J Autism Dev Disord (2015) 45:1042–1061
DOI 10.1007/s10803-014-2260-1

ORIGINAL PAPER

Use of Emotional Cues for Lexical Learning: A Comparison of Autism Spectrum Disorder and Fragile X Syndrome

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Published online: 16 October 2014

Abstract The present study evaluated the ability of males with fragile X syndrome (FXS), nonsyndromic autism spectrum disorder (ASD), or typical development to learn new words by using as a cue to the intended referent an emotional reaction indicating a successful (excitement) or unsuccessful (disappointment) search for a novel object. Performance for all groups exceeded chance-levels in both search conditions. In the Successful Search condition, participants with nonsyndromic ASD performed similarly to participants with FXS after controlling for severity of ASD. In the Unsuccessful Search condition, participants with FXS performed significantly worse than participants with nonsyndromic ASD, after controlling for severity of ASD. Predictors of performance in both search conditions differed between the three groups. Theoretical and clinical implications are discussed.

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Keywords Fragile X syndrome · Autism spectrum disorder · Lexical learning · Fast mapping · Emotion

Introduction

From birth, children are immersed in a world that requires ongoing social learning. Most children learn to successfully negotiate interactions with social partners and master the ability to efficiently determine the meaning of novel words within the first 2 years of life (Baldwin 1995). During the word learning process, children utilize a number of strategies to identify the referent that an adult is labeling. Many of these strategies involve interpreting subtle social cues to the adult's communicative intent. Thus, the ability to form label-object pairings is not only important for children's lexical development, but may, more generally, serve as an important indicator of children's ability to negotiate shared meanings with social partners. In the present study, we focused on examining the process of word learning in two groups of children with neurodevelopmental disorders: fragile X syndrome (FXS) and nonsyndromic autism spectrum disorder (ASD), with nonsyndromic ASD referring to those children with ASD for whom a specific genetic etiology has not been identified. FXS and nonsyndromic ASD are characterized by difficulties effectively navigating ongoing social interactions that can be expected to negatively affect the ways in which words are learned.

Recent scientific advances have paved the way for a new age of targeted treatments for neurodevelopmental disorders. Despite these advances, there are ongoing hurdles to evaluating the widespread efficacy of such treatments. In the case of FXS, for example, whereas targeted treatments have been found to "rescue" many phenotypic features in the *FMR1* KO mouse and other animal models of the disorder (for review, see Bagni and Oostra 2013), the effects of these same drugs in humans have been surprisingly modest (e.g., Berry-Kravis et al. 2012). Many human behaviors may be more amenable to social or educational treatment than to pharmaceutical interventions or may require a multimodal treatment approach. Studies of the social aspects of word learning could be used to aid the development of multimodal treatments targeting the language deficits observed in FXS and in nonsyndromic ASD. In addition, the learning processes involved in the language acquisition of individuals affected by neurodevelopmental disorders has the potential to inform the development of outcome measures for clinical trials.

FXS is the most common single-gene cause of ASD, with the risk of comorbid FXS and ASD higher than the risk associated with any other single known factor for ASD (Marshall et al. 2008; Hagerman et al. 2008). This high rate of co-occurrence has led many researchers to suggest that research on the mechanisms underlying the development of the FXS phenotype will also provide insight into mechanisms underlying nonsyndromic ASD (e.g., Belmonte and Bourgeron 2006). Although a number of similarities have been observed between the FXS and nonsyndromic ASD phenotypes (e.g., Klusek et al. 2014; Philofsky et al. 2004; Roberts et al. 2001), there is a growing body of research documenting important differences in the manifestations and correlates of ASD in FXS relative to nonsyndromic ASD (McDuffie et al., in press; Thurman et al. 2014; Wolff et al. 2012). Thus, research on the extent to which the FXS and nonsyndromic ASD phenotypes reflect the same or different underlying neurocognitive mechanisms is vital to determine the circumstances in which the same treatment approaches can be used in both conditions. In the present study, we used an experimental approach to study the process of word learning and its determinants in a group of young males with FXS and compared their performance to an age-, nonverbal IQ-, and nonverbal cognitive growth score-matched group of males with nonsyndromic ASD. In addition, a younger group of males with typical development was included, matched to participants with FXS or nonsyndromic ASD on nonverbal growth score.

