Published in final edited form as:
Clin Linguist Phon. 2020 December 01; 34(12): 1088–1111. doi:10.1080/02699206.2020.1719208.

Grammatical Judgment and Production in Male Participants with Idiopathic Autism Spectrum Disorder

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Abstract

This study examined grammatical judgment and production in 22 male participants with idiopathic autism spectrum disorder (ASD) who had a range of nonverbal IQ from 44 – 111 (mean = 72.23), and were between 9.42 to 16.75 years of age (mean = 13.45). Relationships between grammatical judgment and production and nonverbal IQ were examined.

Participants completed the Test of Early Grammatical Impairment (TEGI; Rice & Wexler, 2001) to describe relative strengths and weaknesses in their ability to judge and produce grammatical tense. Participants also completed the Leiter-R (Roid & Miller, 1997) to assess the relationship between nonverbal IQ and grammatical judgment and production. Relative strengths were found across participants in judging correct use of subject-verb agreement in sentences, and correctly producing verbs that linked sentences (e.g., auxiliaries and copulas of *be* "*Is* she resting?"). Participants had the greatest difficulty judging the correctness of a sentence using a dropped verb tense marker (e.g. "He *look* happy now"), and producing irregular verb tense markers. Nonverbal IQ did not contribute to the variance in performance on any tasks of grammaticality judgment or production. Grammatical markers that mark tense in past tense verbs as well as the production of auxiliary *do* may be an important focus of language intervention for boys with ASD.

Keywords

autism spectrum disorder; vocabulary; grammar; language comprehension; language production; intellectual disability

Research to date suggests there may be a number of reasons that grammatical development is impacted in some children with autism spectrum disorder (ASD). In a review of the literature examining characteristics and causes of differences in grammatical skills in children with ASD, Boucher (2012) suggests reasons range from ASD symptom severity, joint attention, nonverbal IQ, and cognitive skills such as weak central coherence, enhanced perceptual processing, and difficulties with semantic memory. In children with ASD who use at least word combinations (Tager-Flusberg et al., 2009), it is unclear if there are specific grammar structures that are areas of weakness, and in turn, contribute to communication

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Statement of Interest
The authoras report no conflicts of interest.

difficulties, and if this ability is related to childrens' nonverbal IQ. Attempts to understand language ability in older children with ASD have often only used measures of expressive language as an index of grammar, without defining more specifically the use of grammatical morphemes that could identify areas of grammatical strength and weakness with greater precision (Kjelgaard & Tager-Flusberg, 2001; Roberts, Rice, & Tager-Flusberg, 2004; Tager-Flusberg & Joseph, 2003). Furthermore, few studies with children with ASD have included measures of both grammatical judgment and production. Grammatical judgment tasks are designed to assess specific knowledge of grammatical rules (Ambridge, Bannard, & Jackson, 2015; Eigsti & Bennetto, 2009). This study will describe relative strengths and weaknesses in grammatical judgment and production skills found in children with ASD, and identify the relationship between these skills and nonverbal IQ. Describing relative strengths and weaknesses in grammatical skill will reveal specific grammatical forms that children with ASD are more likely to have difficulty with, identify if this difficulty may be due to nonverbal IQ, and provide clinicians with areas of intervention that support language development.

One aspect of grammar that has been studied in ASD includes grammatical tense markers, which overtly mark verb tense and agreement, and include past tense (e.g., "she walk*ed* to the store"; "she *ran* to the store"), third person singular present tense (e.g., "a baker bake*s* bread"), auxiliaries and copulas of *be* (e.g., "*Is* she hungry?") and auxiliaries of *do* (e.g., "*Does* he like bread?"). Children without ASD who have developmental language disorder (DLD) have impairments in grammatical production, specifically in grammatical tense markers, and thus this has been a focus of the literature describing language profiles of children with a specific subtype of DLD, specific language impairment (SLI; Rice, Tomblin, Hoffman, Richman, & Marquis, 2004; Rice, Wexler, & Redmond, 1999). Children with SLI have a particular weakness in producing grammatical tense markers, despite having nonverbal IQ scores within normal limits (Rice et al., 2004). Children with SLI have been suggested to be in an extended optional infinitive (EOI) stage of development, where they accept as correct sentences that drop third person singular *-s*, regular past tense *-ed*, and free-standing morphemes of *be* and *do*, while omitting these grammatical forms in production (Rice et al., 1999). Parallels have been made between children with SLI and ASD, suggesting that children with ASD often also have areas of relative strength and weakness (Roberts, Rice & Tager-Flusberg, 2004). Others have found that children with ASD often have difficutly with language across domains of phonology, vocabulary and pragmatics, with grammar relatively spared (Ambridge et al., 2015; Rapin & Dunn, 2003). The literature to date reports mixed findings regarding the extent to which grammar is impaired relative to nonverbal IQ in individuals with ASD, with some studies suggesting it is spared relative to nonverbal IQ, and others suggesting that it is not (Ambridge et al., 2015; Eigsti & Bennetto, 2009; Eigsti, Bennetto, & Dadlani, 2007; Tager-Flusberg & Joseph, 2003). Examining grammatical skills in children with ASD with nonverbal IQ ranging from below to above average, can provide greater characterization of language ability in ASD, and the relative impact of nonverbal IQ on grammatical ability.

The Relationship Between Language and Nonverbal IQ in ASD

Approximately 20 – 50% of children with ASD have a co-occurring intellectual disability (Christensen et al., 2016). Notably, children with ASD who have nonverbal IQ ranging from below to above average have language skills that are not necessarily correlated with their nonverbal IQ (Ellis Weismer, Lord, & Esler, 2010; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg & Joseph, 2003). Ellis Weismer et al., (2010) found that toddlers with ASD showed greater language production than comprehension skills. When these skills were compared to nonverbal cognitive ability as measured by the nonverbal subscales of Mullen Scales of Early Learning (Mullen, 1995), toddlers with ASD had greater nonverbal cognitive ability than receptive or expressive language relative to their age. Kjelgaard and Tager-Flusberg (2001) found variability between nonverbal IQ (Differential Abilities Scales; Elliot, 1990) and language, among 89 children 4 – 14 years of age with ASD. When looking at language skills as measured by the Clinical Evaluation of Language Fundamentals (CELF; Semel, Wiig, & Secord, 1995; Wiig, Secord, & Semel, 1992) the authors found that some children with low nonverbal IQs had language skills in the normal range, while others with nonverbal IQs in the normal range had impaired language skills. The relationship between nonverbal IQ and language skills in individuals with ASD therefore is a critical relationship that is not necessarily a linear one, and warrants further examination. We have chosen to examine the relationship between nonverbal IQ and grammatical skill in the current study to understand if this relationship is an important contributor to grammatical language skills in children with ASD. In reviewing the literature we found nonverbal IQ has not been a consistent measure used. We have specified when an alternate measure of cognitive ability was used.

Thurm and colleagues (2007) examined the relationship between language and nonverbal cognitive ability as assessed by either the Differential Abilities Scale Nonverbal composite (DAS; Elliot, 1990) or Mullen Scales of Early Learning's nonverbal subscales (Mullen; Mullen, 1995). They found that in children with ASD, nonverbal cognitive skills at age 3 did not predict expressive language at age 5 as assessed by the Vineland Adaptive Behavior Scales (VABS; Sparrow, Bala, & Cicchetti, 1984). Expressive language skills at age 3 however, were a stronger predictor of language comprehension at age 5 than nonverbal cognitive ability. Participants were all children with DAS or Mullen scores below 70 and had either a diagnosis of ASD ($n = 59$), PDD-NOS ($n = 24$), or a non-spectrum developmental delay ($n = 35$). This study also found that children who had better joint attention as reported on the VABS had better language comprehension regardless of their DAS or Mullen score, indicating intrinsic variables other than cognitive abilities were key in explaining the variance in language comprehension. Both Kjelgaard and Tager-Flusberg (2001) and Ellis Weismer et al., (2010) suggested that language skills can be independent of nonverbal IQ in ASD, and these language skills are critical in understanding functional communication ability.

