putonghua communicative development inventory; TD, typically developing.

Table 2. Sample Layout of the Word Order Video [adapted from Candan et al., 2012]

Trial	Left video	Audio	Right video	Length (sec)
Part I—Character identification segment				
P	Blank	*Ou4, kan4, xiao3ma3!* "Oh, look, a horse!"	Blank	3
P	Blank	*Kan4, xiao3ma3! Kan4, you3 xiao3ma3!* "Look, a horse! See, a horse!"	Horse waves	4
P	Blank	*Ou4, kan4, xiao3niao3!* "Oh, look, a bird!"	Blank	3
P	Bird waves	*Kan4, xiao3niao3! Kan4, you3 xiao3niao3*! "Look, a bird! See, a bird!"	Blank	4
P	Blank	*Ou4, kan3 zher4!* "Oh, look here!"	Blank	3
P	Bird waves	*Kan4 liang3bian1 dou1 you3!* "We see both!"	Horse waves	4
P	Blank	*Xiao3ma3 zai4 na3li3?* "Where is the horse?"	Blank	3
P	Bird waves	*Kan4 xiao3ma3!* "Look at the horse!"	Horse waves	4
P	Blank	*Xiao3niao3 zai4 na3li3?* "Where is the bird?"	Blank	3
P	Bird waves	*Kan4 xiao3niao3!* "Look at the bird!"	Horse waves	4
Part II—Word order comprehension				
ITI1	Blank	*Ou4, kan4 zher4! Tui1!* "Oh, look here! Push!"	Blank	3
1	Bird pushes horse	*Kan4, tui1! Kan4, tui1!* "Look, push! See, push!"	Blank	6
ITI2	Blank	*Ou4, kan4 zher4! Tui1!* 'Oh, look here! Push!'	Blank	3
2	Blank	*Kan4, tui1! Wa3, tui1!* "Look, push! Wow, push!"	Horse pushes bird	6
ITI3	Blank	*Ou4, xian4zai4 kan4!* "Oh, look now!"	Blank	3
3 control	Bird pushes horse	*Ta1men liang3bian1 dou1 you3!* "They are on both screens!"	Horse pushes bird	6
ITI4	Blank	***Wa3! Xiao3niao3 zai4 tui1 xiao3ma3!*** **"Wow! The bird is pushing the horse!"**	Blank	3
4 test (first and second halves)	**Bird pushes horse**	***Kan4! Xiao3niao3 zai4 tui1 xiao3ma3!*** **"Look! The bird is pushing the horse!"**	Horse pushes bird	6

Note. ITI, inter-trial-interval. Bolded text indicates the matching audio and video.

side and with Agent B and Patient A on the other side. During these trials, the action was labeled in a neutral frame (e.g., *Tui1!* "Push!"). In Trial 3 (the control-for-salience trial), both renditions of the action were presented simultaneously along with a nondirecting audio (e.g., *Ta1men liang3bian1 dou1 you3!* "They are on both screens!"); this entire control trial provided the baseline measure of stimulus salience. During the inter-trial-interval (ITI) before Trial 4, the test sentence was presented for the first time, in which the verb was placed in a simple transitive sentence (e.g., *Xiao3niao3 zai4 tui1 xiao3ma3* "The bird is pushing the horse"), with blank screens on both sides. Trial 4 presented the test sentence for the second time, with only one of the two scenes matching the audio stimulus. This trial examined whether the child understood the difference between "A verbs B" (e.g., the bird is pushing the horse) and "B verbs A" (e.g., the horse is pushing the bird). For analysis purposes, these entire test trials will be further divided into two equal halves (i.e., the first 3 sec comprised the first half and the last 3 sec comprised the second half) to measure the participants' efficiency of online processing during the test trials. Six familiar verbs (tui1 "push", mo1 "touch", la1 "pull", xi3 "wash", bao4 "hug", and bei1 "carry") and actions were introduced. The side of the screen depicting the matching video was counterbalanced across trials. Each child viewed all six test trials presented with a fixed order [see also Candan et al., 2012; Swensen et al., 2007].

Procedure

The child sat in a floor mat approximately 2 feet away from the monitors. The SVO order video was always the first of two or three IPL video tasks that the child watched. The other two video tasks, assessing children's noun bias and grammatical aspect, targeted younger or older preschool children with ASD, respectively. After the viewing session, parents in the training centers or kindergartens were asked to fill out the PCDIs and the ABCs, which were collected within 1 week after the IPL experiments.

Coding

The child's visual fixations were coded frame by frame from silent video of the child's face. An individual trial was considered missing if the child looked at both scenes, combined, for less than 1 sec. On each trial, visual fixations were registered after the child had looked at the center lights during the ITIs for more than 0.3 sec. Trials following ITIs in which the child did not look at the center light for a minimum of 0.3 sec were excluded. The percentage of excluded trials was 1.97% for the TD and 5.71% for the ASD group, which are typical figures for IPL studies (usually less than 10%) [Naigles et al., 2011]. The average number of verbs included was 5.81 ± 0.40 for the TD and 5.37 ± 0.80 for the ASD group. Each child's video was coded by two research assistants to assess reliability. The correlation between coders averaged 0.94 ($SD = 0.08$, $P < 0.05$).