Word Learning in Typical Development

Typically developing (TD) children's early words are learned when the child is systematically exposed to a novel label in the presence of an object for which the child does not yet have a name (Schaffer and Plunkett 1998; Woodward et al. 1994). In support of this associative learning process, also known as fast-mapping (Carey and Bartlett 1978), numerous studies of naturalistic parent/child interaction have demonstrated that children have larger vocabularies to the extent that caregivers spend time labeling the objects toward which children are directing their attentional focus (Harris et al. 1986; Tomasello and Farrer 1986). That is, children's language learning is facilitated when caregivers create temporal contiguity between novel labels and their object referents. Using an experimental approach, Hollich and colleagues (Hollich et al. 2000) found that, at 12 months of age, TD children required multiple overlapping cues (e.g., object movement, indicating gestures, temporal contiguity between novel label and referent) presented in synchrony to support word learning.

Although such associative learning/mapping may account for word learning early in development, TD children soon use a variety of more sophisticated strategies to disambiguate, or narrow in on, the referent that an adult intends to label. For example, children monitor adult gaze to determine which referent an adult is labeling (Baldwin 1991) and can use referential cues even with a delay between hearing the novel label and seeing the identity of the target object (Baldwin 1993). The strategies children use to disambiguate the intended referent primarily involve utilizing subtle social cues to inform the accurate establishment of label-object pairings.

Subsequent studies have attempted to identify the types of social cues beyond adult gaze direction that young children use when learning new words under nonostensive conditions; that is, contexts in which temporal contiguity between label and object is not sufficient for word learning. Tomasello and Barton (1994; Study 4) utilized a finding game paradigm in which an experimenter suggested to each child that they needed to find "a toma" by searching in a series of five buckets, each of which contained a novel object. TD children ranged in age from 23 to 26 months and each child participated in one of two conditions: (1) Without Search, in which the experimenter presented a novel label, immediately found the object, reacted excitedly, and offered the object to the child, and (2) With Search, in which the experimenter presented a novel label, then found and rejected two objects prior to removing the target object from the bucket, reacted excitedly, and offered the object to the child. In both conditions, children were exposed to the novel label three times, but never in temporal contiguity with an object. Subsequent comprehension testing revealed that the children learned the target word equally well in both search conditions, which led to the conclusion that these young children were able to disambiguate the adult's intended referent by using affective cues.

Tomasello et al. (1996; Study 1) implemented a variation of the Tomasello and Barton (1994) task with younger TD participants who had an average age of 18 months. In this paradigm, children again observed an experimenter as she sequentially opened and removed a toy from each of four buckets with lids. The buckets were fixed in place such that the relative positions of the containers remained the same throughout the task. According to the script for the task, each object was removed from a bucket, examined by the child, and replaced in its bucket before the next object was found. Two experimental conditions differed in the examiner's behavior after she announced, by labeling, her intention to find the novel object. Immediately following the presentation of the novel label in the Without Search condition, the target object was removed from the bucket, the experimenter looked at it with wide eyes and gasped "ah!" and then handed the object to the child. Following the presentation of the novel label in the With Search condition, the examiner sequentially opened and removed objects from two buckets, rejecting each with disappointment before demonstrating excitement to indicate the successful finding of the target object, which was handed to the child. Subsequent comprehension testing demonstrated that there was not a significant difference in word learning between these two conditions, and participants in both conditions performed better than comparison participants who had heard neutral language during the task. Thus, young children are able to use an adult's emotional reaction to correctly guide their label-object mappings in comprehension, even when that reaction is not synchronous with the label.

In summary, young TD children are quite sophisticated in their ability to leverage nonverbal social cues from an adult speaker when learning new words in nonostensive contexts. In the current study, we were interested in whether children with FXS or nonsyndromic ASD were able to use the emotional reaction of an examiner as a cue to the adult's intended referent using an adaptation of the paradigm developed by Tomasello and Barton (1994) and Tomasello et al. (1996; Study 1).

Fragile X Syndrome

FXS is the leading inherited cause of intellectual disability (Crawford et al. 2001) and results from an expansion of the cytosine-guanine-guanine (CGG) sequence of nucleotides within the *FMR1* gene on the X chromosome to more than 200 repeats (Oostra and Willemson 2003). This expansion typically leads to the reduction or absence of FMRP, the protein normally produced by the *FMR1* gene, which is critical for the regulation of biochemical processes involved in synaptic maturation and experience-dependent learning (Bassell and Warren 2008). As in most X-linked disorders, males with FXS are typically more severely affected than are females as a result of the moderating effects of the second unaffected X chromosome in females (Mazzocco 2000). Virtually all males with the FXS full mutation have IQ scores characteristic of an intellectual disability (IQ < 70; Hessl et al. 2009). The FXS phenotype is also associated with a variety of behavioral difficulties, especially in males, including hyperactivity, impulsivity, anxiety, and autism symptomatology (e.g., Cornish et al. 2007; Scerif et al. 2012; Cordeiro et al. 2011; Kau et al. 2000; Harris et al. 2008), which may limit the ability to learn from/navigate social interactions.