Eigsti et al., (2007) found a unique profile of grammatical delay in children with ASD that was not related to nonverbal IQ as assessed by the short form of the Stanford-Binet Intelligence Scale- Fourth edition nonverbal reasoning factor (SB-IV; Thorndike, Hagen, & Sattler, 1986). Participants included children with ASD between 3 – 6 years of age (mean nonverbal IQ = 80), children with non-specific developmental delays matched on nonverbal IQ, and a group of typically developing children matched on mental age. They found that children with ASD produced grammatically less complex utterances during free play than the comparison groups. They did not find errors in grammar production, but instead found that the children used fewer verb phrases, noun phrases, and questions overall, suggesting delayed development of grammar that was not correlated with nonverbal IQ. These findings may be an effect of the observational context, such that children with ASD may have been more likely to talk about the present rather than more complex events temporally removed from the free play activity. Contexts that require children to judge or use sentences composed of more complex discourse are needed to determine if these findings remain throughout development in children with ASD.

Studies in ASD have found atypical patterns between vocabulary development and nonverbal IQ.Prior research has identified a subset of children with ASD with lower vocabulary comprehension compared to vocabulary production.This delay in comprehension was lower than expected relative to children’s nonverbal IQ (Haebig & Sterling, 2017; Kover, McDuffie, Hagerman, & Abbeduto, 2013). Notably, this difference in vocabulary comprehension and production is not evident across all children, and has not been found to be a consistent marker of ASD (Jarrold, Boucher, & Russell, 1997; Kjelgaard & Tager-Flusberg, 2001) (Kwok, Brown, Smyth, & Oram Cardy, 2015). Haebig and Sterling (2017) found that there was not a significant relationship between nonverbal IQ and vocabulary production, suggesting that abilities other than nonverbal IQ may drive spoken vocabulary development. Vocabulary and grammar, according to the declarative/procedural model of language suggests that vocabulary or lexical knowledge is stored in declarative memory, different from grammatical knowledge which is stored in procedural memory (Ullman, 2001). It is unclear if this relationship between vocabulary and nonverbal IQ found in children with ASD extends to grammar.

Grammar development in ASD

The declarative/procedural model (Ullman, 2001) provides a neurocognitive perspective on language development suggesting that children use a dual-system of language learning, with lexical (i.e., semantic) and grammatical information stored separately. This dual-system theory suggests that children use declarative memory to process semantic information regarding language, and procedural memory for grammatical knowledge, or the rules governing how words are combined to produce sentences. In contrast, single-system theories suggest that grammatical development is accomplished by a single system that is reliant upon the processing of both semantic meaning and syntactic structure through experience with language input (Bruner, 1991; MacDonald, Pearlmutter, & Seidenberg, 1994). Children with ASD present with unique strengths and areas of difficulty with language development across areas of vocabulary knowledge, grammatical knowledge, and pragmatic use. Exploring grammatical development in children with ASD provides evidence of relative strengths and/or weakness in grammar, that when compared to vocabulary knowledge, may further evidence if children with ASD may be using a dual versus single system framework for language.

In support of the single-system theory of language development, Rollins and Snow (1998) found that joint attention skills predicted the rate per month of grammatical growth in very young children with ASD between the ages of 1 and 3 years. Rispoli, Hadley, and Holt (2012) describe the Gradual Morphosyntactic Learning Account (GML), suggesting that learning of tense and agreement for sentence production is inherently gradual, and influenced by input the child hears, and experience with production. A central component of the GML is that comprehension does not equal production, and that children demonstrate sensitivity to tense and agreement morphemes before they are able to produce them. In a longitudinal study with twenty typically developing children between 21 to 33 months of age, Rispoli and colleagues found that the copula *be* was produced before other morphemes, and auxiliary *be* was the slowest to be produced. Third person singular, past tense *–ed*, and auxiliary *do* increased at the same rate. There are few studies however, that have used assessment measures specifically aimed at understanding grammatical development in children with ASD at older ages (Ambridge et al., 2015; Eigsti & Bennetto, 2009; Eigsti et al., 2007; Roberts et al., 2004; Sterling, 2018). Roberts and colleagues (2004) examined productive use of third person singular, regular, and irregular past tense in 62 children with ASD between 5 – 15 years of age with a range of nonverbal IQ (43-153). Production of regular and irregular past tense was found to be a consistent area of difficulty. Children with ASD and language impairment had difficulty with tasks of third person singular *-s* and past tense *–ed,* with additional unique error patterns found across the group that reflected difficulty with pragmatic use of language, rather than grammatical form. For example, children responded with verb forms that were not elicited, or were semantically inappropriate, yet grammatically correct. Performance on tasks of past tense was correlated with their nonverbal IQ, although this was not true for third person singular, perhaps because overall, children with ASD with both low and high nonverbal IQs had greater percentage correct responses to third person singular probes. The current study extended this work by assessing additional components of grammar production including irregular finite verbs, copulas and auxiliaries of *be* and auxiliaries of *do*, and included a comparison to grammatical judgment in a group of children with a range of nonverbal IQ.

Grammatical Judgment

Grammatical judgment tasks have been used to evaluate knowledge of grammar structure in children with language disorders. Children are asked to evaluate and make judgments on grammatical and ungrammatical sentences (e.g., “The bear is jump.” vs “The bear is jumping.”). Rice et al. (1999) developed a grammaticality judgment task based on verb tense markers, to assess whether children with language impairment who use incorrect productions involving tense markers, also judge these incorrect productions as correct in order to test the EOI theory (Rice, Wexler, & Cleave, 1995). The grammaticality judgment tasks included sentences with and without dropped verb tense markers such as “he eat toast” and “he behind the box”. Other items included in this task assessed children’s judgment of subject-verb agreement such as “I likes toast” and the obligatory use of progressive –ing such as “he is cough”. These items of subject-verb agreement and progressive -ing served as a comparison to the items including dropped markers to determine if children’s grammatical errors in production were due to the child being in an EOI period of grammatical development, or if they were due to an underlying difficulty related to subject-verb agreement. Children with SLI accepted errors of dropped markers in the grammaticality judgment task that they were likely to produce, and correctly identified errors that they were unlikely to produce (Rice et al., 1999). This work led to the development of the Test of Early Grammatical Impairment (TEGI; Rice & Wexler, 2001) used in the current study.

In grammatical judgement tasks, children must be able to reflect on a statement and make a determination regarding the correctness of the sentence rather than show comprehension of the semantic content alone. Grammaticality judgment tasks are often difficult for children younger than 4 years of age because they are still developing the ability to make a yes/no decision about the correctness of a sentence (Rice & Wexler, 2001). Grammaticality judgment tasks require reasoning skills, therefore performance on judgment tasks may be expected to interact not only with a child's language knowledge, but to some degree with a child's nonverbal IQ. Poor performance across all tasks of grammaticality judgment, when relative strengths are found in grammatical production may be suggestive of a meta-cognitive difficulty rather than a grammatical weakness (Rice & Wexler, 2001; Rice et al., 1999).

Grammaticality Judgment in children with ASD.

