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BRIEF REPORT

Brief Report: A Comparison of Statistical Learning in School-Aged Children with High Functioning Autism and Typically Developing Peers

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Abstract Individuals with autism spectrum disorders have impairments in language acquisition, but the underlying mechanism of these deficits is poorly understood. Implicit learning is potentially relevant to language development, particularly in speech segmentation, which relies on sensitivity to transitional probabilities between speech sounds. This study investigated the relationship between implicit learning and current language abilities in school-aged children with high functioning autism and a history of language delay ($n = 17$) and in children with typical development ($n = 24$) using a well-studied artificial language learning task. Results suggest that high functioning children with autism (HFA) and TD groups were equally able to implicitly learn transitional probabilities from a lengthy stimulus stream. Furthermore, task performance was not strongly associated with current language abilities. Implications for implicit learning research in HFA are discussed.

Keywords Autism · Language · Implicit learning · Statistical learning · Speech segmentation

"One gets to the heart of the matter by a series of experiences in the same pattern…"

-Robert Graves.

The present study was conducted by Jessica D. Mayo, University of Connecticut and Inge-Marie Eigsti, University of Connecticut.

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Implicit learning is the ability to detect regularities in one's environment without explicit effort, and appears to be critical in multiple higher-order cognitive skills (Perruchet and Pacton 2006). Understanding the role that implicit learning abilities play in the cognitive development of individuals with autism spectrum disorders (ASD) has been the source of ongoing study and interest (see Eigsti and Mayo 2011, for a review). Although several studies have reported intact implicit learning abilities in individuals with ASD (Barnes et al. 2008; Mostofsky et al. 2004; Brown et al. 2010), other studies have reported significantly impaired abilities (Mostofsky et al. 2000; Gordon and Stark 2007; Sears et al. 1994; Gidley Larson and Mostofsky 2008), or different patterns of neural activity during implicit learning tasks, suggesting atypical approaches to learning (Müller et al. 2003, 2004). Studies have also indicated that individuals with ASD demonstrate difficulty with skills that are implicitly learned in typically developing individuals (e.g., difficulty generalizing learned skills across contexts; Lovaas et al. 1973; Ozonoff and Miller 1995; difficulty interpreting social cues; Hwang and Hughes 2000).

Aspects of early language acquisition and processing also appear to rely on implicit learning abilities (Redington and Charter 1997). Specifically, one of the initial steps in learning language is determining word boundaries from within a continuous speech stream. Segmenting a continuous stream of speech into meaningful linguistic units (i.e., words) is a fundamental requirement of language learning, but is particularly difficult because auditory pauses do not reliably occur *between* words and therefore do not provide a useful cue to word boundaries (Cole et al. 1980). Previous research suggests that infants rely on multiple cues to bootstrap language acquisition including phonotactic regularities (Friederici and Wessels 1993; Mattys and Jusczyk

2001), prosodic patterns (Jusczyk et al. 1993, 1999), and early rhythmic information (Nazzi et al. 1998; 2000; 2006). An alternate cue to word segmentation is present in the statistical co-occurrence of syllables (i.e., "transitional probability"). Sensitivity to the statistical relationships among small units of speech, such as syllables, may be particularly important as a learner begins to segment speech into meaningful linguistic units (i.e., words). By tracking transitional probabilities of syllables in a speech stream, individuals can learn that frequently co-occurring sounds form larger units such as words (Saffran et al. 1996). Experiments using artificial language paradigms have demonstrated that typically developing adults (Saffran et al. 1997), children (Evans et al. 2009) and 8-month old infants (Saffran et al. 1996) are sensitive to transitional probabilities (i.e., they are able to determine word boundaries in an artificial language using only statistical cues). This learning occurs *without* explicit instruction to listen for patterns in the speech stream; the learning is implicit.

Further evidence for the importance of implicitly learning transitional probabilities comes from studies of individuals with language impairments. Specific Language Impairment (SLI) is diagnosed in children who have impairments in both phonological and non-phonological language processes, and who may have additional weaknesses in semantic skills despite adequate hearing, intelligence, and physical development (Bishop and Snowling 2004; Whitehouse and Bishop 2008). Compared to an age- and IQ-matched comparison group of typically developing (TD) children, children with SLI exhibit striking impairments in using transitional probabilities to determine word boundaries after 20 min of exposure to an artificial language (Evans et al. 2009).