Language difficulties also are observed in the vast majority of males with FXS (Abbeduto et al. 2007). In general, although impaired relative to chronological age expectations, receptive vocabulary has been described as keeping pace with nonverbal cognitive ability in FXS (e.g., Abbeduto et al. 2003; McDuffie et al. 2013; Pierpont et al. 2011; Price et al. 2007). Furthermore, receptive language, more generally, is an area of strength relative to expressive language in FXS (Roberts et al. 2001; Philofsky et al. 2004). These studies, however, have primarily focused on measures of receptive vocabulary that indicate the number of words mastered but not the process of how those words were learned. Moreover, these studies have focused largely on older children and adolescents, leaving the early course of word learning in FXS unexplored.

Fast Mapping by Children with Fragile X Syndrome

Relatively little is known about the mechanisms underlying language learning in FXS. In the only published study of fast mapping in FXS, McDuffie et al. (2013) directly paired novel labels with novel objects in an ostensive manner, creating a situation in which there was no ambiguity regarding the adult's intended referent. This study provided an initial metric of the ability of children with FXS to use associative learning as the core of word learning, independent of the ability to understand the speaker's referential intent. McDuffie and colleagues compared the word learning performance of boys with FXS, from 4 to 10 years of age, to that of younger TD boys and to same-aged boys with nonsyndromic ASD. Results indicated that boys with FXS performed worse on the fast-mapping task than did the TD boys, measured both in terms of mean number of correct object selections and in the number of individuals who learned all of the words. Despite having lower levels of nonverbal cognitive ability, however, boys with FXS demonstrated better performance than did the boys with nonsyndromic ASD in terms of mean number of correct objects selected across all trials. No significant between-group differences were observed, however, in terms of the number of individuals who learned all of the words. Finally, for boys with FXS, significant positive associations were observed between fast mapping performance and concurrently measured nonverbal cognitive ability, receptive vocabulary, and expressive vocabulary.

Although results from the McDuffie et al. study provide some insight into the process of word learning in FXS, much remains to be understood. Given the multiple situations in which a young child may be exposed to label-object pairings as well as multiple factors that can support or impede the learning process, it is important to more fully examine word learning in FXS in situations in which children are required to utilize more subtle and complex cues to disambiguate the speaker's intended referent. Furthermore, given our interest in understanding the extent to which difficulties navigating social interactions observed in boys with FXS and boys with nonsyndromic ASD are similar or different, the use of more challenging word learning paradigms is needed to fully differentiate these two disorders. In the present study, we extended our understanding of the mechanisms underlying word learning in FXS by examining the ability to learn a new word based on the speaker's emotional reaction to disambiguate referential intent.

Nonsyndromic Autism Spectrum Disorder

In contrast to FXS, nonsyndromic ASD is a behaviorally diagnosed disorder. Despite considerable variation in behavioral presentation, individuals with nonsyndromic ASD share some core characteristics. As specified by the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-5), ASD is defined by a core impairment in socio-communicative behaviors that is accompanied by the presence of repetitive and stereotyped behaviors (American Psychiatric Association 2013). Currently, it is estimated that ASD occurs in 1 out of every 68 children (Centers for Disease Control and Prevention 2012). There are several other non-diagnostic behavioral features that are commonly observed in nonsyndromic ASD, including intellectual disability, behavioral difficulties (Jang et al. 2011), attentional difficulties (Remington et al. 2009), and epilepsy (Spence and Schneider 2009). In addition, although no longer part of the diagnostic criteria for ASD in the DSM-V, language delay is and is often the first recognized symptom of developmental difficulty for these individuals (e.g., DeGiacomo and Fombonne 1998; Seltzer et al. 2004; Tager-Flusberg et al. 2009). Furthermore, results from multiple studies have found receptive vocabulary to be an area of relative weakness when compared to developmental-level expectations and even relative to expressive language abilities for many children with nonsyndromic ASD (e.g., Ellis Weismer et al. 2010; Kover et al. 2013; Volden et al. 2011).