Eigsti and Bennetto (2009) examined several grammatical structures in a grammaticality judgment task with 21 children with ASD between the ages of 9 to 16 years. It is important to note that in this study, none of the participants with ASD had a co-occurring intellectual disability(IQ scores:91 – 138). Performance was compared to a group of peers with typical development matched for age, full scale IQ, and vocabulary. Results identified a set of problematic grammatical markers that included tense marking, particle movement, and auxiliaries, including specific difficulties with third person singular and present progressive tense. While no participants in this study had intellectual disability, performance on grammaticality judgment tasks was associated with verbal IQ, but not performance IQ (e.g., tasks assessing more global cognitive ability without a verbal requirement). Therefore, the authors suggested that grammaticality judgment was more closely linked with linguistic rather than cognitive skills in participants without intellectual disability, and that core ASD symptoms additionally compounded linguistic development. Findings from Eigsti and Bennetto (2009) suggest that adolescents with ASD have difficulty with subtle grammatical rules in spite of normative performance on standardized language assessments. Links between grammatical judgment and production were not examined however, nor was grammatical skill in children with ASD and intellectual disability. Examining performance on grammatical judgment tasks in children with ASD and intellectual disability across a similar age rangecan provide evidence regarding the role of nonverbal IQ in grammar development, and facilitate important discussions regarding the role of nonverbal IQ versus core features of ASD as Boucher (2012) identified (joint attention, weak central coherence, enhanced perceptual processing, difficulty with semantic memory) in the development of grammatical skills.

More recently, Ambridge et al., (2015) used a grammaticality judgment task with 16 children with ASD aged 11 – 13 who had a range from mild to no intellectual disability, based on the Wechsler intelligence scale for children- 4th edition (WISC-IV; Wechsler, 2004) Ambridge and colleagues focused on one type of syntactic error involving intransitive-only verbs such as *fell.* Sentences were presented in correct and incorrect transitive-causative form to children (e.g. "The cup fell off the shelf" vs "Lisa fell the cup off the shelf"). A subtle impairment in children with ASD was found such that they accepted incorrect sentences as correct compared to typically developing peers matched on full scale IQ. Notably, only children with mild to no intellectual disability participated in the study, and the authors suggested that future studies examine this relationship in children with ASD with intellectual disability. Examining additional grammatical structures of tense markers, use of verbs that mark agreement with the subject, and verbs that mark progressive -ing as Rice et al. (1999) did, would allow for greater understanding of specific grammatical forms that children with ASD have difficulty judging as correct, and if these are similar forms that are difficult in production.

By specifically examining the role of tense markers within judgment tasks, we can understand if there are relative strengths in knowledge about the rule structure of language compared to their production skills. Few studies have explored performance on grammatical judgment tasks in children with ASD who include children with below to above average nonverbal IQ. Naigles and Tek (2017) discussed this lack of research in children with ASD, and noted the need for studies that explore in depth grammatical knowledge in children with intellectual disability. The current small scale study is an initial attempt to characterize, in participants with ASD both with and without intellectual disability, their knowledge about the rule structure of grammatical morphemes, and grammar production skill with a focus on tense marking.

Current Study

The present study is an extension of Haebig and Sterling (2017) to examine the relationship between knowledge of grammatical structure as measured by a grammatical judgment task, and grammar production, with a particular focus on tense markers given the difficulty noted in children with ASD in prior research (Roberts et al., 2004). Additionally, this study aimed to understand if participants' grammatical skill in judgment or production was related to their nonverbal IQ. Exploring these questions within a group of participants with ASD with similar ASD symptom severity, while allowing nonverbal IQ to vary allowed for the characterization of the role of nonverbal IQ in the judgment and production of grammar structures, and allowed for examination of the relationship between performance on grammatical judgment tasks and production of similar grammar structures. Twenty-two boys with ASD with nonverbal IQ ranging from 44 – 111 and between 9 -16 years of age participated. We had three specific aims:

1) To understand if boys with ASD have relative strengths and weaknesses in judging the grammaticality of tense in sentences, and in producing grammatical tense markers.

Given the prior work of Roberts and colleagues (2004), we hypothesized that participants would have the most difficulty judging and producing sentences involving past tense. Participants were expected to have difficulty judging the correctness of subject-verb agreement, and difficulty using questions containing copulas and auxiliaries of *be* and *do* given prior research by Eigsti and colleagues (2007).

2) To describe the relationship between grammaticality judgment and grammar production, and nonverbal IQ in boys with ASD.

Given the previous literature (Kjelgaard & Tager-Flusberg, 2001; Sterling, 2018), we hypothesized that nonverbal IQ would be negatively correlated with grammatical judgment and production, given that children with high nonverbal IQ are expected to have difficulty with grammatical forms related to verb tense (Roberts et al., 2004).

3) To understand if nonverbal IQ accounts for unique variance in the ability to judge the grammaticality of sentences, and produce grammatical tense markers in boys with ASD.

We hypothesized that nonverbal IQ would not account for unique variance in the judgment and productive use of tense markers by participants in this study given that nonverbal IQ was not found to predict language ability in the work of Kjelgaard and Tager-Flusberg (2001).

Method

Participants

Participants were part of a larger study investigating language development in fragile X syndrome (FXS) and idiopathic ASD (Haebig & Sterling, 2017; Haebig, Sterling, & Hoover, 2016; Sterling, 2018). Children with idiopathic ASD met diagnostic criteria for ASD with no known syndromic cause. A total of 22 boys with idiopathic ASD were included in the current study. The larger study controlled for sex as a biological variable in FXS and ASD and recruited only boys because of the significant gender differences in FXS.

Participants ranged in age from 9.42 to 16.75 years (M = 13.45, SD = 1.90). Participants were included if they used multi-word combinations as their primary means of communication. Average mean length of utterance in morphemes (MLUm) for participants was 5.28 (SD = 1.94). FXS and other genetic disorders as a cause of ASD were ruled out through prior molecular genetic testing. Participants had a diagnosis of ASD from a community service provider and were given the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 1999; Lord, Rutter, DiLavore, Risi, & Gotham, 2012) as part of this study to determine ASD symptom severity. All participants spoke only English, and had hearing within normal limits as determined by parent report. Per parent report, 19 participants were white, two were multiracial, and one reported as other. One participant identified as Hispanic or Latino. Table 1 reports participant means, standard deviations and medians for chronological age, ASD symptom severity, brief nonverbal IQ as assessed by the Leiter-R (Roid & Miller, 1997), and receptive and expressive vocabulary.

Procedure

The entire assessment battery took place over the course of a day. Participants were continuously monitored by examiners for level of engagement, and parents observed all sessions to communicate the need for breaks as necessary to support their child’s engagement. Participants were provided adequate time for lunch and other breaks as needed. Participants were seen in a research laboratory setting that was quiet and free from distraction. The university institutional review board approved this study. Parents provided written informed consent, and participants provided assent. The order of assessment measures was kept consistent across all participants.

Assessment of ASD Severity

Each participant was assessed using the ADOS (Lord et al., 1999, 2012). The examiner was either research reliable or being trained for research reliability per the ADOS conventions with a research reliable coder present for live coding. The ADOS consists of a series of semi-structured activities to elicit social interaction and communication. There are four modules in the ADOS, and selection is based on the participant's language production ability. Five participants completed module two and 17 participants completed module three.

Cognitive and Language Assessments

Nonverbal IQ.—The Leiter-R (Roid & Miller, 1997) was used to assess nonverbal IQ. Subtests of Figure Ground, Form Completion, Sequential Order, and Repeated Patterns were administered in order to calculate a Brief IQ composite.