Description of Dependent Variables

Five dependent variables were calculated. The first three measures were *the percent looking to match* measures, which capture the child's preference for the matching scene during the test trials compared with the control trials, averaged across all verbs. Recall that during the control trials, a neutral audio was presented that did not direct the children's attention to any of the two videos, whereas during the test trials, the test audios, if understood, were expected to change the child's scene preference in the correct direction. Thus, the percent looking to match measures provide an indication of the extent to which the child shifted his or her attention to the matching scenes of the test trials, over and above their baseline preferences during the control trials. The total-percent-looking-to-match measure compares the entire control trials to the entire test trials. Moreover, as mentioned above, each entire test trial was divided into two halves resulting in one measure including just the first half of each test trial (beginning after the child's last look to the center/away during the preceding ITI) and the other including just the second half. Looking preference during each half will also be compared with the entire control trial, averaged across all verbs [see Naigles, Bavin, & Smith, 2005, for further justification]. Early selection, during the first half of the test trials (after the first presentation of the test audio), may indicate good processing facility; later selection, during the second half of the test trials (after hearing the test audio a second time), may indicate a slower processing speed or less facility with word order knowledge. The *latency of first look* measures when children's first look to the matching versus nonmatching scenes during the test trials occurs. The zero time point of this measure is the last time the child centered or looked away, during the just-previous ITI, before the start of the test trial. Children who understood the audio should look more quickly at the matching than the nonmatching scene. The *number of switches of attention* children make on control versus test trials assesses children's continuing certainty about the match between audio and video. Children should switch attention more during control trials, with no directing audio to guide looking, than during test trials, when attention should be more focused on the match if the test audio is understood.

Data Analysis Plan

To assess on-line comprehension of SVO sentences in these Mandarin-exposed children with ASD, we first conducted two-way analyses of variance (ANOVAs) for four of the five dependent variables, with diagnostic group (TD vs. ASD) as the between-subjects measure and trial (control vs. test) as the within-subjects measure. For *the latency of first look* measure, the scene (matching vs. nonmatching scenes in the test trials) was included as the within-subjects measure. Because we were interested in whether the ASD group manifested the same effects as the TD group on different measures, follow-up *t*-tests (one-tailed, because the prediction was always unidirectional) were performed for each group separately [Naigles et al., 2011]. Next, because we expect to delineate the course of online processing, more detailed scrutiny and comparison of the TD and the ASD groups' timecourses of looking during the control and test trials of the SVO videos were performed. Finally, pairwise correlation analyses were conducted between four IPL variables and the standardized test measures to discover relationships between children's understanding of SVO order and their general language and autistic levels [Tovar et al., 2015]. The four IPL measures were (a) percent looking to match during the entire test trials, (b) percent looking to match during first half of the test trials, (c) percent looking to match during second half of the test trials, and (d) first-look latency to match. The standardized measures included the total vocabulary production scores and the MLU3 via the PCDI, and the total and subscale scores of the ABC. Scatterplots of some of the significant correlations will be presented to further capture individual variation in the on-line processing of SVO sentences. All of these statistical analyses were performed using SPSS version 25 [IBM Corp, 2017].

Results

Table 3 presents the descriptive data of each IPL measure for the ASD and TD groups during the control and test

Table 3. Intermodal Preferential Looking Results for Word Order Video by Diagnostic Groups

Measure	TD (*N* = 52)	ASD (*N* = 70)
Total trial percent looking to match		
Control trials	52.58 (7.51)	48.93 (10.99)
Test trials	54.52 (8.16)	52.17 (10.28)*
First half percent looking to match		
Test trials	55.69 (11.50)*	50.52 (12.60)
Second half percent looking to match		
Test trials	53.36 (10.80)	52.64 (14.87)*
Latency of first look (sec)		
Matching	1.37 (0.73)	1.35 (0.80)
Nonmatching	1.93 (0.70)***	1.62 (0.90)**
Number of switches		
Control trials	7.10 (1.17)	7.53 (1.51)
Test trials	6.38 (1.11)***	6.89 (1.46)***

Note. ASD, autism spectrum disorder; TD, typically developing. Comparison of test trials vs. control trials. *t*-tests (one-tailed), $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

trials. Moreover, all of the children in the final participant pool looked correctly at the bird or the horse at least once while hearing *Kan4 Xiao3niao3* "Look at the bird!" or *Kan4 Xiao3ma3* "Look at the horse!" in the pretest trials of the character identification segment, indicating that they understood the labels.

With the total *percent looking to match* measure, mixed-effects ANOVAs yielded significant main effects of trial, $F(1, 120) = 5.55$, $P = 0.020$, $\eta^2 = 0.04$, and group, $F(1, 120) = 4.88$, $P = 0.029$, $\eta^2 = 0.04$. Follow-up *t*-tests revealed that both groups looked longer to the match during the total test trials than the control trials, with the ASD group's comparison reaching statistical significance (though the effect size of the TD group was comparable to the ASD group), ASD: $t(69) = 2.00$, $P = 0.025$, $d = 0.30$; TD: $t(51) = 1.47$, $P = 0.075$, $d = 0.25$. When the test trials were divided into two halves, a main effect of group, $F(1,120) = 8.16$, $P = 0.005$, $\eta^2 = 0.06$, emerged during the first half of the test trials. The TD group had overall greater percent looking to the match than the ASD group, during both the control trials, $t(119) = 2.18$, $P = 0.031$, $d = 0.39$, and first half of the test trials, $t(120) = 2.32$, $P = 0.022$, $d = 0.43$. However, no significant effects or interactions emerged during the second half of the test trials. *T*-tests further revealed that the TD children looked significantly longer to the match during the test relative to control trials for the first half of the test trials, $t(51) = 1.72$, $P = 0.046$, $d = 0.32$, whereas children with ASD looked significantly longer to the match during the test relative to control trials for the second half of the test trials, $t(69) = 1.75$, $P = 0.042$, $d = 0.28$ (Fig. 1).