Fast Mapping by Children with Nonsyndromic Autism Spectrum Disorder

Fast mapping paradigms have been utilized frequently to examine the process of word learning in children with nonsyndromic ASD. Some of this research has assessed the ability of children with nonsyndromic ASD to learn words under highly scaffolded conditions in which one label is presented in the presence of only one object and accompanied by additional attention-directing cues (McDuffie et al. 2006, 2013; Luyster and Lord 2009). Luyster and Lord (2009) demonstrated that children with nonsyndromic ASD (age range 17–61 months) performed similarly on an associative task of label-object pairing to an expressive vocabulary-matched group of younger TD children (age range 14–24 months). In contrast, McDuffie et al. (2013) found that although performance on a highly scaffolded fast mapping task exceeded chance levels for 4- to 10-year-old boys with either FXS or nonsyndromic ASD, younger TD boys outperformed both groups of boys with neurodevelopmental disorders and boys with FXS outperformed boys with nonsyndromic ASD despite having lower levels of nonverbal cognition.

Other studies have focused on examining the ability of children with nonsyndromic ASD to use the speaker's direction of gaze when learning new words (Baron-Cohen et al. 1997; Bani Hani et al. 2013; Gliga et al. 2012; Luyster and Lord 2009; Preissler and Carey 2005). For example, Preissler and Carey (2005) reported that children with nonsyndromic ASD ranging in age from 5.2 to 9.6 years were significantly less likely to use the speaker's direction of gaze to guide word learning in a discrepant labeling condition than were TD toddlers. In fact, children with nonsyndromic ASD consistently chose the object to which they themselves were attending as the speaker's referent regardless of the speaker's gaze. In response to hearing a novel label, however, these same children with nonsyndromic ASD were able to use mutual exclusivity to guide their selection of an unknown picture or object that was paired with a familiar picture or object foil. Bani Hani et al. (2013) also reported that the ability of children with nonsyndromic ASD to use the speaker's gaze was concurrently predictive of their receptive and expressive language skills. Similarly, McDuffie et al. (2006) demonstrated that fast mapping mediated the predictive association between following adult attentional cues and later receptive and expressive vocabulary for preschoolers with nonsyndromic ASD.

Together, these studies provide evidence that, in a word learning task with no requirement to disambiguate the adult's intended referent, very young children with nonsyndromic ASD are able to make an associative pairing between label and object to the same extent as TD children matched on developmental level, although they may begin to fall behind in this area as they age (Baron-Cohen et al. 1997; Preissler and Carey 2005). At the same time, however, children with nonsyndromic ASD show substantial impairments, even relative to developmental level expectations, in using at least some types of social cues in word learning, such as speaker gaze (Baron-Cohen et al. 1997). Speaker gaze, however, is only one important social cue to which word learners must attend. Thus, there is a need to examine the use of a wider range of cues by children with nonsyndromic ASD. Understanding more about the process of word learning for children with nonsyndromic ASD is important as such knowledge can further inform the development of phenotype-specific intervention approaches. Additionally, this same information can add to the growing body of literature illuminating the cognitive processes that are similar or different between nonsyndromic ASD and FXS.

Present Study

Despite considerable research dedicated to understanding language development in individuals with FXS or nonsyndromic ASD, few studies have sought to identify the social cues, in addition to gaze following, that may influence word-learning performance. In the current study, we investigated the ability of boys with FXS, nonsyndromic ASD, or TD to learn a new word based on interpreting the speaker's emotional reaction to either a successful or unsuccessful search for a novel object in the context of a finding game. We were interested in examining whether word learning performance differed between these two conditions and across diagnostic groups. Furthermore, we explored whether or not observed patterns of errors varied as a function of diagnostic group, search condition, or trial type, thereby gaining insight into the learning strategies used. Finally, within each group, we sought to understand which child characteristics predicted word learning performance. Developmental level (i.e., age and nonverbal cognitive ability) and the presence of socially avoidant behaviors and autism symptomatology were predicted to impact word learning performance. Socially avoidant behaviors are frequently reported in individuals with FXS or nonsyndromic ASD and the increased presence of these behaviors was expected to make it less likely that children would use social cues to guide word learning. In addition, it was expected that the increased presence of autism symptomatology would also make it less probable that children would use social cues to guide word learning, as limited social insight and interest are at the core of such symptoms. Finally, we hypothesized that children who are more successful at forming label-object pairings would have higher receptive vocabulary sizes as they should have an advantage in adding new words to their lexicon over time. Thus, the current study addressed the following research questions:

1. Do children with FXS, nonsyndromic ASD or TD use the speaker's emotional reaction to guide word learning in the context of a novel label and an intended object referent?
2. Does the relative profile of fast-mapping performance differ when the speaker's emotional reaction indicates a successful or unsuccessful search for an intended referent for children with FXS, nonsyndromic ASD, or TD?
3. Are there positive associations between performance across conditions (successful vs. unsuccessful search) and does the strength of this association vary across the diagnostic groups?
4. Does the observed pattern of errors vary by (a) Diagnostic group (FXS, ASD, TD); (b) Condition (Successful/Unsuccessful); or (c) Trial type (Comprehension/Generalization)?
5. Do participant characteristics, such as age, nonverbal ability, social avoidant behaviors, or autism symptomatology, account for variance in the ability to use the speaker's emotional reaction in learning new words and does the pattern of prediction vary by experimental task condition for participants with FXS, nonsyndromic ASD, or TD?
6. Within each group, do children who have larger vocabularies more readily acquire new words than do children with smaller vocabularies, irrespective of cognitive level, in response to the speaker's successful and unsuccessful search?