Individuals with autistic disorder have significant and persistent deficits in language and communication (American Psychiatric Association [*DSM-IV-TR*] 2000). Deficits in language are evident early in life; children with autism who eventually develop spoken language speak their first words when they are an average of 38 months old (Howlin 2003), as compared to 12–18 months in typical development. Additionally, deficits in syntactic and morphological skills are salient (Eigsti et al. 2007) and may continue into adolescence, even in high functioning individuals with average IQ (Eigsti and Bennetto 2009). Although delayed language and poor communication is well documented, and is a key prognostic factor in ASD (Gillberg and Steffenburg 1987; Lord and Ventner 1992; Szatmari et al. 1989), the underlying mechanism is poorly understood (Harris et al. 2006).

Given the inconsistent results regarding implicit learning abilities in ASD, the importance of implicit learning to language, and the robust language deficits associated with ASD, it is surprising that few studies have directly examined the relationship between implicit learning ability and language deficits in ASD. One notable exception is a functional MRI study using an artificial language paradigm to examine the implicit ability to detect transitional probabilities in children with ASD (Scott-Van Zeeland et al. 2010). Results revealed markedly different patterns of activation between children with ASD and TD during brief (2.4-min) artificial language presentations. Specifically, unlike the TD group who demonstrated learning-related changes in activation during the presentation of artificial languages (increases in the left supramarginal gyrus (SMG), inferior parietal lobule (IPL), and bilateral striatum), the ASD group failed to demonstrate significant neural evidence of learning. Further, ADI-R communication scores were negatively correlated with signal changes in left IPL and putamen in the ASD group, suggesting that these areas may be particularly relevant to language and communication skills. Although behavioral measures of word learning were not explicitly measured, these fMRI differences suggest that children with high-functioning ASD may employ *less efficient* implicit learning for transitional probabilities, possibly contributing to deficits in language skills. Given the benefit derived from additional language exposure to children with SLI (Evans et al. 2009), it is possible that children with ASD (who also seem to employ less efficient implicit learning) may similarly benefit from lengthy learning opportunities.

The current study was motivated by the inconsistent prior studies of implicit learning and by the clear presence of language impairments in ASD. We aimed to examine implicit learning abilities in a high-functioning group of children with ASD using a well-studied paradigm that had been sensitive to language abilities in a population of children with SLI. Focusing our study on a group of high functioning children with autism (HFA) allowed us to control for the effects of intellectual impairment, while still giving us adequate ability to investigate the contributions of implicit statistical learning to language. Given prior findings of associations between implicit learning and some aspects of language skills (e.g. word learning, Graf Estes et al. 2007; Mirman et al. 2008; sentence processing, Amato and MacDonald 2010; and syntax, Ullman 2001), a second goal was to examine associations between transitional probability learning, autism severity, and performance on standardized measures of cognition and language.

Methods

Participants

Participants were 17 children with high functioning autism (HFA), (14 boys, mean age = 13.1 (2.9) years; range = 7.7–17.2 years) and 24 children with typical development (TD), (15 boys, mean age = 13.0 (2.6) years; range = 8.1–17.8 years).[1] HFA and TD groups were well-matched on chronological age and full scale IQ (HFA: IQ = 103 (11.5), range = 85–127); TD: IQ = 105 (11.5), range = 88–139). Additionally, both the HFA and TD groups demonstrated average to high average performance on a battery of language measures, described below; data are presented in Table 1. In contrast, all participants with HFA had significantly delayed language early in life, per parent report. Delayed language was reported by parents during the ADI-R interview; children's language was considered delayed if the child spoke his or her first words later than 24 months old or first phrases later than 36 months old.

Participants were recruited from local schools and surrounding communities as part of a larger study of ASD and language development. All children in the HFA group met criteria for Autistic Disorder, based on DSM-IV-TR [APA, 2000] criteria; diagnoses were confirmed using the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2000), the Autism Diagnostic Interview, Revised (ADI-R; Lord et al. 1994), the Social Communication Questionnaire (Rutter et al. 2003) and clinical judgment. Children were considered eligible for the current study if they had diagnoses of Autistic Disorder, a history of language delay as reported during parent interview, and IQ in the average to above average range as measured by the Stanford-Binet Intelligence Scales-5 (Roid 2003). Participants with typical development, in the comparison group, were excluded if they had first-degree relatives with an ASD diagnosis. Participants in both groups were excluded if they had additional psychiatric disorder, traumatic brain injury, or known neurologic or genetic disorders. This study was approved by the University of Connecticut Institutional Review Board.