With the *latency of first look* measure, a mixed-effects ANOVA yielded a significant main effect of scene, $F(1,120) = 30.16$, $P < 0.001$, $\eta^2 = 0.20$. Both groups looked more quickly to the matching than to the nonmatching scene during the test trials, with the TD group yielding a larger effect size than the ASD group, TD: $t(51) = 4.83$, $P < 0.001$, $d = 0.78$, ASD: $t(69) = 2.79$, $P = 0.004$, $d = 0.32$.

The percent looking to match and latency findings may seem inconsistent for the ASD group: If children with ASD look first more quickly at the match than the nonmatch, then why does their percent of looking to the match not reach significance during the first half of the trial? To explore children's pattern of looking across the whole trial, we compared the timecourse graphs of TD children and

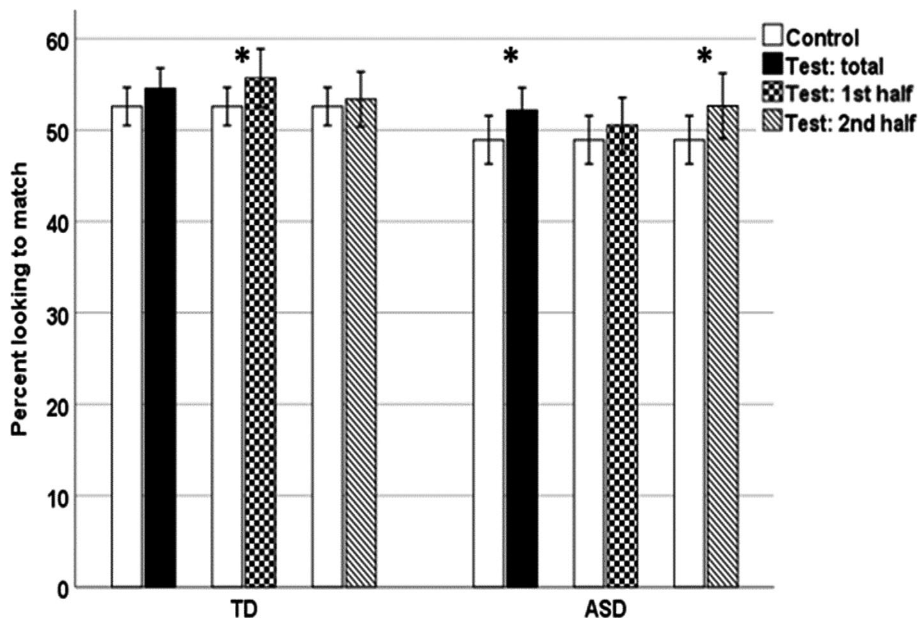

Figure 1. Percent looking to match during control trials and test trials (total, first half and second half) for the word order video by diagnostic groups. $*P < 0.05$.

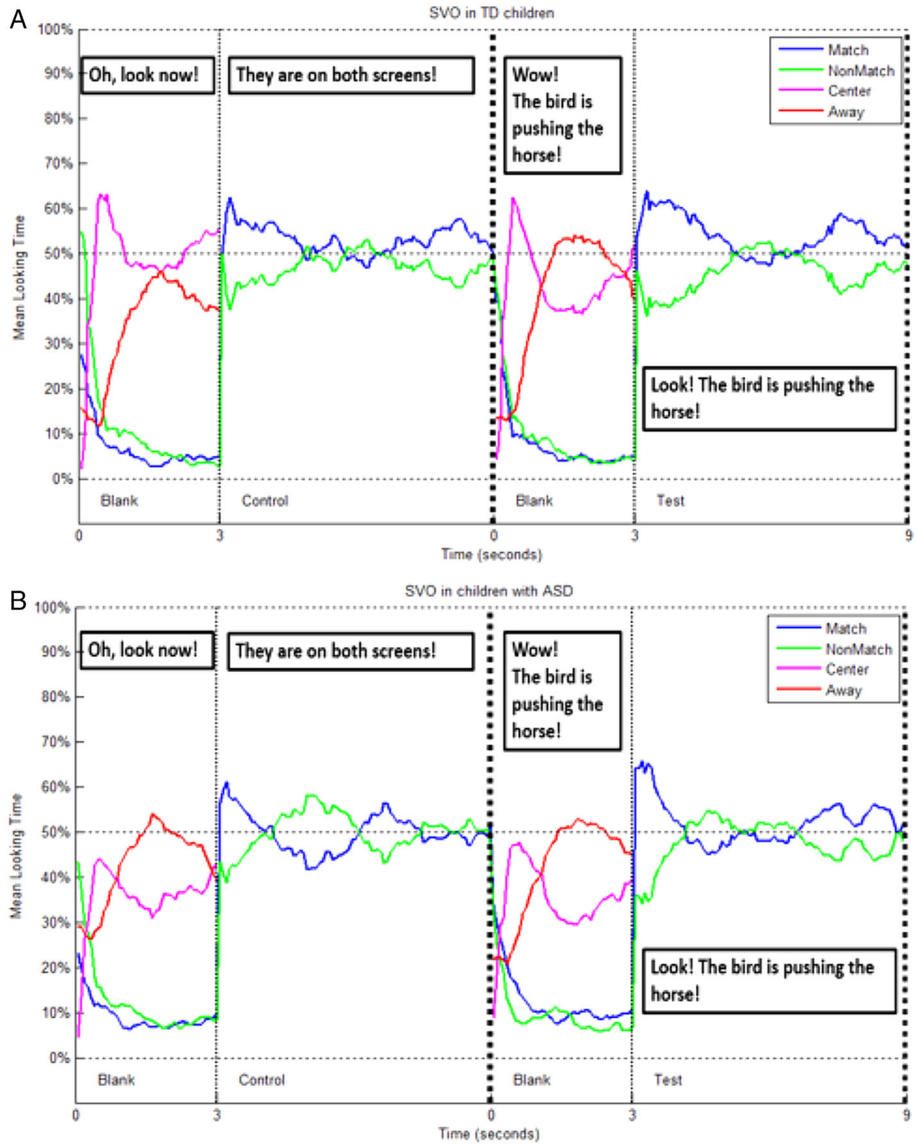

Figure 2. Timecourse of looking to the matching and nonmatching scenes for the word order video for (A) TD children and (B) children with ASD.