Method

Participants

Participants were drawn from a larger study examining the social-affective bases of word learning in males with FXS ($n = 57$), nonsyndromic ASD ($n = 57$), or TD ($n = 58$). Participants with FXS or nonsyndromic ASD were recruited nationally at one of two university sites (University of California, Davis and University of Wisconsin, Madison). TD participants were recruited locally at each site. The Institutional Review Boards of the respective universities approved this study. Inclusion in the larger study required all participants to meet the following criteria (all based on parent report): (a) native English speakers with parents who are fluent English speakers; (b) can comply with simple instructions (e.g., "Give me the ball"); (c) speech is the primary means of communication; (d) produces approximately 10 different words spontaneously within the prior month; (e) no sensory or physical impairments that would limit participation in project activities; and (f) lives at home with biological mother. In addition, participants were tested by project staff and found to have a pure tone, air conduction threshold of 30 dB HL or better in each ear (averaged across 500, 1,000, and 2,000 Hz).

Participants with FXS were required to provide documentation of a diagnosis of the *FMR1* full mutation (i.e.,

>200 CGG repeats, with or without mosaicism). In the case of participants with nonsyndromic ASD: (1) they entered the study with an existing community diagnosis of ASD; (2) parents provided evidence documenting that genetic testing had ruled out FXS; (3) a project physician conducted a dysmorphology and neurological exam to rule out other possible syndromic causes of ASD (e.g., Rett's syndrome, tuberous sclerosis); (4) participants received a calibrated autism severity score of at least four on the Autism Diagnostic Observation Schedule administered by project staff to verify the diagnosis (Gotham et al. 2009); and (5) participants received a classification of ASD according to the criteria outlined by Risi and colleagues (Risi et al. 2006) on the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al. 2003a, b). Project staff who had completed research reliability training administered both the ADOS and the ADI-R. Finally, TD participants were included if they: (1) received an IQ score greater than 80 on the Leiter International Performance Scales; (2) were not receiving special education services at the time of enrollment; and (3) received a score on the Social Communication Questionnaire that did not exceed 11.

Participant Selection for the Current Study

Virtually all males with FXS demonstrate developmental/cognitive delays, whereas nonsyndromic ASD is associated with a much wider range of cognitive functioning (Hessl et al. 2009; Ryland et al. 2012), presenting a significant confound in studies focused on phenotypic comparisons. Thus, the present study sought to compare participant with FXS and participants with nonsyndromic ASD of comparable ability levels. Within the literature, it has been shown that essentially all males with FXS have a nonverbal IQ score that is less than or equal to 85 (Hessl et al. 2009). This cutoff was therefore used to ensure that an objective criteria would be utilized to decide which participants with FXS or nonsyndromic ASD would be included in the present project. Implementation of this criteria resulted in the exclusion of 6 children with FXS (3 IQ data not available, 3 IQ scores > 85) and 20 children with nonsyndromic ASD (4 IQ data not available, 16 IQ scores > 85). Additionally, all participants in the present sample had completed four valid trials of the experimental task (i.e., Speaker Emotional Reaction Task described below). Implementation of the latter criteria resulted in the exclusion of 1 participant with FXS, 2 participants with nonsyndromic ASD, and 4 participants with TD. Participants with FXS and those with nonsyndromic ASD were well matched on chronological age ($p = .73$, $d = .06$, $s^2_{ratio} = 1.24$). However, examination of the α-levels, effect sizes, and variance ratios indicated that the samples were not adequately matched (e.g., Frick 1995; Kover and Atwood 2013; Mervis and Klein-Tasman 2004) in terms of either Leiter nonverbal IQ standard score ($p = .01$, $d = .59$, $s^2_{ratio} = 1.20$) or Leiter nonverbal growth score ($p = .03$, $d = .49$, $s^2_{ratio} = 1.21$), with scores for participants with FXS lower than scores for participants with nonsyndromic ASD. Furthermore, comparisons of the TD participants to both the participants with FXS ($p = .08$, $d = .35$, $s^2_{ratio} = 1.38$) and the participants with nonsyndromic ASD ($p = .48$, $d = .16$, $s^2_{ratio} = 1.14$) on Leiter nonverbal growth score, indicated that groups were not adequately matched based on α-levels, effect sizes, and variance ratios.