Table 1 Demographic information for participants with high functioning autism (HFA) and typically developing (TD) control participants

	HFA (n = 17) mean (SD) (range)	TD (n = 24) mean (SD) (range)	p
Gender (M:F)	14:3	15:9	0.16
Age (years)	13.1 (2.9) (7.7–17.2)	13.0 (2.6) (8.1–17.8)	0.82
Nonverbal IQ	11.1 (3.1) (5–17)	11 (2.4) (8–16)	0.95
Verbal IQ	11.1 (3.1) (5–17)	10.8 (2.3) (6–17)	0.52
Full scale IQ	103 (11.5) (85–127)	105 (11.5) (88–139)	0.68
PPVT	110.4 (13.7) (83–131)	115.9 (10.8) (100–147)	0.17
EVT	106.8 (15.7) (81–136)	111.0 (16.3) (84–140)	0.28
CELF-4 *Formulated Sentences*	9.4 (3.2) (4–15)	11.61 (2.1) (8–15)	0.02
CELF-4 *C&FD*	9.7 (2.2) (6–12)	11.69 (1.5) (9–15)	0.03
Non-word repetition	15.7 (2.3) (12–20)	17.9 (1.2) (15–20)	0.002
SCQ total score[a]	20.7 (6.5) (9–33)	1.3 (1.0) (0–4)	<.001
ADOS communication (C)	3.5 (2.0) (1–8)		
ADOS social reciprocity (SR)	6.8 (2.7) (1–13)		

[a] When used as a screening instrument, a cutoff score of 15 is recommended as an indication of a possible ASD (Rutter et al. 2003). All ASD subjects in the final sample, except two, were above the cutoff for possible ASD; these participants scored above the cutoff for ASD on the ADOS and were judged to carry an ASD diagnosis by clinicians on the study

Standardized Procedures and Methods

Diagnostic Assessments. Testing was generally conducted over the course of two non-consecutive days. Autistic Disorder was confirmed through use of the ADOS (Lord et al. 2000), the ADI-R (Lord et al. 1994), and clinical judgment, based on DSM-IV criteria (APA 2000). In addition, social and communication skills were reported by parents using the Social Communication Questionnaire (SCQ; Rutter et al. 2003).

Stanford-Binet Intelligence Scales: Fifth Edition (Roid 2003). The Stanford-Binet is a factor-analytic measure of intellectual functioning. Participants completed the vocabulary and matrices subtests, providing a reliable estimate of verbal and nonverbal cognitive functioning.

Language Abilities. Subjects' language abilities were assessed using several standardized language measures. The *Peabody Picture Vocabulary Test*, Third Edition (PPVT-III; Dunn and Dunn 1997) and the *Expressive Vocabulary Test* (EVT; Williams 1997) were used to provide measures of receptive and expressive vocabulary, respectively. The *Clinical Evaluation of Language Fundamentals, Fourth Edition* (CELF-4; Semel et al. 2003), was administered to assess language skills, including

[1] Note the large age range of the subjects included. Although there is evidence that age may play a role in statistical learning abilities (Arciuli and Simpson 2011), age did not appear to play a role in the current sample. That is, age was not significantly related to performance on our measure of implicit learning (i.e., the 2AFC test) for either the TD or HFA groups. Nevertheless, it was important to ensure that groups were well-matched on age.

syntax. *Nonword repetition* (based on Gathercole et al. 1997) required subjects to repeat nonsense words. Nonword repetition ability is thought to be a sensitive measure of phonological working memory which is thought to play a key role in language learning (Baddeley and Wilson 1993; Hoff et al. 2008).