children with ASD (Fig. 2). These show children's average timecourse of looking during the ITIs (labeled "blank": 3 sec each) and through the control and test trials (6 sec each). The pink line shows percent of time looking at the center and the red line shows percent of time looking away from the screens entirely; the green line traces children's percent of time looking to the nonmatching scene, and the blue line traces their percent of time looking to the matching scene. Figure 2 illustrates two different looking patterns for the two groups: The TD children look first to the matching scene, maintain this preference for the first third of the trial, switch briefly to look at the nonmatching scene, and then return to looking at the match for the rest of the trial. The children with ASD show a similar overall pattern but cannot seem to maintain their first look to the match for very long, and their switch to the nonmatching scene is longer; thus, they only demonstrated a sustained look to the match (over 1 sec) during the second half of the test trial.

With the *number of switches* measure, there were significant effects of trial, $F(1, 120) = 33.79$, $P < 0.001$, $\eta^2 = 0.22$, and group, $F(1, 120) = 4.63$, $P = 0.034$, $\eta^2 = 0.04$. The number of switches of attention decreased significantly between the control and the test trials for both the TD group, $t(51) = 4.46$, $P < 0.001$, $d = 0.64$, and the ASD group, $t(69) = 3.94$, $P < 0.001$, $d = 0.43$. Moreover, the ASD group displayed more shifts of attention than the TD group during the test trials, $t(120) = 2.11$, $P = 0.037$, $d = 0.39$.

Correlation analyses were conducted for each group to see whether their looking behaviors were related to age, vocabulary production scores, MLU3, or the ABC total and

Table 4. **Pearson Correlations between the PCDI Measures and SVO Comprehension for Children with ASD (N = 70)**

Variable	Percent looking to match during second half of the test trials	Latency of first look to match during the test trials
Vocabulary production score	0.325**	−0.299*
MLU3	0.354**	−0.302*

Note. MLU3, mean length of three longest utterances. *P < 0.05; **P < 0.01; ***P < 0.001.

subscale scores. For the TD group, older children displayed shorter latencies to the matching scenes during the test trials, r = −0.335, P = 0.015. Within the ASD group, significant correlations emerged primarily with the PCDI measures, as illustrated in Table 4. However, no significant correlations emerged between children with ASD's IPL measures and their ABC total and subscale scores ($P \geq 0.105$).

As depicted in the scatterplots, children with ASD with higher MLU3 spent a greater percentage of time looking at the match during the second half of the test trials (Fig. 3A) and had shorter latencies to the match during the test trials (Fig. 3B). However, although children with higher MLU3 generally displayed better IPL performances, as circled in the scatterplots, 15 minimally verbal children with MLU3 at zero (i.e., producing no multiword utterances) were able to show preferences for the match (e.g., their percent looking to the match during the second half of the test trials was higher than 50%); moreover, 16 minimally verbal children with MLU3 at zero showed faster looking to the match (e.g., found the matching scene in less than 1.5 sec).

Finally, a preliminary comparison of the processing of SVO order between a subset of 12 Mandarin-exposed children with ASD and the 17 English-exposed children with ASD studied by Naigles et al. [2011] was performed. The subset of Mandarin-exposed children was matched on age and gender with the English-exposed children; however, the vocabulary production scores were not matched, due to the different CDI measures (PCDI and MCDI) adopted in our two studies. The results also revealed accuracy of SVO processing in the 12 Mandarin-exposed children with ASD (i.e., more percent looking to match during the total test and second half of the test trials compared to the control trials), but the Mandarin-exposed children with ASD were not yet efficient at looking faster to the match during the test trials (see the Supporting Information Table S2 and Supporting Information S2 for more detail).

Discussion

In this study, we found that comprehension of SVO structures remained a relative strength in a diverse sample of 2- to 5-year-old Mandarin-exposed children with ASD. Both children with ASD and TD children looked longer at the match during the test trials compared with the control trials. Moreover, both groups had shorter latencies to the matching scene than the nonmatching scene during the test trials, and they switched attention more during the control than the test trials, indicating that they were indeed processing the test audio. However, the children with ASD seemed less efficient in online SVO processing, because they only showed reliable looking preferences to the match during the second half of the test trials, whereas the TD children showed reliable looking preferences during the first half. We also found that the PCDI scores of vocabulary production and syntactic complexity were related to the children with ASD's efficiency of SVO processing. Nevertheless, some proportion of minimally verbal children was able to show syntactic processing of SVO order in the IPL task.

