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Intact Statistical Word Learning in Autism Spectrum Disorders

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

Robert Graves

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 & 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 (as reviewed in Eigsti & Mayo, in press). Although several studies have reported intact implicit learning abilities in individuals with ASD (Barnes et al., 2008; Mostofsky, Bunoski, Morton, Goldberg, & Bastian, 2004; Brown, Aczel, Jiménez, Kaufman, Grant, 2010), other studies have reported significantly impaired abilities (Mostofsky, Goldberg, Landa, & Denckla, 2000; Gordon & Stark, 2007; Sears, Finn, & Steinmetz, 1994; Gidley Larson & Mostofsky, 2008), or different patterns of neural activity during implicit learning tasks, suggesting atypical approaches to learning (Müller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003; Müller, Cauich, Rubio, Mizuno, & Courchesne, 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, Koegel, Simmons, & Long, 1973; Ozonoff & Miller, 1995; difficulty interpreting social cues; Hwang & Hughes, 2000).

Aspects of early language acquisition and processing also appear to rely on implicit learning abilities (Redington & 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, Jakimik, & Cooper, 1980). 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 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 the speech stream, individuals can learn that frequently co-occurring sounds form larger units such as words. (Saffran, Aslin & Newport, 1996). Experiments using artificial language paradigms have demonstrated that typically developing adults (Saffran, Newport, Aslin, Tunick, & Barruecco, 1997), children (Evans, Saffran, & Robe-Torres, 2009) and 8-month old infants (Saffran et al., 1996) are sensitive to transitional probabilities, using statistical cues to determine word boundaries in an artificial language. This learning occurs *without* explicit instruction to listen for patterns in the speech stream (that is, it is implicit); indeed, in studies of adults and children, participants engaged in an unrelated drawing task while listening to the speech stream.

Further evidence for the importance of implicitly learning transitional probabilities comes from studies of individuals with language impairments. Specific

Language Impairment (SLI) is recognized in children who have markedly impaired spoken language abilities despite adequate hearing, intelligence, and physical development (Whitehouse & Bishop, 2008). Compared to an age- and IQ-matched TD comparison group, children with SLI exhibited striking impairments in using transitional probabilities to determine word boundaries after 20 minutes of exposure to an artificial language (Evans et al., 2009); given 40 minutes of exposure, however, the SLI group performed similarly to the TD group. Findings suggested that insensitivity to transitional probabilities could be implicated in language impairments, as task accuracy after the 40 minute-exposure was positively correlated with receptive vocabulary (raw scores).

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 to 18 months in typical development. Additionally, deficits in syntactic and morphological skills are salient (Eigsti, Bennetto, & Dadlani, 2007) and may continue into adolescence (Eigsti & Benetto, 2009). Although delayed language and poor communication is well documented, and is a key prognostic factor in ASD (Gillberg & Steffenburg, 1987; Lord & Ventner, 1992; Szatmari, Bartolucci, Bremner, Bond, & Rich, 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 ASDs, 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, McNealy, Wang, Sigman, Bookheimer, & Dapretto, 2010). Results revealed markedly different patterns of activation between children with ASD and TD during brief (2.4-minutes) 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 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 adolescents with high-functioning ASD may employ *less efficient* implicit learning of 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, with a goal of examining implicit learning abilities in ASD using a well-studied paradigm that had been sensitive to language abilities in a population of children with SLI. Given the hypotheses and prior findings of associations between implicit learning and some aspects of language skills (e.g. word learning (Graf Estes, Evans, Alibali, & Saffran, 2007; Mirman, Magnuson, Graf Estes, & Dixon, 2008), sentence processing (Amato, & MacDonald, 2010), syntactic abilities (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 a diagnosis of ASD (mean age, 12.75 years) and 24 children with typical development (mean age, 12.97 years) matched on chronological age, gender, and full scale IQ; demographic details are shown in Table 1.

ASD diagnosis was confirmed through use of the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), the Autism Diagnostic Interview, Revised (ADI-R; Lord, Rutter, & LeCouteur, 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, Bailey, & Lord, 2003). All ASD participants had a significant history of language delay as indicated by parent report. Participants were excluded if they had other psychiatric disorder, traumatic brain injury, or known neurologic or genetic disorders. All participants were native speakers of English and had a Full Scale IQ greater than 80, in order to insure that any differences in performance were specific to ASD rather than a reflection of intellectual impairment. Participants were recruited from the community through flyers and at local schools. These data were collected as part of a larger study that included a battery of standardized and experimental tests. Testing was generally conducted over the course of two nonconsecutive days. The study was approved by the University of Connecticut Institutional Review Board; all participants provided informed consent and assent.