Table 1 Descriptive statistics for final participant sample

	FXS ($n = 32$) Mean (SD, range)	Nonsyndromic ASD ($n = 32$) Mean (SD, range)	TD ($n = 32$) Mean (SD, range)
CA	7.29 (2.03, 4.06–10.32)	7.37 (1.87, 4.02–10.86)	3.93 (1.09, 2.05–5.8)
Nonverbal IQ[a]	64.91 (11.30, 42–83)	65.50 (11.85, 40–83)	111.09 (14.98, 82–141)
Total nonverbal growth score[a]	456.16 (11.56, 426–476)	457.78 (11.80, 439–479)	457.09 (12.75, 429–482)
Receptive vocabulary raw score[b]	73.25 (30.80, 22–130)	55.81 (33.39, 8–139)	83.16 (28.65, 26–132)

[a] Leiter Brief IQ Test

[b] Peabody Picture Vocabulary Test, 4th edition

Given these findings, participants with FXS and with nonsyndromic ASD were selected, utilizing the sampling procedures outlined by Mervis and John (2008), to create samples matched on CA ($p = .85$, $d = .04$, $s^2_{ratio} = 1.18$), Leiter nonverbal IQ ($p = .85$, $d = .05$, $s^2_{ratio} = .91$), and Leiter nonverbal growth score ($p = .59$, $d = .14$, $s^2_{ratio} = .96$), thereby ensuring that the two groups would demonstrate not only the same ability levels but also the same degree of delay relative to chronological age within the nonverbal domain. In addition, TD participants were selected, utilizing the same matching procedures, to match the FXS ($p = .76$, $d = .08$, $s^2_{ratio} = .82$) and nonsyndromic ASD ($p = .82$, $d = .06$, $s^2_{ratio} = .86$) groups on nonverbal growth score to evaluate how performance by participants with FXS or nonsyndromic ASD compared to performance by TD children of the same nonverbal cognitive level. This matching process resulted in the final participant sample of 32 participants with FXS, 32 participants with nonsyndromic ASD, and 32 TD participants for the present study. Based on the available data, of the 32 participants with FXS included in the final participant sample, 32/32 participants were observed to demonstrate at least some autism symptomatology and 23/32 participants met study criteria (described previously) for a comorbid diagnosis of ASD. Of the 9 participants who did not meet study criteria for an ASD diagnosis, the ADI-R was unavailable for 2 participants with FXS who met ASD criteria on the ADOS, 4 participants met ASD criteria on the ADI-R but not the ADOS, 1 participant met ASD criteria on the ADOS but not the ADI-R, and 2 participants did not meet ASD criteria on either the ADOS or the ADI-R. Descriptive statistics for this final participant sample are presented in Table 1.

Assessment Measures

The Leiter International Performance Scale: Revised

The Leiter International Performance Scale—Revised (Leiter-R; Roid and Miller 1997) is a nonverbally administered standardized assessment of nonverbal intelligence. The subtests comprising the Brief IQ were administered; namely, Figure Ground, Form Completion, Sequential Order, and Repeated Patterns. Two metrics from the Leiter-R were utilized: the brief IQ standard score and the total growth score. The brief IQ provides information about a child relative to his/her peers at a given time. The mean IQ for the Leiter-R standardization sample is 100, with a standard deviation of 15. The total growth score provides an equal interval scale estimate of the participant's absolute ability level at a given time point. Thus, the total growth score is a better metric for matching purposes and statistical analyses than an age-equivalent score (e.g., MA), which does not provide an equal interval scale because it reflects the median chronological age at which a particular raw score was obtained.

Peabody Picture Vocabulary Test: 4th Edition

The Peabody Picture Vocabulary Test-4th edition (PPVT-4; Dunn and Dunn 2007) is an individually administered assessment of concrete receptive vocabulary. For each item, the participant is presented a page containing four pictures in color and asked to select the picture that matches the vocabulary word spoken by the examiner. Approximately half of the participants in each group received Version A or B of this measure. Raw scores were used as a metric for receptive vocabulary ability.

Anxiety, Depression, and Mood Scale

The Anxiety Depression and Mood Scale (ADAMS; Esbensen et al. 2003) is a 28-item informant questionnaire designed as a screening instrument for psychiatric disorders in individuals with intellectual disability. Behaviors are rated using a 4-point Likert scale indicating severity of problem behavior, with higher scores indicative of increased severity of problem. The ADAMS yields 5 subscale scores: Manic/Hyperactive Behavior, Depressed Mood, Social Avoidance, General Anxiety, and Obsessive/Compulsive Behavior. Only the Social Avoidance subscale score was used in this project. Biological mothers were respondents.