Conversation language sample.—In order to collect descriptive information about participant MLUm, each participant completed a video and audio recorded 10-minute conversation language sample based on techniques used by Berry-Kravis et al. (2013). A trained examiner used a standard set of open ended questions about interests including school, family, vacation, pets, and sports, and minimized the use of yes/no questions. Research assistants trained in the Systematic Analysis of Language Transcript (SALT) software (Miller & Iglesias, 2012) transcribed all language samples into communication units (C-units). C-units break utterances into main clauses that can stand by themselves, but leave utterances that consist of subordinate clauses with the main clause together, resulting in a higher MLUm for participants who used more complex sentence structures (Miller & Iglesias, 2012). C-units therefore are appropriate when evaluating language samples of children with more complex language because they are a more accurate measure of language ability for children who have skills beyond that of 3 years of age (Abbeduto, Benson, Short, & Dolish, 1995). MLUm is commonly used as a comparison variable in both the literature on developmental language disorders and neurodevelopmental disorders (Channell, Loveall, Conners, Harvey, & Abbeduto, 2018; Haebig et al., 2016; Rice, Smolik, Perpich, Thompson, & Blossom, 2010; Sterling, 2018; Tager-Flusberg & Anderson, 1991).

Vocabulary.—The Peabody Picture Vocabulary Test-4th edition (PPVT-4; Dunn & Dunn, 2007) and the Expressive Vocabulary Test- 2nd edition (EVT-2; Williams, 2007) were used to assess vocabulary comprehension and production. Mean standard scores and age equivalents are reported in Table 1 to contextualize participants' lexical abilities.

Grammar.—The Test of Early Grammatical Impairment (TEGI; Rice & Wexler, 2001) was used to systematically examine participants' grammatical judgment and production skills. The TEGI has been used in a number of prior studies examining grammatical skill in clinical populations of children with language impairment, ASD, and FXS (Haebig et al., 2016; Rice, Tomblin, Hoffman, Richman, & Marquis, 2004; Sterling, 2018; Sterling, Rice, & Warren, 2012). Participants first completed the phonological probe to confirm they were able to produce word final phonemes /s/, /z/, /t/, and /d/ in production subtests for third person singular and past tense grammatical forms (e.g., painte*d*). All participants were able to produce all final consonant phonemes.

Grammaticality Judgment.: The TEGI grammaticality judgment probe included 10 training items and 35 test items assessing whether or not a verb tense marker could be omitted at the end of a verb (Grammaticality Judgment tense; e.g., "He *eat* hamburger"), if it was ungrammatical to use a verb tense that did not agree with number marking on the subject (Grammaticality Judgment agreement; e.g. "He *are* mad"), and whether or not it was ungrammatical to drop the progressive –ing marker (Grammaticality Judgment –ing; e.g., "He is *cry*") within sentences. Participants were told they were going to play a listening game with two robots who sometimes spoke sentences that were not quite right. The examiner spoke for the robot a sentence that was either grammatically correct (e.g., "I found two bears") or incorrect (e.g., "These are two fork"). The participant was instructed to tell the examiner if the sentence was "good" or "not so good". All 35 test items were administered. The TEGI used A' (A prime) values to determine scores of percent correct for each set of items assessing accurate judgment of dropped tense markers, subject verb agreement, or progressive –ing. A' values represented scores of percent correct and are an adjusted measure of sensitivity that allowed for the consideration that children were more likely to say "yes" than "no" to an item they were asked to judge. A' can be interpreted as the proportion of correct responses given if the child was presented with a choice between two sentences, one grammatical and one not (Rice et al., 1999).

Grammar Production.: The TEGI also assessed children's spoken production of sentences containing third person singular (e.g., "a painter *paints*"), past tense regular, irregular and irregular finite forms (e.g., "he *painted*" vs "he *ate"* vs "he *eated"*), copulas and auxiliaries of *be* (e.g., "*Is* she thirsty?") and auxiliaries of *do* (e.g., "*Does* she like milk?") in an obligatory context. The subtest for third person singular used a picture elicitation task with one practice item and 10 test items. Past tense regular, irregular, and irregular finite forms were also elicited using a picture elicitation task consisting of two practice items and 18 test items. Copulas and auxiliaries of *be* and auxiliaries of *do* were elicited using a puppet-play task where the child directed his attention to a puppet engaged in a script of activities that the child was asked to make statements or questions about. This subtest consisted of one practice item and 36 test items. Scores were computed for each subtest based on the TEGI manual. A probe score for each subtest of grammar production was derived that represented the percent correct of attempted items within each subtest that were scoreable. In order to be considered scorable, the response had to occur in an obligatory context. An item was considered unscoreable if the participant used a verb form or tense other than the target verb tense being elicited. An item was considered unscoreable even if a participant used a grammatically correct sentence, but did not include an overt tense marker. For example, on the third person singular probe, when asked what a painter does, a correct response would be "he paint*s*", or "he get*s* yellow out". An incorrect response would be "he paint a house", and an unscoreable response would be "she's painting". When evaluating production of past tense, probe scores were divided between subtests assessing production of regular verbs, irregular verbs, and irregular finite verbs where a finite past tense marker was used (overregularization e.g., "catch*ed"*).

Reliability.—All TEGI grammaticality judgment probe scores were scored during the assessment task, and the examiner verified scores from the audio-recording. A second independent rater reviewed the accuracy of scoring. Any discrepancies were noted by the second rater, and consensus was determined with the initial examiner. For the grammar production subtest, 30% were scored by an independent rater for reliability. Percent agreement was calculated for scoring items as unscoreable, correct, or incorrect. Scoring agreement for the subtest assessing production of auxiliaries and copulas of *be* and *do* was 94%. Scoring agreement for the subtests assessing production of third person singular and past tense was 100%.

Data Analysis

Aim 1) Grammatical judgment and production—To identify relative strengths and weaknesses in judgment and production, boxplots were examined to note the distribution of performanceusing A' scores for grammaticality judgment and probe scores for grammar production. Grammaticality judgment A' scores and grammar production probe scores were next used in a repeated measures analysis of variance (ANOVA) to determine if there were significant differences in performance between judgment and production subtests. Effect sizes were noted following guidelines from (Cohen, 1988) such that a partial eta squared (η^2) of 0.01 = small effect, 0.06 = medium effect, 0.14 = large effect. There were outliers in the data as assessed by boxplots and Shapiro-Wilk tests ($p < .050$). The assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, χ^2 (27) = 0.02, ($p = .000$) therefore, a Greenhouse-Geisser correction was applied ($\varepsilon = 0.54$). Post-hoc analyses with an alpha set at $p = .050$ were done to evaluate differences between each subtest.

Aim 2) Relationship between grammaticality judgment, production, and nonverbal IQ—Spearman correlations were completed to examine the relationship between grammaticality judgment, production, and nonverbal IQ. Nonparametric Spearman correlations were determined to be appropriate after visual inspection of the data indicated the data was not normally distributed. A' scores were used on subtests of grammatical judgment, and probe scores were used to represent grammar production. Nonverbal brief IQ composite standard scores from the Leiter-R were used. Spearman correlation coefficients between .10 - .30 were considered small, .30 - .50 medium, and coefficients greater than .50 were considered large (Cohen, 1988).

Aim 3) Does nonverbal IQ account for variance in grammatical judgment and production?—Two separate hierarchical linear regressions controlling for age were done for the combined subtests of grammatical judgment and grammar production. Given the broad age range, we controlled for age to account for the variance that may be associated with language development and intervention experience of participants. Chronological age was entered in step 1 and nonverbal IQ standard score was entered in step 2 in each model. In the first model, a total composite A' score was used to represent performance on subtests of grammatical judgment. In the second model, the elicited grammar composite probe score was used to represent performance on subtests of grammar production. There was independence of residuals as assessed by a Durbin-Watson statistic of 1.50 for grammaticality judgment, and 2.02 for grammar production. The data did not violate multicollinearity, with tolerance scores above .10. Although the utility of post-hoc power analysis is debated (Hoenig & Heisey, 2001), a post hoc power analysis was done to examine the power to detect true interaction effects using hierarchical regression analysis. For grammaticality judgment, a sample size of 22, small effect size, alpha level of .460, power was calculated at .62. For grammatical production, a sample size of 22, medium effect size, and an alpha level of .054, power was determined to be .67 (Faul, Erdfelder, Buchner, & Lang, 2009). Regression analyses were judged as sufficient to use with this sample size as have been done with similar sample sizes (Ambridge et al., 2015; Haebig & Sterling, 2017)

Results

Aim 1) Grammatical judgment and production

Table 2 reports means, standard deviations, median values, confidence intervals and age equivalents for each subtest of grammatical judgment and production, along with composite scores for each subtest.