Experimental Task

Participants listened to a 21-min, continuous speech stream containing 12 syllables, identical to the stimuli used in Saffran et al. (1997) and Evans et al. (2009). Within the continuous speech stream, syllables were presented in a fixed order that systematically varied the transitional probability between syllables. Six combinations of syllables formed trisyllabic "words" with high internal transitional probabilities (0.32–1.0), as shown in Table 2. Internal transitional probability between syllables in a "word" was higher (0.32–1.0) than the transitional probabilities between syllables across "word" boundaries (0.10–0.20). The speech stream contained no prosodic cues to word or utterance boundaries. To ensure that subjects did not direct their explicit attention to the task of word segmentation, subjects were told that examiners were studying the "effects of sound on creativity." As they listened, children engaged in a drawing activity. Immediately following exposure, children completed a 36-trial, two-alternative forced-choice (2AFC) test. Test choices included a "word" (three syllables with high transitional probabilities) and a non-word foil (three syllables that did not co-occur during the speech stream). Participants were directed to choose the item (word or non-word foil) that "sounded more like the language that they heard while drawing." Chance performance (50%) suggests a failure to use statistical properties of the artificial language to learn word boundaries.

Table 2 Items from the 2AFC test (adapted from Evans et al. 2009)

Words	Transitional probability
Dutabu	1.00
Tutibu	0.75
Pidabu	0.65
Patubi	0.50
Bupada	0.42
Babupu	0.37
Non-word foils	
Batipa	
Bidata	
Dupitu	
Pubati	
Tapuba	
Tipabu	

Note: A "word" is a grouping of three syllables with high transitional probabilities. A "non-word foil" is a grouping of three syllables that did not co-occur during the speech stream. Children were presented with a "word" and a "non-word foil" and were asked to choose which of the two sounded "more like the sounds they heard."

Results

To test the hypothesis that HFA and TD groups differ in implicit learning, *t* tests were used to test for differences in 2AFC test accuracy. ANOVA and planned post hoc tests allowed closer investigation of how 2AFC test variables (i.e., internal transitional probability of each word and prior exposure to foil words) explained and interacted with groups' performance. Finally, correlational statistics were used to investigate the associations among implicit learning, cognitive ability, language skills, and symptom severity.

One-sample *t* tests indicated that both the HFA and TD groups performed significantly above chance (i.e., 0.50), HFA mean accuracy (SD) = 0.59 (0.14), $p = 0.01$; TD mean accuracy (SD) = 0.60 (0.11), $p < 0.001$, indicating that both groups implicitly learned transitional probabilities, using these statistical cues to determine word boundaries. Independent sample *t* tests indicated that overall performance did not differ between groups, $t(39) = 0.15$, $p = 0.88$; both groups were equally able to use the statistics of co-occurrence to identify words (see Fig. 1).

A repeated-measures ANOVA was used to examine relative sensitivity to transitional probability (e.g.,

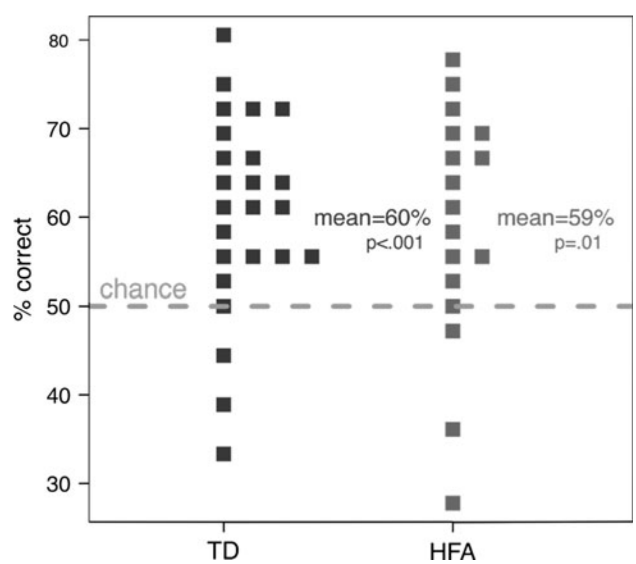

Fig. 1 Percent of correctly-identified words by group

accuracy on the 2AFC) as a function of group. Results indicate a significant main effect of transitional probability (that is, groups of words with a given internal transitional probability) on accuracy, $F(5, 195) = 2.95$, $p = 0.01$, indicating that, as expected, the internal transitional probability between syllables in the "words" significantly impacted performance. There was no significant effect of group, $F(1, 39) = 0.04$, $p = 0.86$, or group by transitional probability interaction, $F(5, 195) = 0.46$, $p = 0.80$, suggesting that the HFA and TD groups responded similarly to differences in transitional probability.