Autism Diagnostic Observation Schedule

The Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2007) is a semi-structured play-based interaction in which a trained examiner creates specific interactive contexts to observe the participant's reciprocal social interaction skills as well as the presence of repetitive behaviors. One of four ADOS modules is administered based upon the participant's expressive language level. In the current project, participants received ADOS modules 1, 2, or 3. Calibrated Severity Scores, which allow comparisons across different modules, were computed based upon the algorithms provided by Gotham et al. (2009). All examiners were research reliable. Reliability was maintained and assessed over the course of the study by independent coding and consensus discussions for 10 % of administrations for each participant group (i.e., FXS or nonsyndromic ASD) by all active examiners across sites (a total of 4 examiners). Reliability was generally good, although it was somewhat lower for participants with FXS than for those with nonsyndromic ASD. This is not surprising as training for this instrument is based upon evaluating the characteristics of individuals with nonsyndromic ASD. For the participants with FXS and those with nonsyndromic ASD selected for cross-site reliability, overall reliability was 74 and 83 %, respectively.

Social Communication Questionnaire

The Social Communication Questionnaire (SCQ; Rutter et al. 2003a, b) is a caregiver-report screening questionnaire, which probes for characteristics associated with a diagnosis of ASD. Total scores range from 0 to 39. This measure was used to assess the presence of autism symptomatology in the TD participants.

Experimental Fast-Mapping Measure: Speaker's Emotional Reaction Task

Overview

The Speaker's Emotional Reaction Task, modeled after Tomasello and Barton (1994) and Tomasello et al. (1996), was designed to assess the participant's ability to learn a new word based on interpreting the speaker's emotional reaction in the context of a finding game. The finding game included four episodes and involved searching for a target object in four differently colored buckets, each of which contained a novel object. Each episode consisted of two training trials. Prior to each training trial, the examiner announced her intention to find a particular novel object (i.e., the target object) which was labeled with a nonsense word. To maintain child engagement, a routine was established such that the examiner took the lid off each bucket, and the child removed the object and handed it to the examiner. Once the examiner obtained the object, she reacted with either positive (excitement) or negative (disappointment) emotional reaction and then returned the object to the child who replaced it into the bucket. This search procedure was repeated for each of the four buckets and the same novel objects were used in both training trials within an episode. At the conclusion of two training trials, the examiner administered two test probes using a forced choice array in which four objects (two novel, two familiar) were arranged in four plastic trays, attached horizontally, adjacent to one another.

Novel Objects

Four sets of novel objects were created for this task. Each object set consisted of five brightly colored wooden objects that were created from wooden shapes glued together such that they did not resemble any conventional object likely to be recognized by the participant. For a given participant, the object set assigned to each episode of this task was selected from a sequential list of all possible permutations of 4 (4!). Two objects, within each set of five objects, were assigned as the target and foil object for each episode were also randomly selected by using the first two numbers from a sequential list of all possible permutations of 5 (5!).

Conditions

The Speaker Emotional Reaction Task involved two different conditions: (a) a Successful Search condition during which the labeled/intended object (i.e., the object that elicited a positive reaction) was found in one of the four buckets; and (b) an Unsuccessful Search condition during which the labeled/intended object was not found in any of the four buckets (i.e. all objects elicited a negative reaction). In the Successful Search condition, the labeled object was found in the bucket that was searched second or third. When the target object was found, the Examiner reacted with a facial expression of excitement accompanied by vocalization of "Wow!" When each of the three non-target objects was found, the Examiner reacted with a facial expression of disappointment accompanied by shoulder shrug and vocalization of "Oh (falling intonation)." Four episodes were presented to each child, two per condition; episodes were always presented in the following order: Successful, Unsuccessful, Successful, and Unsuccessful. A short break was provided between the second and third episodes. Table 2 indicates the search order and bucket containing the target object for each episode within each condition.

Presentation of Novel Label

A different novel label and object set was used during each episode. The novel labels were CVCV nonsense syllables that were screened to make sure they did not resemble any words that would be familiar to participants. At the onset of each of the two training trials within an episode, the Examiner used the novel label three times in sentence-final position (e.g., "Let's find a *teeto*. We need to find a *teeto*. Let's look for a *teeto!*"). After the child searched in the first two buckets, the Examiner would remind the child of the novel label (e.g., "Remember, we are looking for some *teetos*!"). The child and examiner would then search in the remaining two buckets. The sequence of novel label presentation and search was then repeated during a second training trial. Thus, the child was exposed to each novel label 8 times during an episode. Novel labels were counterbalanced across participants and assigned sequentially from a list of 68 novel words with the constraint that no two words assigned to any participant began with the same phoneme or differed only by one phoneme.