To determine if there were relative strengths and weaknesses in grammatical judgment and production similar to those found in prior work and in other clinical populations of children with developmental language disorders, a one-way within subjects analysis of variance (ANOVA) was done using all nine subtests of the TEGI. Significant differences in performance between subtests were found, $F(3.36, 70.52) = 5.79$, $p = .001$, $\eta^2 = 0.22$. Post hoc comparisons with a Bonferroni adjustment for multiple comparisons revealed that there were differences found within subtests of grammaticality judgment and production. There was a significant difference between participants' ability to judge the correct use of subject verb agreement and dropped verb tense markers, with participants having greater ability to judge the correctness of subject verb agreement (e.g., "I *drinks* milk"; $M = .87$, $p = .031$, 95% CI = −0.149, −0.002) than the correctness of a sentence using a dropped verb tense (e.g. "He *look* happy now"; $M = .80$).

In terms of production, significant differences were found between participants' use of third person singular, and past tense irregular verbs and irregular finite verbs. Participants did significantly better on the subtest eliciting the production of third person singular forms ($M = .97$) than producing past tense irregular verbs ($M = .66$, $p = .011$, 95% CI = −0.573, −0.046) or using past tense irregular finite forms ($M = .84$, $p = .037$, 95% CI = −0.253, −0.004). Participants also performed significantly better when asked to produce copulas and auxiliaries of *be* ($M = .99$) compared to their production of past tense regular ($M = .77$, $p = .037$, 95% CI = 0.007, 0.435), irregular ($M = .66$, $p = .007$, 95% CI = 0.060, 0.603), and irregular finite verbs ($M = .84$, $p = .023$, 95% CI = 0.013, 0.289). There were no significant differences found between performance on any subtest of grammatical judgment and grammatical production. Notably, participants had the greatest difficulty judging the correctness of a sentence using a dropped verb tense marker (e.g. "He *look* happy now"), and also had difficulty producing verb tense markers. However, they had relative strengths judging subject-verb agreement and correctly producing verbs that linked sentences (e.g., auxiliaries and copulas of *be* "*Is* she resting?").

Aim 2) Relationship between grammaticality judgment, production, and nonverbal IQ

Table 3 reports the results of Spearman correlations between grammatical judgment, production, and nonverbal IQ. All correlations between nonverbal IQ and grammaticality judgment, and nonverbal IQ and grammar production were small and nonsignificant. Medium to large significant correlations were found between subtests of grammaticality judgment of dropped verb tense markers, and grammatical production of past tense, irregular past tense, and irregular past finite verbs. A large significant correlation was found between judgment of subject-verb agreement and production of auxiliaries of *do*.

Aim 3) Does nonverbal IQ account for variance in grammatical judgment and production?

Table 4 reports regression results to determine if the amount of variance in grammatical judgment or production could be accounted for by participants' nonverbal IQ when controlling for age.

Nonverbal IQ did not account for a significant amount of variance in participants' grammatical judgment of sentences or grammar production skills. The final models for grammaticality judgment ($R^2 = 0.04$, $F(2, 19) = 0.39$, $p = 0.684$; adjusted $R^2 = -0.06$), and production ($R^2 = 0.22$, $F(2, 19) = 2.61$, $p = 0.100$; adjusted $R^2 = 0.13$), were not statistically significant.

Scatterplots in Figure 1 show that most participants, regardless of nonverbal IQ had high performance on subtests of grammatical judgment. Figure 2 shows the variability in the relationship between nonverbal IQ and individual subtests of grammatical production. The greatest variability in performance was noted on the production tasks of past tense regular, irregular, and use of irregular finite verb forms.

Discussion

This study evaluated the relationship between the grammaticality judgment and production subtests of the TEGI, as well as the relationship between nonverbal IQ and grammar skills in a group of boys with ASD. Overall, we found consistent patterns regarding strengths and weakness in grammatical structures related to past tense, and regular and irregular verb tense marking across judgment and production tasks. Regarding the role of nonverbal IQ, these results suggest that there is no evidence for an effect of nonverbal IQ on the ability to judge the grammaticality of sentences, or to produce grammar forms in boys with ASD in this study.

Our hypothesis that participants would have the most difficulty with grammatical markers of past tense was supported. However, participants did not have as much difficulty using questions or statements containing copulas and auxiliaries of *be* and *do* as we had expected. Participants had the greatest difficulty judging the correctness of a sentence that dropped a verb tense marker (e.g. "He *look* happy now"), and also had difficulty using verb tense markers, particularly irregular ones. Participants often used irregular past finite markers (e.g., "catched" instead of "caught") instead of the correct irregular verb form. These findings suggest that participants in this study, with a range of nonverbal IQ spanning from 44 – 111 were able to complete metacognitive tasks of grammaticality judgment, and similar to Rice et al., (1999), boys with ASD may largely fall within an extended optional infinitve period of development. Similar to the findings of Rispoli, Hadley and Holt, (2012) however, our participants also had strengths in the use of the copula *be,* with greater difficulty using tense markers. Large, significant correlations between judgment and production tasks further support our findings that these specific tense markers were a pervasive area of weakness for participants. The greater use of irregular past finite markers compared to irregular verbs suggested that participants were developing an understanding of the finiteness marking properties of past tense, and used overregularizations typical of younger children. Our findings are supportive of those found by Eigsti et al., (2007) suggesting delayed development of grammar in boys with ASD in irregular past tense verbs, and also supportive of the Gradual Morphosyntactic Learning Account (Rispoli, Hadley, & Holt, 2012). In agreement with the Gradual Morphosytnactic Learning Account, our findings suggest that as a child's expressions become more diverse and the need to use irregular past tense is required, children with ASD may resort to using higher-frequency morphemes of regular past tense (e.g., *-ed*). These higher-frequency morphemes may become an obstacle to the learning of an irregular tense and agreement system that is less frequent (Rispoli, Hadley, & Holt, 2012). By using these overregularizations, accuracy for marking past tense for boys with ASD in our study increased from 66% correct to 84% correct and provides evidence that participants understood the need to mark past tense, but were still developing the ability to use the appropriate irregular verb form. Alternately, within the framework of a dual-system model of grammatical development such as the declarative/procedural one (Ullman, 2001), boys with ASD at older ages may still be developing the part-whole structure of word forms for irregular verbs, but have an understanding of regular stems and the rule-based system in which they apply. Participants had relative strengths judging subject-verb agreement and progressive *-ing* in sentences and correctly producing verbs that used third person singular and linked sentences.

Grammaticality judgment and relationship to production and NVIQ

The participants in this study had the greatest difficulty judging sentences as incorrect when the sentence contained a dropped tense marker, and this difficulty was not correlated with nonverbal IQ, but was correlated with their production skills. These grammaticality judgment targets frequently left out a progressive tense verb within a sentence or marker on the end of a word (e.g. "He behind the box" and "He eat hamburger"). In many of these sentences, the omitted markers were auxiliary verbs such as "*is"* and progressive endings to verbs that did not provide additional semantic content to the sentence critical to interpreting the meaning at hand. In opposition to the declarative/procedural model, children with ASD may have misjudged these errors as correct since the semantics of the sentence remained relatively intact, supporting theoretical claims that children's language during the development of grammatical rules may be grounded in the semantic meaning underlying the information being expressed (Bruner, 1991; Leonard, 1976; MacDonald et al., 1994).