Post hoc paired *t* test analyses were used to determine whether "easier" words (i.e., those words with high internal transitional probability of 1.0) were indeed, associated with more accurate performance than words with low internal transitional probabilities of 0.37). Results indicated that participants in both groups were more accurate in identifying words with high internal transitional probabilities although the TD group performed significantly better for high compared to low transitional probability words, $t(23) = 2.46$, $p = 0.02$, and the HFA group had less differentiation between probability levels, $t(16) = 1.80$, $p = 0.09$, suggesting a possible lesser sensitivity to such probabilities in the HFA group (see Fig. 2). Independent-sample *t* test analyses were used to compare accuracy for words with high and low internal transitional probability directly as a function of group. Results indicated that HFA and TD groups had similar accuracy on words with the highest internal transitional probability (1.0), $t(39) = 0.77$, $p = 0.47$; accuracy (SD) was 0.61 (0.26) and 0.67 (0.19), respectively. Similarly, the HFA and TD groups were equally accurate on words with low transitional probabilities (0.37), $t(39) = 0.24$, $p = 0.82$, mean (SD) = 0.48 (0.26) and 0.50 (0.25), respectively. Similar performance on items with both the highest and lowest transitional probabilities suggests that neither group demonstrated an advantage on items that were particularly easy or more difficult to learn (see Fig. 2).

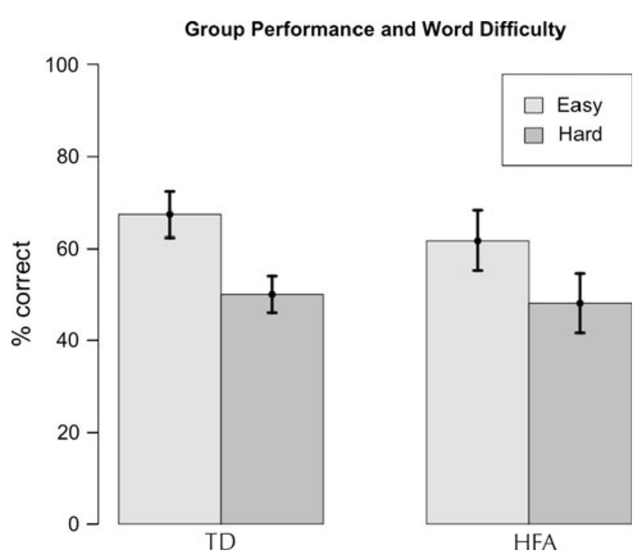

Fig. 2 Group performance on 2AFC test for "hard" and "easy" words

Inspection of performance on the 2AFC test suggested that accuracy decreased over the course of the 2AFC test, suggesting that the design of the 2AFC test may have played a role in the accuracy with which participants correctly discriminated between "words" and non-word foils. In an initial test of this hypothesis, we examined correlations between test item number (1–36) and accuracy on each item, collapsed within each group. For the TD group, accuracy was significantly negatively correlated with test item number, $r(34) = -0.34$, $p = 0.04$, such that over the course of the 2AFC test, accuracy decreased significantly. This negative correlation was present in the HFA group, although the relationship did not reach significance, $r(34) = -0.28$, $p = 0.10$. This significant pattern of declining performance in the TD group only suggested that the groups' understanding of transitional probabilities may have unfolded differently over the course of the test.

To more carefully examine the possibility that the 2AFC test design influenced performance, we tested, as a function of group, 2AFC accuracy for trials in which the non-word foil had been previously presented during the 2AFC. That is, on each trial of the 2AFC test, subjects were presented with one word and one of the six non-word foils (listed in Table 2). Each of these six non-word foils occurred six times over the course of the 2AFC test. In this analysis, repeated-measures ANOVA was used to compare accuracy for trials where the non-word foil had been presented once previously, to trials where the non-word foils had been presented twice previously, or three times previously, etc. Results indicated a significant main effect of *prior exposure to the non-word foil* on accuracy, $F(5, 195) = 5.35$, $p < 0.001$, such that prior exposure to a particular non-word foil on the 2AFC led to increased likelihood that participants would (incorrectly) choose that non-word foil. There was no main effect of group, $F(1, 39) = 0.04$, $p = 0.85$, and no interaction, $F(5, 195) = 0.49$, $p = 0.79$, suggesting that the HFA and TD groups responded similarly to additional exposures to non-word foil words. Furthermore, post hoc correlational within-group analyses indicated that additional exposures to a foil word resulted in a significantly greater likelihood of choosing that non-word foil for participants in *both* the HFA and TD groups, $r(34) = -0.39$, $p = 0.02$, and $r(34) = -0.46$, $p = 0.004$, respectively. That is, participants in both groups appeared to be systematically less accurate at differentiating between words and non-word foils when they were exposed to additional exemplars of a non-word foil over the course of the test (see Fig. 3).