Measures

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 & Dunn, 1997) and the *Expressive Vocabulary Test* (EVT; Williams, 1997) were used to provide measures of receptive and expressive vocabulary, respectively. Subtests from the *Clinical Evaluation of Language Fundamentals, Fourth Edition* (CELF-4; Semel, Wiig, & Secord, 2003), including *Formulated Sentences* (FS) and *Concepts and Following Directions* (C&FD) were administered to assess language skills, including syntax. *Nonword repetition* (based on Gathercole, Hitch, Service, & Martin, 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, & Wilson, 1993; Hoff, Core, & Bridges, 2008).

Experimental task

Procedures

Participants listened to a 21-minute, 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 (0.5) suggests a failure to use statistical properties of the artificial language to learn word boundaries.

Results

One-tailed t-tests indicated that both the ASD and TD groups performed significantly above chance on the 2AFC test, ASD = .59 (.14), $p = 0.01$, TD = .60 (.11), $p < 0.001$, indicating that both groups implicitly learned transitional probabilities, using these statistical cues to determine word boundaries. Two-tailed t-tests indicated that overall performance did not differ between the groups, $p = 0.76$; the groups were equally able to use the statistics of co-occurrence to identify words (see Figure 1).

Similarly, both groups were equally able to detect words with the highest internal transitional probabilities (1.0), $p = 0.47$; mean (SD) of .61 (.26) and .67 (.19) for ASD and TD groups, respectively. They were equally able to detect words with lower transitional probabilities (.37) as well, $p = 0.82$, mean (SD) = .48 (.26) and .50 (.25), respectively. Both groups were more accurate in identifying words with the highest internal transitional probability, although the TD group performed significantly better for high compared to low transitional probability words, $p = 0.02$; the ASD group had less differentiation, $p = 0.09$, as shown in Figure 2, suggesting a lesser sensitivity to such probabilities in the ASD group.

Interestingly, the design of the 2AFC test appeared to play a role in the likelihood of a participant correctly choosing the "word" versus the non-word foil. That is, for the TD group, performance on the 36 item-2AFC test was negatively correlated with test item ordering, $r(34) = -0.34$, $p = 0.04$, such that TD participants were significantly more likely to respond correctly to *early-occurring* items on the 2AFC test. The pattern of more accurate responses to *early-occurring* items was present in the ASD group, although the relationship did not reach significance, $r(34) = -0.28$, $p = 0.10$, indicating that both groups were less able to discriminate "words" from "non-words" as the 2AFC test progressed, and suggesting that their understanding of the transitional probabilities may have been affected by the presentation of foil words *during the 2AFC test.* Consistent with this possibility, as they heard additional presentations of a non-word foil on the 2AFC test, participants in both groups were significantly more likely to choose that non-word foil, $r(34) = -0.39$, $p = 0.02$, and $r(34) = -0.46$, $p = 0.004$, for the ASD and TD groups, respectively. 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.

Contrary to previous studies (Scott-Van Zeeland, et al., 2010; Evans, et al., 2009), 2AFC test performance did not show significant correlations with scores on any cognitive or language tasks or symptom severity measures. Correlational data are shown in Table 3. Given that accurate performance 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 cognitive (NVIQ, VIQ, or FSIQ) or language (PPVT, EVT, Nonword repetition, or two CELF subtests, *Formulated Sentences* (FS) and *Concepts and Following Directions* (C&FD)) measures for either group, as shown in Table 4.

The broad pattern of results thus indicates generally similar performance in learning transitional probabilities from a speech stream presented for a lengthy period of 20 minutes. This identical task has been effectively employed in numerous previous studies of typically developing children and 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 ASD group in the current study demonstrated an ability to detect transitional probabilities as well as their IQ- and age-matched peers.

Discussion

In the current study of school-aged children and adolescents with high-functioning ASD, we found strong evidence of intact implicit learning: participants with ASD had similar accuracy compared to a group of age-, IQ-, and language-matched TD peers. Performance accuracy was tested in multiple ways. *First*, the ASD group successfully differentiated “words” in the artificial language from foil words with the same accuracy as their TD peers. *Second*, the ASD and TD groups were equally able to identify words with the highest internal transitional probability, and were equally able to identify words with the lowest internal transitional probability, indicating that neither group had an advantage in learning easier or more difficult words; that is, the ASD 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 ASD group, accepting a null hypothesis requires careful attention to any subtle differences between groups. There were group differences in performance only in the sense that the ASD group appeared less sensitive to the distinction between high versus low transitional probabilities. These differences, however, were quite subtle, and the primary finding seems to be that the ASD group was able to learn transitional probabilities as effectively as age- and IQ-matched peers after a 21-minute 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), 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), and infant studies that reported that early segmentation skill predicts later vocabulary level (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006; Singh, Nestor, Paulson, & Strand, 2007)[1]. 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 & Mackintosh, 2007; Reber, Walkenfeld, & Hernstadt, 1991; Feldman, Kerr & Streissguth, 1995; Unsworth, Heitz, Schrock, & Engle, 2005), language (Eigsti, Weitzman, Schuh, de Marchena, & Casey, 2011), and autism symptoms (Brown, et al., 2010).