Participants, regardless of nonverbal IQ, were more likely to accurately identify sentences that contained errors in subject-verb agreement and errors in the use of progressive –ing, suggesting that participants did not perform similarly across all grammatical judgment tasks, and had metacognitive skills to complete these tasks. Additionally, grammatical omissions of subject-verb agreement in these sentences may have been more salient when interpreting the meaning of the sentence, and thus more readily identified as incorrect.

These findings may also support theories of language in children with ASD proposed by Tesink and colleagues (2011). Children with ASD are described as having difficulty with exception handling and mental flexibility needed for language. Tesink and colleagues (2011) suggest that children with ASD may have diffictuly integrating conflicting contextual information during language comprehension. These findings may apply to our current use of grammatical judgment tasks such that, when presented with sentences that were grammatically incorrect, but attempted to state the meaning of what they had just observed in a play scenario, some participants still identified these sentences as correct. This lack of cognitive flexibility with language to reconcile both semantic meaning and grammatical structure may have been difficult, requiring the participant to shift perspectives regarding the semantic nature of the task, and participants more readily interpreted the semantic meaning as correct rather than the syntactic structure as incorrect. Alternately, participants had relative strengths in the production of subject-verb agreement, particularly in the use of copulas and auxiliaries of *be*. Given the ceiling effects found in production of copulas and auxiliaries of *be,* participants' relative strengths overall may have supported their performance on judgment tasks. Production of auxiliaries of *do* was significantly correlated with judgment of subject-verb agreement given that there was greater variability in performance across participants relative to ceiling effects found in production of auxiliaries and copulas of *be*.

Performance on the grammatical judgment tasks was not correlated with nonverbal IQ, nor was their production on any task of grammar production supporting the findings of Ellis Weismer et al., (2010) who also found discrepancies between nonverbal cognitive ability and language skill in a younger group of children. We found that participants had the greatest difficulty on grammar production tasks measuring earlier developing grammatical skills of past tense regular and irregular verb production (e.g., "paint/paint*ed"*), as well as the production of auxiliaries of *do* (e.g., "*Does* she like milk?"). They had the least difficulty in correctly judging the use of progressive tense markers of *–ing* and producing third person singular verbs, and copulas and auxiliaries of *be* regardless of their nonverbal IQ as evidenced by the highest mean scores in these areas across the participants. Greater variability, shown by scatterplots in Figures 1 and 2, was found on grammaticality judgment tasks of dropped tense markers, and production tasks of past tense regular, irregular, and irregular finite verb forms. While this variability did not have a significant linear relationship to nonverbal IQ, visual inspection of the scatterplots showed that there was a greater range of performance in the judgment and production of these grammatical markers for participants with the lowest nonverbal IQ, with the exception of the production of past tense irregular verbs. A range of performance was noted in the production of past tense irregular verbs for participants with lowest and highest nonverbal IQs. Future work with larger sample sizes should examine this trend to see if there is greater variability of grammatical skills found in individuals with ASD with lower nonverbal IQ. Clearly, for some participants with lower nonverbal IQs, these grammatical structures were not impacted, but for others they were. The majority of the participants had strengths in grammatical judgment of progressive *-ing*, the use of third person singular, and copulas and auxiliaries of *be* regardless of nonverbal IQ.

These findings are consistent with those of Roberts et al. (2004), who found that some aspects of tense were particularly difficult for children with ASD, particularly past tense regular and irregular verb forms. According to Brown's stages of morphological development (Brown, 1973), typically developing children are able to produce past tense regular and irregular verbs (e.g., "paint*s*/paint*ed*"; "eat*s/ate*") prior to third person singular verbs. Because participants had difficulty producing past tense verbs, but had relative strengths in production of third person singular and the copula BE, this suggests a specific area of grammatical weakness for past tense for participants with ASD in this study different from children with SLI.

A subset of participants with ASD had difficulty with production of the auxiliary *do* as noted in the scatterplot in Figure 2. In order to receive credit for a correct response on the TEGI for auxiliary *do*, a child was asked to form a question about a specific interest or need of the puppet used during the elicitation task (e.g., "*Does* he want more milk?"). Alternatively, when eliciting productions of copulas and auxiliaries of *be*, the child was directed to ask a question related to an immediate action or need of a puppet (e.g., "*Is* she laughing?"). Participants with ASD had less difficulty producing questions using copulas and auxiliaries of *be,* but some had difficulty producing questions containing auxiliaries of *do.* In order to develop a question using an auxiliary of *do*, participants had to take the perspective of another person/character to grammatically form the sentence, blending aspects of the meaning of the sentence, grammar structure and pragmatics. Given that children with ASD have primary weaknesses in pragmatics, these findings regarding the difficulty of constructing questions using the auxiliary *do* should be further explored within the context of the relationship between pragmatic skill and grammatical development. Findings from Sterling (2018) suggest that boys with ASD may not only have weaknesses in the production of past tense, but additionally in the production of auxiliary *do*. This study did not provide evidence that nonverbal IQ accounted for this difficulty. Recent hypotheses support these findings and suggest that an interaction between language development and specific behavioural symptoms of ASD such as pragmatic and social difficulties are at play (Koegel, Koegel, Green-Hopkins, & Carter Barnes, 2010; Tomblin, 2011). Tomblin (2011) suggested that these factors not only affect the child, but also his/her communication partners to influence language development at the grammatical level.

These findings support the need to look at other correlated aspects of behaviour in children with ASD that may contribute to differences in specific aspects of grammar development beyond explanations of nonverbal IQ. Studies have shown that joint attention and social engagement play a role in early language development at the level of vocabulary learning in children with ASD, and that domains of grammar and pragmatics are closely related (Rollins & Snow, 1998; Kasari, Gulsrud, Freeman, Paparella & Helleman, 2012). Rollins and Snow (1998) found, in children with ASD at the earliest stages of language development (1 – 3 years of age), one source of variation in the amount of monthly change in grammatical skill was children's ability to maintain a joint focus of attention. This relationship warrants continued understanding as children with ASD age, and develop more complex grammar. Additionally, when considering difficulties with theory of mind in children with ASD (Bennet, et al., 2013), when producing language, children with ASD may be more focused on the semantic content of the sentence, and have less regard for adjusting the grammaticality of the sentence to meet their listener's rule based grammatical expectations. With a better understanding of specific components that drive judgment and production of grammar, better intervention targets can be created to develop these language skills in children with ASD.

Clinical Implications

Findings related to grammatical judgment combined with findings from the production task provide important implications for areas of continued language intervention for children and adolescents with ASD. Grammatical markers that mark tense using auxiliaries and copulas as well tense markers used in both regular and irregular verbs may be an important focus of language intervention. Participants had relative strengths correctly producing verbs that linked sentences (e.g., auxiliaries and copulas of *be* "*Is* she resting?"), however they did not see them as necessary in judging the correctness of sentence structure (e.g., "He brown"). Thus, interventions focused on appropriate forms of sentences containing auxiliary verbs, while contrasting them with past tense markers that use irregular verbs (e.g., "He *is* eat*ing*" vs "He *ate*") may be a key area of focus in language instruction for some school age and adolescent boys with ASD.