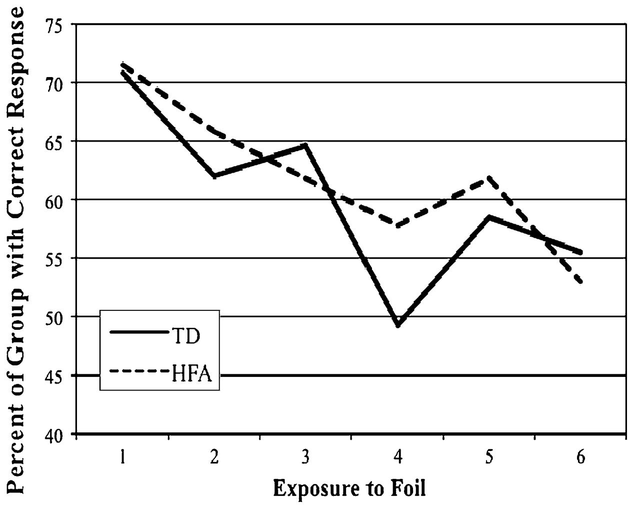

Fig. 3 Exposure to foil and avererage group performance

To summarize the findings so far: there was a similar overall accuracy for HFA and TD groups. Accuracy in both groups was sensitive to the internal transitional probability of the words. An initial correlational analysis suggested that the TD group exhibited a steady decrease in accuracy over the course of the test, whereas the HFA group did not, suggesting a greater sensitivity to prior exposures to non-word foils in the TD group. However, there was substantial overlap between test item number and number of prior exposures to foils (these factors were significantly correlated, $r(70) = 0.896$, $p < 0.001$); and when directly testing the effects of non-word foil exposures, there were no differences between the groups.

Given previous studies (Scott-Van Zeeland et al. 2010; Evans et al. 2009), accuracy on the 2AFC test was examined for associations with language abilities, symptom severity, and IQ. In contrast to those prior results, in the current study, there were no significant correlations of 2AFC accuracy with standardized *or* raw scores on any cognitive or language tasks or symptom severity measures. Correlational data based on standardized scores are shown in Table 3; the pattern of results is identical if raw test scores are analyzed. Given that accuracy was correlated with exposure to foil words on the 2AFC test, and thus with item number on the test, performance on standardized measures of cognitive and language skills was examined separately for the first and second halves of the test. Again, performance on the individual 2AFC test halves was not significantly correlated with cognition (NVIQ, VIQ, or FSIQ) or language (PPVT, EVT, Nonword repetition, or two CELF subtests, *Formulated Sentences* and *Concepts and Following Directions*) in either group, as shown in Table 3.

The broad pattern of results thus indicates generally similar performance in learning transitional probabilities from a speech stream presented for a lengthy period of 21 min. This identical task has been effectively employed in numerous previous studies of typically developing children, adults, and children with SLI, and has been found to map onto other language skills. As such, it was the best candidate task for testing for differences in implicit learning of language-related probabilities. Interestingly, contrary to Scott Van-Zeeland et al. (2010), who found evidence consistent with weaknesses in implicit learning after a very brief language exposure, the HFA group in the current study demonstrated an ability to detect transitional probabilities as well as their IQ- and age-matched peers.

Table 3 Correlations of 2AFC test accuracy with other measures, for HFA and TD groups

	Age (years)	NVIQ	PPVT	EVT	NWR	SCQ–C	CELF–FS	CELF–C&FD	ADOS (C)	2AFC Test
Age (years)		−0.24	0.18	0.31	0.60*	0.03	−0.22	−0.53	−0.69**	0.10
NVIQ	−0.45*		−0.30	−0.17	−0.30	0.18	0.10	−0.23	0.13	0.21
PPVT	−0.29	0.52**		0.88**	0.47	0.15	0.52*	0.31	−0.54*	0.07
EVT	−0.08	0.25	0.63**		0.39	−0.01	0.48	0.65	−0.54*	0.05
NWR	0.51*	−0.02	−0.03	0.31		−0.17	−0.19	−0.49	−0.44	−0.28
SCQ–C	0.08	−0.02	−0.18	−0.25	−0.17		0.34	−0.65	−0.63	0.37
CELF–FS	−0.23	0.01	0.12	0.06	0.04	0.33		0.44	−0.07	0.12
CELF–C&FD	−0.23	0.44	0.50	0.66*	0.17	0.07	−0.27		−0.07	−0.25
ADOS–C	–	–	–	–	–	–	–	–		-0.27
2AFC Test	0.10	−0.47*[a]	−0.36	−0.004	0.002	−0.11	−0.19	−0.05	–	