SVO Order Is a Strength in Mandarin-Exposed Preschool Children with ASD

Overall, our study provides further evidence that a diverse sample of Mandarin-exposed preschool children with ASD across the spectrum is capable of establishing the mapping between the position of NPs and their thematic roles, in basic active sentences [Naigles et al., 2011; Swensen et al., 2007; Zhou et al., 2017]. Moreover, these participants had more severely delayed expressive language level than those who participated in Zhou et al. [2017], and the children with ASD's vocabulary size was significantly lower than the TD controls. Yet, despite their overall disadvantaged expressive language levels, these Mandarin-exposed children with ASD demonstrated syntactic awareness of SVO order. Hence, consistent with the results in Naigles et al. [2011; see also Swensen et al. 2007], children with ASD with a wide range of vocabulary production scores may demonstrate knowledge of core grammatical constructions or patterns, not limited by their concurrent vocabulary production abilities.

It is worth emphasizing that this basic syntactic awareness of word order is preserved in children learning a language (i.e., Mandarin) whose environment lacks consistent linguistic models of SVO order (unlike English), due to the variant word orders and the frequent ellipsis of NPs in Mandarin Chinese. Moreover, given children with ASD's general pragmatic deficits, they may be challenged in recovering the omitted NPs and relating them to the corresponding thematic roles in appropriate discourse contexts. Consequently, one expectation was that the children would not have acquired a stable SVO order for Mandarin Chinese. The fact that they did so raises the possibility that such stable word orders can be acquired based on relatively little input (i.e., comprising less than 40% of the relevant utterances) [Lee & Naigles, 2005].

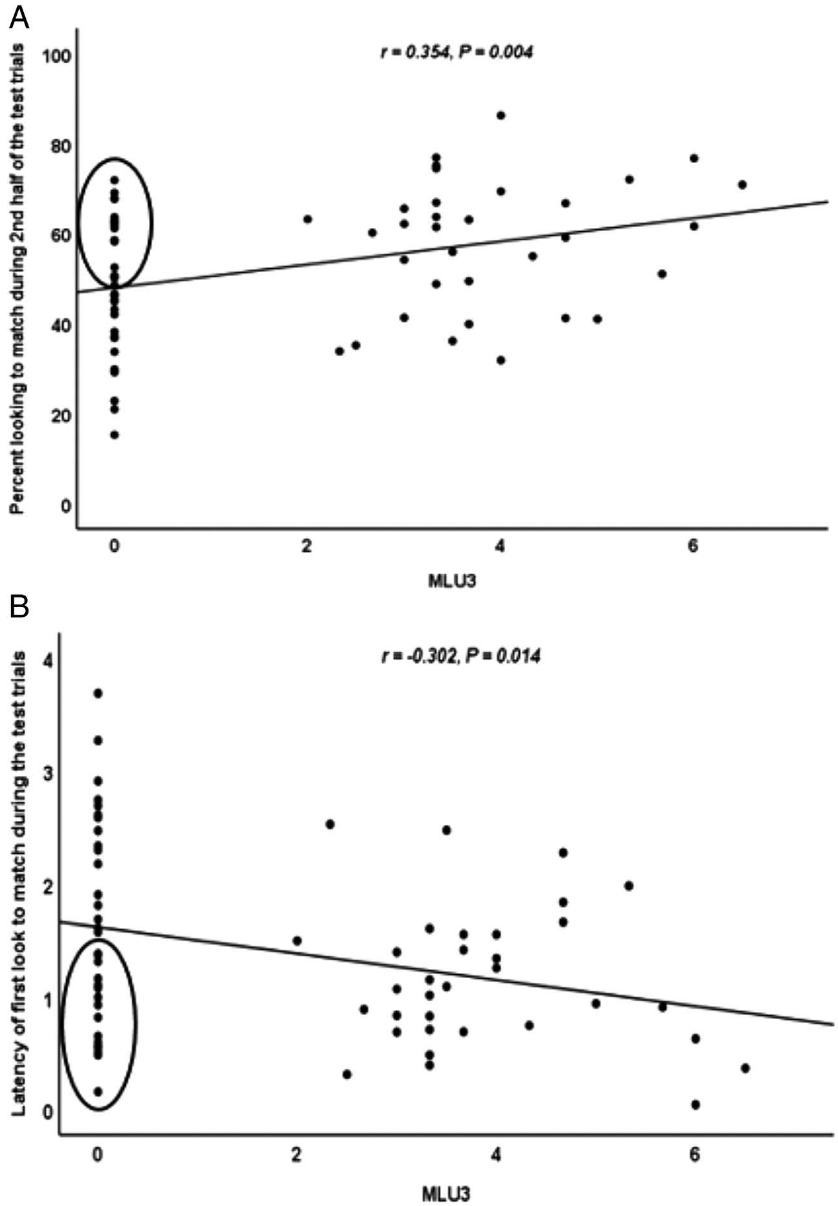

Figure 3. Scatterplots of significant relationships between children with ASD's (A) percent looking to the match during the second half of the test trials and MLU3 and (B) latency of first look to the match during the test trials and MLU.