Limitations and Future Directions

This study provides an initial look at differences in judgment and production of grammar forms as assessed by the TEGI, as well as nonverbal IQ as assessed by the Leiter-R (Roid & Miller, 1997) to understand grammatical variability in boys with ASD. Clearly, there is more work to be done to understand if other intrinsic skills such as ASD symptom severity, joint attention, pragmatic skills, and additional nonverbal cognitive skills not measured in this study are related to grammatical development. Future work should consider using naturalistic measures of grammatical production provided by language samples in addition to standardized tools such as the TEGI. Productivity measures developed by Hadley and Short (2005) could be used to compare to children's grammatical performance on the TEGI to understand differences are found in spontaneous speech. A comparison of spontaneous grammatical skill versus grammatical ability as assessed on the TEGI may provide more insight regarding dual versus single-framework hypothesis for grammatical development in children with ASD. Additionally, extrinsic factors of school instruction and access to intervention may interact with these intrinsic skills to influence grammatical judgment and production skills. One notable limitation is the sample size. Although the sample size is in line with previous published studies on this topic (Eigsti & Bennetto, 2009; Sterling, 2018), it is important to note that a larger sample size would provide less skew in the data, more statistical power, and allow for relationships between related variables beyond nonverbal IQ to be modeled that may explain grammatical performance. Larger sample sizes, along with a longitudinal framework would also provide information regarding developmental trajectories of grammatical development while exploring these additional factors. It also be noted that while confidence intervals do not cross zero, the *p*-value for the effect of nonverbal IQ in the regression model was 0.054, and should be interpreted with caution. Additional work with larger sample sizes that include a range of nonverbal IQ are warranted to support these findings. Additionally, more work needs to be done that is inclusive of girls with ASD to understand if there are similarities or differences compared to boys.

An understanding of the grammatical judgment and production skills of children with idiopathic ASD as done in this study provides important information that advances our understanding of language development in children with ASD. Findings from this study may aid in the development of targets for language intervention that could improve language skills of boys as they develop into adolescence. Importantly, this study provides support that children with ASD and low nonverbal IQ have strengths in grammatical judgment and production. Children's language skills should be systematically evaluated as they develop so that adequate support may continue for language intervention regardless of nonverbal IQ. These grammatical skills become increasingly important not only for functional communication, but also as children with ASD learn to read and comprehend academic information in school.

Acknowledgements

The authors would like to thank the families and children who participated in this study. Research reported in this publication was supported by The National Institute on Deafness and Other Communication Disorders of the National Institutes of Health under Award Number DC011616 to Audra Sterling, the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under Award Number T32HD007489 and U54 HD090256 and start-up funds from the University of Wisconsin-Madison. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

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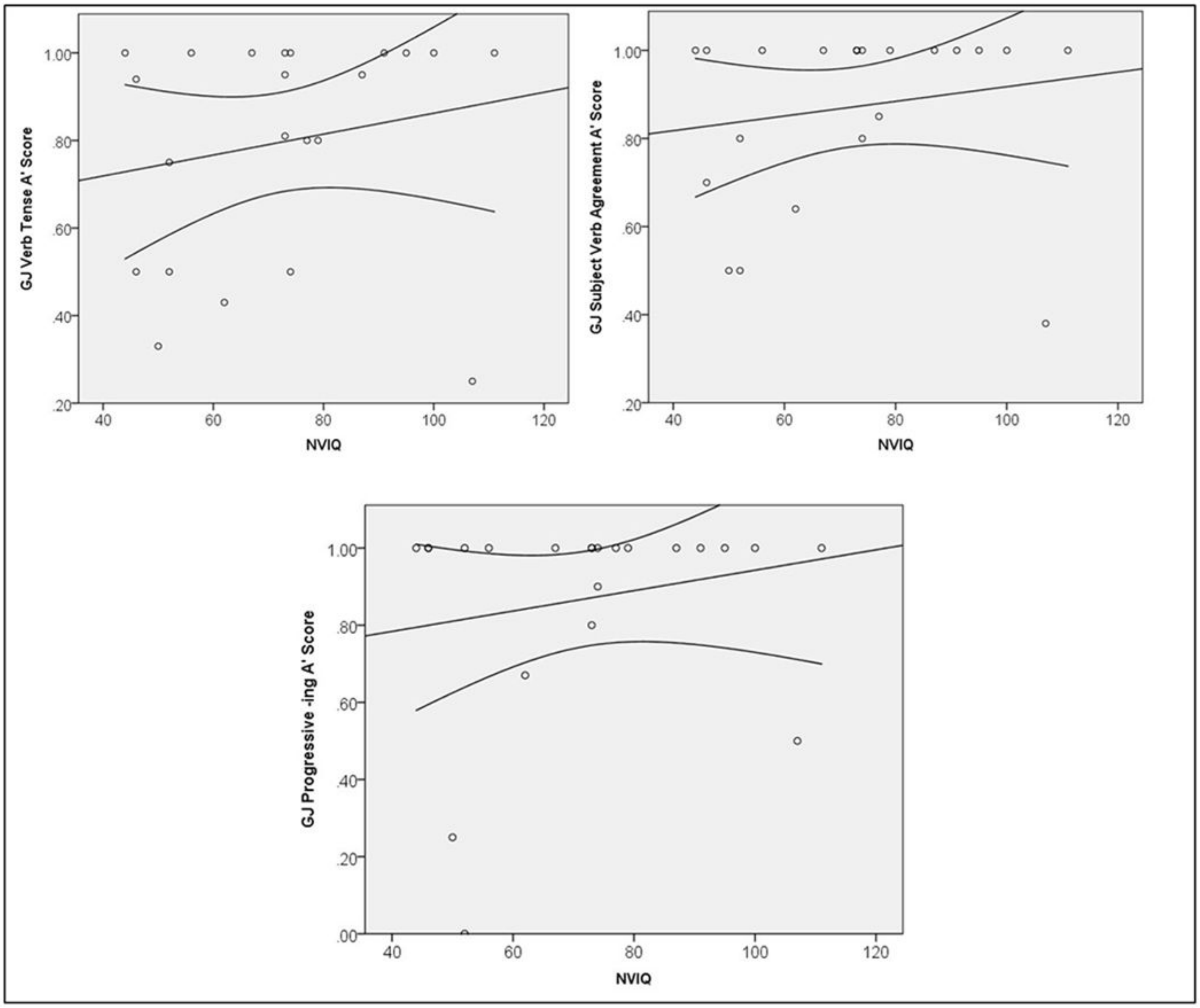

Figure 1.
Scatterplots with 95% confidence intervals showing the relationship between nonverbal IQ (NVIQ) and grammatical judgment of verb tense, subject-verb agreement, and progressive –ing.