The results demonstrate that, given a lengthy verbal speech stream, school-aged children with ASD 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 proposed relevance of implicit learning in language development (e.g., Ullman 2004; Gerken, 2004; Gomez & Gerken, 1999), the presence of delayed language among individuals with ASD (Tager-Flusberg & Caronna, 2007), and 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 ASD group. While the current finding of equivalent performances in the ASD and TD groups may suggest that impairments in implicit learning of statistical regularities play no role in language delays in ASD, there are some alternative explanations for this pattern of results.

First, the artificial language in the current study was far less complex than a real language, and was presented for a lengthy period of 20 minutes. 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 ASD 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-minute 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 ASD-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 ASD group).

Second, although all ASD participants had a history of significant language delay, the current sample represents only high-functioning individuals, 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 & Bennetto, 2009), a finding that strengthened the prospects of finding implicit learning deficits in a similar group.

Finally, in the absence of behavioral differences, there may nonetheless be neural differences in how individuals with ASD approach the task, a possibility not addressed in the current study. The current results do not examine the neural substrates of implicit learning in ASD. It is possible that the ASD 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 weaknesses in ASD are not a result of implicit learning deficits, or that implicit learning deficits are resolved earlier in development; 2) given a lengthy 21-minute exposure, individuals with ASD are able to detect statistical regularities; 3) only children with ASD who are high-functioning and school-aged are able to capitalize on implicitly learned statistical regularities to segment words; or 4) 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 ASD, 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 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 language abilities and cognitive functioning and/ 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 ASD. School-aged children with ASD clearly demonstrated intact implicit learning of statistical regularities within a lengthy artificial language and performed comparably to age- and IQ-matched TD peers, with only subtle group differences in the sensitivity to the easiest to learn words (i.e. those words with the highest transitional probability). 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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Footnotes

1 One theory of language acquisition (Ullman, 2001; Walenski, Tager-Flusberg, & Ullman, 2006) proposes that vocabulary development is contingent on declarative learning and memory systems, and that syntactic development is contingent upon implicit learning systems. To investigate this possibility, we examined correlations of 2AFC accuracy with more syntactically-driven subtests of the CELF, including *Word Structure/Word Classes* and *Formulated Sentences*. These analyses failed to reveal any significant correlations.

Table 1. Demographic information for participants with autism spectrum disorders (ASD) and typically developing (TD) control participants.

	ASD *M* (*SD*) Range	TD *M* (*SD*) Range	*p*
N	17	24	
Gender (M:F)	14:3	15:9	.16
Chronological Age (years)	13.1 (2.9) 7.7 - 17.2	13.0 (2.6) 8.1 - 17.8	.82
Nonverbal IQ	11.1 (3.1) (5 – 17)	11 (2.4) (8 – 16)	.95
Verbal IQ	10.2 (2.9) (6 – 17)	10.8 (2.3) (6 – 17)	.52
Full Scale IQ	103 (11.5) (85 – 127)	105 (11.5) (88 – 139)	.68
PPVT	110.4 (13.7) (83 – 131)	115.9 (10.8) (100 – 147)	.17
EVT	106.8 (15.7) (81 – 136)	111.0 (16.3) (84 – 140)	.28
SCQ			
Communication	6.1 (2.7) 1 – 10	0.7 (0.8) 0 – 3	< .001
Social Reciprocity	7.6 (3.2) 2 – 13	0.5 (0.7) 0 – 2	< .001
Repetitive Behaviors	5.1 (2.5) 1 – 8	0.8 (0.3) 0 – 1	< .001
SCQ (total score)[b]	20.7 (6.5) 9 – 33	1.3 (1.0) 0 – 4	< .001
ADOS (administered only to ASD group)			
Communication (C)	3.5 (2.0) 1 – 8		
Social Reciprocity (SR)	6.8 (2.7) 1 – 13		
C + SR [a]	10.29 (4.2) 2 – 20		

[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.

[b] On the ADOS, 7 is the cutoff for a diagnosis on the autism spectrum, 10 is the cutoff for autism. All ASD participants in the final sample, except one, were above the cutoff for an ASD diagnosis on the ADOS; this participant had a high SCQ Total score (24) and was judged to carry an ASD diagnosis by clinicians on the study.