Furthermore, basic syntactic knowledge of SVO order in Mandarin Chinese seems not to be hampered by children with ASD's social-pragmatic deficits in recovering the relevant argument-drop sentences in the Mandarin language input. Additionally, no significant correlations were observed between children with ASD's accuracy or speed in processing SVO structures and the severity of their autistic behaviors, as indicated by the ABC total and subscale scores. In this respect, our results provide further evidence for the dissociation between grammatical knowledge versus social-pragmatic deficits in children with ASD (Tager-Flusberg, 1994; see also Su et al., 2018). Recall that previous IPL findings also suggested a dissociation between strengths in comprehending a number of grammatical structures (e.g., grammatical aspect and wh-questions) versus deficits manifested by producing these structures less frequently in speech, in English-exposed young children with ASD [Naigles & Fein, 2017]. This dissociation between children with ASD's grammatical strengths versus their social-pragmatic deficits has been observed by Tager-Flusberg [1994, p. 189], who stated that "Certain aspects of language development are profoundly impacted by the kinds of social impairments that are at the core of the autistic syndrome; at the same time… other domains of language develop in a relatively normal fashion and thus, appear to be largely independent of social influences." For instance, "the more formal aspects of language, which include…the grammatical system, depend on separate computational mechanisms that are specific to the domain of language" [Tager-Flusberg, 2001, p. 188]. In the current study, a diverse sample of children with ASD exposed to Mandarin Chinese seems to demonstrate very similar inherent word order knowledge as typical language learners, even without consistent support from the language input or despite the discourse-pragmatic deficits characterizing this population. Future cross-linguistic studies are needed to test to what extent other core grammatical structures, properties, or mechanisms that have been identified in typical language development may also be preserved in language acquisition of children with ASD learning a variety of languages. Such findings may provide evidence that the computational part of the human language faculty may be selectively preserved in at least some children with ASD across languages [Leivada, Kambanaros, & Grohmann, 2017; Su & Su, 2015].

Mandarin-Exposed Preschool Children with ASD Are Less Efficient in Online Processing of SVO Order

The most obvious group difference in looking behavior in this study was that TD children preferred the matching scene primarily during the first half of the test trials, whereas the children with ASD showed their preference for the match most strongly during the second half. The ASD group also had smaller effect sizes than the TD group in the latency to match measure, and they seemed less certain of the matching scene than the TD group, as displayed by their greater number of shifts of attention during the test trials. Hence, unlike the TD children who showed processing facility upon the first presentation of the test audio, these children with ASD appeared to be less efficient at SVO processing [see also Bavin & Baker, 2017; Naigles & Fein, 2017; Zhou et al., 2018; Zhou et al., 2019]. In addition, we found that when hearing the SVO audio, these children with ASD did not maintain their first look to the match for very long, instead, there was a drop-off in proportion of looking at the match and a switch of attention to the nonmatch during the first half of the test trials.

There are a number of possible explanations for this "delay" in processing. For example, the Mandarin-exposed children with ASD's SVO representations may be more fragile, such that parsing or recognition of SVO utterances is not always successful; alternatively, they may be slower processors of auditory stimuli in general. Under both explanations, the children with ASD may have needed to hear the SVO sentences twice for successful online processing. Moreover, given that both vocabulary production scores and MLU3 negatively correlated with children with ASD's latency of first look to match during the test trials, it is possible that both lexical access and syntactic complexity in children with ASD were related to the efficiency of their online processing of SVO structures. Notably, our findings for the TD group of better processing of SVO during the first half of the trials, and of older children's faster processing of the test stimuli, corroborate those reported in Candan et al. [2012].

Individual Differences of SVO Processing in Mandarin-Exposed Children with ASD

Due to the heterogeneity in ASD samples, it is important to investigate how individual characteristics predispose children with ASD to have more or less difficulties with online sentence processing. As mentioned, we found that Mandarin-exposed children with ASD's vocabulary size and MLU3 on the PCDI were related to the efficiency of their online sentence processing. Thus, across languages, children with ASD with better general language skills (e.g., measured via the parental report of MCDI/PCDI) are likely to demonstrate better IPL performances during online language processing [Naigles & Fein, 2017].

Despite this, it is worth noting that some proportion of minimally verbal children (about 21%–23% of the total group) exhibited reliable comprehension as seen in their accuracy and/or speed. Hence, despite the general pattern that children with ASD with higher PCDI scores demonstrate better processing abilities, some minimally verbal children with ASD may exhibit considerable covert syntactic competence. These findings are consistent with the results of previous IPL studies among English-exposed preschool children with ASD; namely, that some children with ASD with limited language production skills were able to reveal nonobvious syntactic sensitivities to grammatical structures such as SVO order, wh-questions, or grammatical aspect in IPL experiments [Naigles & Fein, 2017].

In summary, we have extended previous IPL findings testifying to the grammatical competence of English-exposed preschool children with ASD [Naigles & Fein, 2017] to a diverse sample of preschool Mandarin-exposed children with ASD. These children with ASD's knowledge of basic SVO order in Mandarin Chinese thus yields further evidence that core grammatical knowledge such as basic word order may be preserved in children with ASD across languages, even in the face of radical differences in language environment and consistency of input, social/pragmatic deficits, and neurological organization. However, these Mandarin-exposed children with ASD were less efficient in online sentence processing than the TD children. Moreover, the children with ASD with higher vocabulary production or syntactic complexity scores generally showed better grammatical comprehension abilities. Notably, although, the demonstration of nonobvious grammatical knowledge in some minimally verbal children with ASD suggests that first, nonsocial assessment or intervention paradigms could be utilized by researchers or practitioners to better reveal linguistic competence, and second, that further stratification of subtypes of the minimally verbal children with ASD is needed to enhance individual-tailored intervention in this group of children with ASD across countries.

Limitations of this study include the absence of direct testing of specific processes or strategies the children may have adopted during online language processing. Nor were we able to compare vocabulary-matched TD children and children with ASD to more directly assess the role of vocabulary size in the timecourse of SVO processing, because the vocabulary production scores of the TD children were much higher than those of the children with ASD in the present study. Moreover, a wider range of standardized assessments of MLU and receptive language ability, as well as the assessments of executive function or attention abilities will be necessary in future research to inform other possible accounts for individual differences in grammatical processing. Future cross-linguistic studies with carefully matched participant groups (e.g., via language production levels in speech) are also needed to more systematically and directly assess the roles of the maternal input and the social-pragmatic skills (e.g., via joint attention) in children with ASD exposed to different languages, to reveal the nature of language acquisition in children with ASD across countries, for example, to investigate how much the human genome contributes to language development in ASD, and how much this development is influenced by language environment and the social-pragmatic deficits characteristic of ASD.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (31500889), the Philosophy and Social Science Fund Project of Hunan Province (17YBA424), and Hunan Provincial Natural Science Foundation of China (2018JJ2494). We gratefully acknowledge our invaluable research assistants in data collection, as well as the children and families who participated in the study. We are grateful to the support from the teachers in the autism training centers who assisted in the execution of this project.