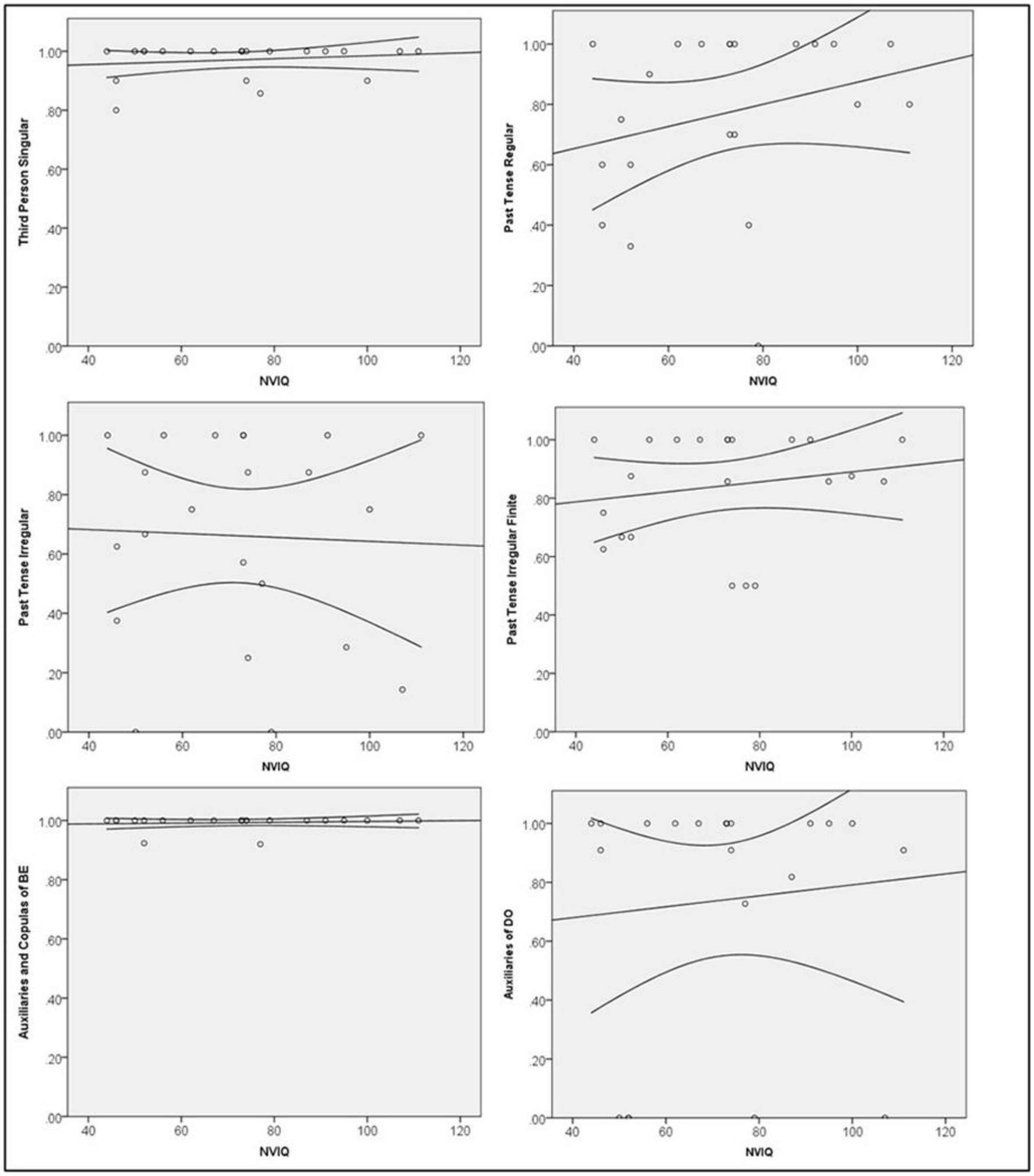

Figure 2.

Scatterplots with 95% confidence interval showing the relationship between nonverbal IQ (NVIQ) and grammatical production of third person singular, regular verbs, irregular verbs, irregular finite verbs, auxiliaries and copulas of be, and auxiliaries of do.

Table 1

Participant Descriptives

	CA	NVIQ SS	ADOS Severity	PPVT-4		EVT	
				SS	AE	SS	AE
Mean	13.45	72.23	7.18	80.91	10.11	83.55	10.09
SD	1.90	20.15	2.08	20.10	3.38	17.78	3.46
Median	13.34	73.00	7.00	79.50	9.00	81.00	9.25

Note. AE = age equivalent; CA = chronological age in years; SS = standard score. ADOS = Autism Diagnostic Observation Schedule (Lord, et al., 2012; Lord, Rutter, DiLavore, & Risi, 1999); NVIQ = Leiter Brief nonverbal IQ; PPVT-4 = Peabody Picture Vocabulary Test- 4th edition (Dunn & Dunn, 2007); EVT-2 = Expressive Vocabulary Test- 2nd edition (Williams, 2007).

Table 2

Performance on TEGI subtests of Grammaticality Judgment and Grammar Production

Measure	Mean	*SD*	Median	95% CI	AE range[a]
Grammaticality Judgment					
GJ tense	0.80	0.25	0.95	[0.683, 0.909]	5.00 – 6.11
GJ agreement	0.87	0.20	1.00	[0.783, 0.960]	4.00 – 8.11
GJ -ing	0.87	0.28	1.00	[0.747, 0.991]	below 4.00 – 6.11
GJ composite	0.85	0.23	0.96	[0.745, 0.946]	-
Grammar Production					
Third Person Singular	0.97	0.06	1.00	[0.945, 0.995]	8.00 – 8.11
Past Tense Regular	0.77	0.28	0.85	[0.650, 0.890]	-
Past Tense Irregular	0.66	0.35	0.75	[0.510, 0.810]	-
Past Tense Irregular Finite	0.84	0.19	0.86	[0.761, 0.919]	-
Past Tense Overall	0.81	0.19	0.92	[0.731, 0.889]	4.06 – 6.11
Copulas and auxiliaries of *be*	0.99	0.02	1.00	[0.982, 0.998]	7.00 – 8.11
Auxiliaries of *do*	0.74	0.42	1.00	[0.560, 0.919]	5.00 – 8.11
Production Composite	0.93	0.08	0.95	[0.897, 0.966]	-

Note.

[a]AE = age equivalent ranges reported are based on the lower and upper limit of the 95% confidence interval, CI = confidence interval, GJ = grammaticality judgment. A’ scores are reported for subtests of grammaticality judgment, probe scores are reported for subtests of grammar production. GJ composite score represents the average of the A’ scores for each of the three subtests for each participant. Production composite score represents the elicited grammar composite score on the TEGI.

Table 3

Summary of Spearman Correlations, for Nonverbal IQ, Grammaticality Judgment and Production

Measure	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1. Nonverbal IQ	-									
2. GJ tense	0.25	-								
3. GJ agreement	0.24	0.88**	-							
4. GJ -ing	0.13	0.69**	0.73**	-						
5. Third person singular	0.09	0.17	0.12	−0.16	-					
6. Past tense regular	0.26	0.44*	0.27	−0.07	0.50*	-				
7. Past tense irregular	−0.06	0.68*	0.48*	0.27	0.35	0.52*	-			
8. Past tense irregular finite	0.08	0.60**	0.42	0.10	0.57**	0.80**	0.87**	-		
9. Copulas and auxiliaries of *be*	0.05	0.19	0.24	−0.19	0.26	0.46*	0.16	0.41	-	
10. Auxiliaries of *do*	−0.05	0.63**	0.54**	0.38	0.04	0.56**	0.55**	0.59**	0.38	-

Note. GJ = grammaticality judgment, Nonverbal IQ = Leiter-R Brief nonverbal IQ standard score.

* $p < 0.050$

** $p < 0.010$.

Table 4

Summary of Hierarchical Multiple Regression for NVIQ Accounting for performance on TEGI Subtests of Grammaticality Judgment and Production

Variable	*B*	SE_B	β	*p*-value	95% CI	R^2	ΔR^2
Grammaticality Judgment							
Intercept	0.658	0.593		0.281	[−0.583, 1.899]		
Chronological age	0.002	0.033	0.013	0.963	[−0.067, 0.070]		
NVIQ	0.002	0.003	0.205	0.460	[−0.004, 0.009]	0.039	0.029
Grammar Production							
Intercept	0.521	0.184		0.011	[0.136, 0.906]		
Chronological age	0.020	0.010	0.487	0.062	[−0.001, 0.041]		
NVIQ	0.002	0.001	0.504	0.054	[0.000, 0.004]	0.216	0.174

Note. CI = confidence interval, NVIQ = Leiter-R Brief nonverbal IQ standard score.

* $p < .050$

** $p < .010$.