Note: Correlations are presented *above* the diagonal for the HFA group and *below* for the TD group

* $p < 0.05$ (two-tailed); ** $p < 0.01$ (two-tailed)

[a] Correlation appears to be driven by a single outlying score of a subject who scored two standard deviations below the group mean on the 2AFC test. When removed from analyses, this correlation no longer reaches significance. When this participant's data was removed from all analyses, there was no change in the pattern of correlations

Discussion

In the current study of school-aged children and adolescents with HFA, we found strong evidence of intact implicit learning: participants with HFA and a history of early language delay had similar accuracy compared to a group of age-, IQ-, and language-matched TD peers. Performance accuracy was tested in multiple ways. *First*, the HFA group successfully differentiated "words" in the artificial language from foil words with the same accuracy as their TD peers. *Second*, the HFA and TD groups were equally able to identify words with the highest internal transitional probability, and to identify words with the lowest internal transitional probability, indicating that neither group had an advantage in learning easier or more difficult words. The HFA group was not simply identifying the easiest-to-learn words. *Third*, both groups showed a similar pattern of decreased performance as the 2AFC test progressed. Subjects from both groups demonstrated a similar pattern of updating their implicit knowledge of the transitional probabilities within the artificial language as they were exposed to additional learning opportunities, although this pattern was stronger in the TD group.

Although these results clearly suggest generally intact implicit learning ability in our HFA group, accepting a null hypothesis requires careful attention to any subtle differences between groups. There were weak group differences in performance, in that the HFA group appeared less sensitive to the distinction between high versus low transitional probabilities. These differences, however, were quite subtle, and the primary finding was that the HFA group was able to learn transitional probabilities as effectively as age- and IQ-matched peers after a 21-min exposure period.

Performance on the 2AFC test was not correlated with standardized measures of cognition, language, or autism severity. This lack of correlation contrasts with a prior study, using the same task, which reported positive correlations between 2AFCT performance and receptive and expressive vocabulary scores in a TD sample (Evans et al. 2009), and an fMRI study that found that social communication was correlated with learning-related changes in the basal ganglia and left temporo-parietal cortex in an ASD sample (Scott Van-Zeeland et al. 2010). Absence of significant relationships between our measure of implicit learning and standardized measures of cognitive skills is, however, consistent with previous reports of dissociations between performance on implicit learning tasks and standardized measures of cognition (Gebauer and Mackintosh 2007; Reber et al. 1991; Feldman et al. 1995; Unsworth et al. 2005), language (Eigsti et al. 2011), and autism symptoms (Brown et al. 2010). In the current study, we used language tests that assess broad language domains (e.g., receptive and expressive vocabulary, a limited set of syntactic structures); although these tests provide a good measures of functional language, and were related to this implicit learning task in prior work in SLI, they may not adequately probe knowledge of statistical regularities that are present in language (e.g., all aspects of syntax).

The results demonstrate that, given a lengthy (21-min) speech stream, school-aged children with HFA implicitly tracked statistical cues successfully; relying exclusively on the frequency cues from transitional probabilities, they were able to segment words as well as their TD peers. Given the presence of delayed language among individuals with HFA (Tager-Flusberg and Caronna 2007), the proposed relevance of implicit learning in language development in TD populations (e.g., Ullman 2004; Gerken 2004; Gomez and Gerken 1999), and the evidence of atypical neural activation during a similar task (Scott Van-Zeeland et al. 2010), these results are somewhat surprising; we anticipated implicit learning impairments in the HFA group. While the current finding of equivalent performances in the HFA and TD groups may suggest that impairments in implicit learning of statistical regularities play no role in early language delays in HFA, there are some alternative explanations for this pattern of results.