Conflict of Interest

The authors declare that they have no competing interests.

References

Allen, S. E. (2007). Interacting pragmatic influences on children's argument realization. In M. Bowerman & P. Brown (Eds.), Crosslinguistic perspectives on argument structure: Implications for learnability (pp. 191–210). New York: Routledge.

American Psychiatric Association. (2000). Diagnostic and statistical manual of mental disorders (4th ed. ed., *text rev.*). Washington, DC: American Psychiatric Pub.

Arunachalam, S., & Waxman, S. R. (2010). Meaning from syntax: Evidence from 2-year-olds. Cognition, 114(3), 442–446. https://doi.org/10.1016/j.cognition.2009.10.015

Baron-Cohen, S., Baldwin, D. A., & Crowson, M. (1997). Do children with autism use the speaker's direction of gaze strategy to crack the code of language? Child Development, 68(1), 48–57.

Bavin, E. L., & Baker, E. K. (2017). Sentence processing in young children with ASD. In L.R. Naigles (Ed.), Innovative investigations of language in autism spectrum disorder (pp. 35–47). Washington, DC: American Psychological Association.

Bavin, E. L., Kidd, E., Prendergast, L., Baker, E., Dissanayake, C., & Prior, M. (2014). Severity of autism is related to children's language processing. Autism Research, 7 (6), 687–694. https://doi.org/10.1002/aur.1410

Bavin, E. L., Prendergast, L. A., Kidd, E., Baker, E., & Dissanayake, C. (2016). Online processing of sentences containing noun modification in young children with high-functioning autism. International Journal of Language & Communication Disorders, 51(2), 137–147. https://doi.org/10.1111/1460-6984.12191

Candan, A., Kuntay, A. C., Yeh, Y. C., Cheung, H. T., Wagner, L., & Naigles, L. R. (2012). Language and age effects in children's processing of word order. Cognitive Development, 27(3), 205–221. https://doi.org/10.1016/j.cogdev.2011.12.001

Charman, T., Drew, A., Baird, C., & Baird, G. (2003). Measuring early language development in preschool children with autism spectrum disorder using the MacArthur Communicative Development Inventory (Infant Form). Journal of Child Language, 30(1), 213–236. https://doi.org/10.1017/s0305000902005482

IBM Corp. (2017). IBM SPSS statistics for windows (version 25.0). Armonk, NY: IBM Corp.

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., … Reilly, J. S. (1993). The MacArthur communicative development inventories: User's guide and technical manual. San Diego, CA: Singular Publishing Group.

Franck, J., Millotte, S., Posada, A., & Rizzi, L. (2013). Abstract knowledge of word order by 19 months: An eye-tracking study. Applied PsychoLinguistics, 34(2), 323–336. https://doi.org/10.1017/s0142716411000713

Fromkin, V., Rodman, R., & Hyams, N. (2014). An introduction to language. Cengage Lerning: Wadsworth, OH.

Gleitman, L. (1990). Structural sources of verb meaning. Language Acquisition, 1(1), 3–55.

Goodwin, A., Fein, D., & Naigles, L. R. (2012). Comprehension of Wh-questions precedes their production in typical development and autism spectrum disorders. Autism Research, 5(2), 109–123. https://doi.org/10.1002/aur.1220

Guasti, M. T. (2016). Language acquisition: The growth of grammar (2nd ed.). Cambridge, MA: The MIT Press.

Hirsh-Pasek, K. R., & Golinkoff, R. M. (1996). The origins of grammar. Cambridge, MA: MIT Press.

Krug,D. A., Arick, J., & Almond, P. (1980). Behavior checklist for identifying severely handicapped individuals with high levels of autistic behavior. Journal of Child Psychology and Psychiatry, and Allied Disciplines, 21(3), 221-229. https://doi.org/10.1111/j.1469-7610.1980.tb01797.x

Lee, J. N., & Naigles, L. R. (2005). The input to verb learning in Mandarin Chinese: A role for syntactic bootstrapping. Developmental Psychology, 41(3), 529–540. https://doi.org/10.1037/0012-1649.41.3.529

Leivada, E., Kambanaros, M., & Grohmann, K. K. (2017). The locus preservation hypothesis: Shared linguistic profiles across Developmental Disorders and the resilient part of the human language Faculty. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.01765

Lord, C., & Paul, R. (1997). Language and communication in autism. In D. J. Cohen & F. R. Volkmar (Eds.), *Handbook of Autism and Pervasive Developmental Disorders*, 2nd ed. (pp. 195–225). NewYork: Wiley.

Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. Journal of Autism and Developmental Disorders, 20(1), 115–128. https://doi.org/10.1007/bf02206861

Naigles, L. (1990). Children use syntax to learn verb meanings. Journal of Child Language, 17(2), 357–374. https://doi.org/10.1017/s0305000900013817

Naigles, L. R., & Hoff-Ginsberg, E. (1995). Input to verb learning: Evidence for the plausibility of syntactic bootstrapping. Developmental Psychology, 31, 827–837.