Table 2. Items from the 2AFC test.

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 asked to choose which item (a word vs. a non-word foil) sounded "more like the sounds they heard."

Table 3. Correlation between number of subjects, by group, who responded correctly on a given item (of 36) in the 2AFC test, and item characteristics.

	Test item number (1 through 36)	**Prior exposure to foil during test trials**	**Transitional probability of word (averaged across 3 syllables)**	**Percent of group with correct response**
Test item number (1 through 36)		.896***	-.076	-.281‡
Prior exposure to foil during test trials	.896***		-.173	-.388*
Transitional probability of word (averaged across 3 syllables)	-.076	-.173		.158
Percent of group with correct response	-.341*	-.464**	.233	

‡p < .10 (two-tailed), *p < .05 (two-tailed); **p < .01 (two-tailed); ***p < .001 (two-tailed)
Note: Correlations for the ASD group are presented above the diagonal; for the TD group, below the diagonal.

Table 4. Correlations of 2AFC test accuracy with other measures, for ASD and TD groups.

	Age (years)	NVIQ	PPVT	EVT	NWR	SCQ - C	CELF FS	CELF-C&FD	2AFCT
Age (years)		-0.24	0.18	0.31	0.60*	0.03	-0.22	-0.53	0.10
NVIQ	-0.45*		-0.30	-0.17	-0.30	0.18	0.10	-0.23	0.21
PPVT	-0.29	0.52**		0.88**	0.47	0.15	0.52*	0.31	0.07
EVT	-0.08	0.25	0.63**		0.39	-0.01	0.48	0.65	0.05
NWR	0.51*	-0.02	-0.03	.31		-0.17	-0.19	-0.49	-0.28
SCQ – C	0.08	-0.02	-0.18	-0.25	-0.17		0.34	-0.65	0.37
CELF – FS	-0.23	0.01	0.12	0.06	0.04	0.33		0.44	0.12
CELF – C&FD	-0.23	0.44	0.50	0.66*	0.17	0.07	-0.27		-0.25
2AFCT	0.10	-0.47*[a]	-0.36	-0.004	0.002	-0.11	-0.19	-.05	

*p < .05 (two-tailed); **p < .01 (two-tailed)

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

[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 2AFCT. When removed from analyses, this correlation no longer reaches significance.

Figure 1. Percent of correctly identified words by group

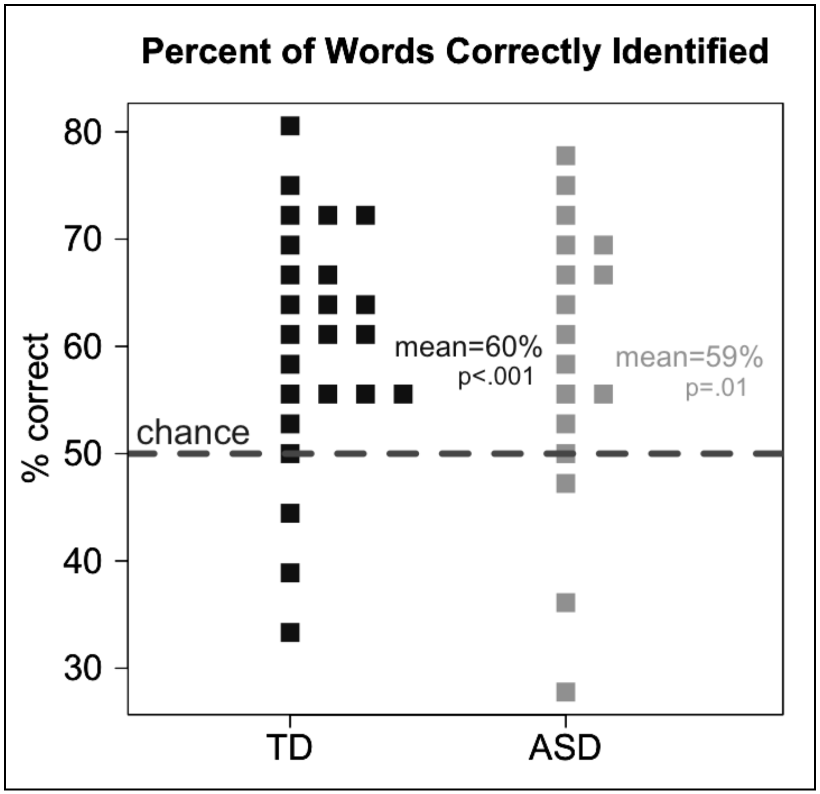

Figure 2. Group performance on 2AFC test for "hard" and "easy" words.