First, although all HFA participants had a history of significant language delay, the current sample represents only high-functioning individuals with ASD, who did not present with current language deficits as measured by standardized tests of language. Difficulties in implicit learning may be less salient in this group; however, it should be noted that, if implicit learning limits language acquisition in ASD, such limitations should be anticipated even in a high-functioning sample with early delays. Furthermore, even a very high-functioning group of children on the spectrum were found to exhibit subtle grammatical deficits into early adolescence, and deficits correlated with degree of early language delay (Eigsti and Bennetto 2009), a finding that strengthened the prospects of finding implicit learning deficits in a similar group.

Second, the artificial language in the current study was far less complex than a real language, and was presented for a lengthy period of 21 min. Although both groups showed a range in test accuracy, such that data were not limited by ceiling effects, it is possible that the parameters of the test may have been insensitive to subtle group differences. The HFA group may have relied on the lengthy stimuli presentation and relatively small set of items (12 syllables, combined to form six "words") to succeed, unlike real-world, complex language experiences. In the most closely related study to date (Scott-Van Zeeland et al. 2010), children listened to 2.4-min speech stream, creating a much more conservative test of implicit learning ability. Increasing the length of exposure to a stimulus stream can facilitate learning in populations that initially show learning deficits (Evans et al. 2009). Thus, in the present study, there may have been HFA-specific differences in the rate of learning that we did not detect given the lengthy exposure (a possibility consistent with the less robust detection of subtle differences in input statistics within the HFA group).

Finally, in the absence of behavioral differences, there may nonetheless be neural differences in how individuals with HFA approach the task, a possibility not addressed in the current study. Although, the current results do not examine the neural substrates of implicit learning, it is possible that the HFA group was able to compensate for a distinctive implicit learning process by employing additional or alternative strategies.

In general, results were consistent with any of the following possibilities: (1) language delays in ASD are not a result of implicit learning deficits; other research has proposed a variety of alternative mechanisms for atypical and delayed language development in ASD, including, for example atypically developed joint attention (Charman 2003), and poor motor control (Gernsbacher et al. 2008); (2) implicit learning deficits are resolved earlier in development; (3) given a lengthy 21-min exposure, individuals with HFA are able to detect statistical regularities; (4) only children with ASD who are high-functioning, school-aged and who are exhibiting no current deficits on standard measures of language are able to capitalize on implicitly learned statistical regularities to segment words; or (5) the measure of learning (a 2AFC test) was not sensitive to subtle differences in how the participants approached the task. In addition to these findings regarding implicit learning in HFA, these data suggest performance on the frequently used 2AFC test should be carefully analyzed; the pattern of performance in the current study indicated that incidental learning *during* the test could contaminate learning that occurred during the initial exposure.

Systematic manipulation of three key methodological factors in future studies may clarify the relationships between implicit learning abilities language skills in ASD. *First,* the length of time that individuals are exposed to language may significantly affect their ability to implicitly detect the statistical regularities within the language. Evidence from the SLI literature suggests lengthening the amount of learning opportunity increases likelihood of learning (Evans et al. 2009). Investigating learning given shorter exposures may reveal more subtle differences in implicit learning abilities. *Second*, future studies should include children who present a variety of levels of current language abilities and cognitive functioning, or should include separate groups of individuals with high and low language skills. *Third,* the method of outcome measure of learning should be carefully considered as both fMRI and behavioral measures are associated with costs and benefits. While behavioral measures (e.g., the commonly employed behavioral indicator of learning, a 2AFC test) are less expensive and allow longer exposure to stimuli than fMRI, it is notable that, in the present study, performance was associated with an important pattern (i.e. children from both groups seemed to be sensitive to incidental learning that took place during the 2AFC test itself). Future studies that employ this type of behavioral measure should explicitly examine the pattern of errors on 2AFC tests, and would ideally make use of a more on-line measure of learning, such as eyetracking. In contrast, fMRI offers a costly but sensitive mechanism for detecting subtle differences in the neural mechanisms underlying speech segmentation. Future studies using fMRI should consider imaging implicit learning during lengthier exposures to artificial language.

In sum, the present study contributes to the ongoing debate regarding implicit learning in autism. School-aged children with HFA clearly demonstrated intact implicit learning of statistical regularities within a lengthy artificial language and performed comparably to age- and IQ-matched TD peers. In the future, alternative methods of detecting implicit learning will be critical to accurate understanding of this phenomenon and its implications on other higher order skills such as language.

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