Naigles, L. R., Bavin, E. L., & Smith, M. A. (2005). Toddlers recognize verbs in novel situations and sentences. Developmental Science, 8 (5), 424-431. https://doi.org/10.1111/j.1467-7687.2005.00431.x

Naigles, L. R., Kelty, E., Jaffery, R., & Fein, D. (2011). Abstractness and continuity in the syntactic development of young children with autism. Autism Research, 4(6), 422–437. https://doi.org/10.1002/aur.223

Naigles, L. R., & Chin, I. (2015). Language development in children with autism. In E. Bavin & L. R. Naigles (Eds.), Cambridge handbook of child language, 2nd (pp. 637–658). Cambridge: Cambridge University Press.

Naigles, L. R., & Fein, D. (2017). Looking through their eyes: Tracking early language comprehension in ASD. In L. R. Naigles (Ed.), Innovative investigations of language in autism spectrum disorder (pp. 49–69). Washington, DC: American Psychological Association.

Naigles, L. R., & Tovar, A. T. (2012). Portable Intermodal Preferential Looking (IPL): Investigating language comprehension in typically developing toddlers and young children with autism. Journal of Visualized Experiments, (70), e4331. https://doi.org/10.3791/4331

Paul, R., Fischer, M. L., & Cohen, D. J. (1988). Sentence comprehension strategies in children with autism and specific language disorders. Journal of Autism and Developmental Disorders, 18(4), 669–679. https://doi.org/10.1007/bf02211884

Su, Y. (. E.)., Naigles, L. R., & Su, L.-Y. (2018). Uneven expressive language development in Mandarin-exposed preschool children with ASD: Comparing vocabulary, grammar, and the decontextualized use of language via the PCDI-toddler form. Journal of Autism and Developmental Disorders, 48(10), 3432–3448. https://doi.org/10.1007/s10803-018-3614-x

Su, Y. (. E.)., & Su, L.-Y. (2015). Interpretation of logical words in Mandarin-speaking children with autism spectrum disorders: Uncovering knowledge of semantics and pragmatics. Journal of Autism and Developmental Disorders, 45(7), 1938–1950. https://doi.org/10.1007/s10803-014-2350-0

Sun, X., Allison, C., Matthews, F. E., Sharp, S. J., Auyeung, B., Baron-Cohen, S., & Brayne, C. (2013). Prevalence of autism in mainland China, Hong Kong and Taiwan: A systematic review and meta-analysis. Molecular Autism, 4(1), 7. https://doi.org/10.1186/2040-2392-4-7

Swensen, L. D., Kelley, E., Fein, D., & Naigles, L. R. (2007). Processes of language acquisition in children with autism: Evidence from preferential looking. Child Development, 78(2), 542–557. https://doi.org/10.1111/j.1467-8624.2007.01022.x

Tager-Flusberg, H. (1981). Sentence comprehension in autistic children. Applied PsychoLinguistics, 2, 5–24.

Tager-Flusberg, H. (1994). Dissociations in form and function in the acquisition of language by autistic children. In H. Tager-Flusberg (Ed.), Constraints on language acquisition: Studies of atypical children (pp. 175–194). Hillsdale, NJ: Erlbaum.

Tager-Flusberg, H. (1997). Language and Understanding Minds: Connections in Autism. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding other minds: Perspectives from autism and developmental cognitive neuroscience* (2nd ed.). Oxford: Oxford University Press.

Tager-Flusberg, H. (2001). Understanding the language and communicative impairments in autism. International Review of Research in Mental Retardation, 23(23), 185–205.

Tardif, T., Fletcher, P., Zhang, Z., & Liang, W. (2008). The Chinese communicative development inventory (Putonghua and Cantonese versions): Manual, forms, and norms. Beijing, China: Peking University Medical Press.

Tek, S., Mesite, L., Fein, D., & Naigles, L. (2014). Longitudinal analyses of expressive language development reveal two distinct language profiles among young children with autism spectrum disorders. Journal of Autism and Developmental Disorders, 44 (1), 75-89. https://doi.org/10.1007/s10803-013-1853-4

Tovar, A. T., Fein, D., & Naigles, L. R. (2015). Grammatical aspect is a strength in the language comprehension of young children with autism spectrum disorder. Journal of Speech Language and Hearing Research, 58(2), 301–310. https://doi.org/10.1044/2014_jslhr-l-13-0257

Yang, X., Huang, Y., Jia, M., & Chen, S. (1993). Clinical application of autism behavior checklist. Chinese Mental Health Journal, 7(6), 279–280.

Zhou, P., Crain, S., Gao, L., & Jia, M. (2017). The Use of linguistic cues in sentence comprehension by Mandarin-speaking children with high-functioning autism. Journal of Autism and Developmental Disorders, 47(1), 17–32. https://doi.org/10.1007/s10803-016-2912-4

Zhou, P., Ma, W., Zhan, L., & Ma, H. (2018). Using the visual world paradigm to study sentence comprehension in Mandarin-speaking children with autism. Journal of Visualized Experiments, (140), e58452. https://doi.org/10.3791/58452

Zhou, P., Zhan, L. K., & Ma, H. M. (2019). Predictive language processing in preschool children with autism spectrum disorder: An eye-tracking study. Journal of Psycholinguistic Research, 48(2), 431–452. https://doi.org/10.1007/s10936-018-9612-5

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting Information S1.
Supporting Information S2.
Supporting Information Table S1. Gender-balanced data set of both diagnostic groups.
Supporting Information Table S2. Subset data of 12 Mandarin-exposed children with ASD.