Test Probes

Each completed episode of two training trials was followed by two test probes (Comprehension and Generalization) using a forced choice paradigm. Each test probe utilized four stimulus objects that were placed into a divided tray such that the objects were horizontally displayed to the child. For the Successful Search condition, the object array for the Comprehension probe consisted of the previously found novel object that had elicited a positive emotional reaction (i.e., the intended target object; designated A), a previously found novel object that had elicited a negative emotional reaction (i.e., the foil; designated B) and 2 objects identified as familiar to the child by the child's mother prior to the task (designated C, D). The Generalization probe for this condition utilized a new exemplar of the target object (designated A′), a new exemplar of the foil object (B′) and two different familiar objects (E, F). For the Unsuccessful Search condition, the object array for the Comprehension probe consisted of a previously unseen novel object (the target; designated A), a previously found

Table 2 Search order and target object location for speaker emotional reaction task

Episode	Condition	Episodes	Search order	Location of target object
1	Successful	Training trial 1	**3** 4 1 2	Bucket searched 3rd
		Training trial 2	4 1 **2** 3	Bucket searched 2nd
2	Unsuccessful	Training trial 1	1 2 3 4	Not found
		Training trial 2	4 1 2 3	Not found
3	Successful	Training trial 1	1 **2** 3 4	Bucket searched 2nd
		Training trial 2	4 1 2 **3**	Bucket searched 3rd
4	Unsuccessful	Training trial 1	3 4 1 2	Not found
		Training trial 2	4 1 2 3	Not found

novel object that had elicited a negative reaction (the foil; designated B), and 2 familiar objects selected by the child's mother prior to the task (designated C, D). The Generalization probe for this condition utilized a new exemplar of the target object (designated A′), a new exemplar of the foil object (B′) and two different familiar objects (E, F).

During both Comprehension and Generalization probes, the child was asked to hand the target object to the Examiner, who stated, "Find the *teeto*! Give me the *teeto!*" The child was also asked to find one of the familiar objects during each type of probe to provide a metric of behavioral compliance and an index of understanding of the task demands. Within a Comprehension or Generalization test probe, the order of requesting either the novel or familiar object was counterbalanced across participants. Each object selected by the child during test probes was placed back into the response tray by the examiner prior to the next probe for that condition. As the experimental task included two Successful Search trials and two Unsuccessful Search trials and each trial included a Comprehension probe and a Generalization probe, each participant was exposed to a total of eight test probes across the experimental conditions.

Reliability and Fidelity All examiners who administered the word-learning task were graduate students or graduate-level professionals in educational psychology, developmental psychology, or speech/language pathology. They were trained to administer the word-learning task to 90 % fidelity criteria by the second author. Immediately after each participant's visit, the examiner who tested that participant scored task performance by watching the videotape of task administration. This examiner also verified validity of the experimental task trials. Trials could be considered invalid due to examiner error, child noncompliance, or interruption of the task. In order to assess reliability of scoring decisions, another trained examiner independently coded the same session. The procedures for determining reliability of scoring decisions and fidelity of task administration for data collected at both sites were conducted by trained examiners at one site. Any scoring discrepancies were resolved through consensus discussions with a third trained examiner. For the current study, data were included in the analyses only if the participant completed four valid trials of the experimental task.

A checklist was used to assess fidelity of administration for 20 % of the experimental fast-mapping tasks randomly selected within each diagnostic group and across sites. A trained examiner other than the one who had initially administered the task evaluated fidelity of administration. The fidelity measure included 40 items querying adherence to rules for: (1) object presentation (16 items; i.e., presentation script, number of labels, equivalent talking about target and distracter); (2) randomization (12 items; i.e., side of presentation, order of presentation, and target object assignment); and, (3) comprehension testing (12 items; i.e., probe script, object placement, prompting of child response). Mean overall percentage of agreement was above 97 % across diagnostic groups and sites.

Results

Prior to evaluating the research questions, performance on the familiar object trials was evaluated to provide a metric of children's ability to understand and comply with the demands of the experimental fast-mapping task. Results of these analyses indicated that, across 8 familiar object trials, all three groups of children were able to complete the task successfully (FXS: *M correct* = 7.87; nonsyndromic ASD: *M correct* = 7.24; TD: *M correct* = 7.87).

To address the research questions focused on the extent to which participants used the speaker's emotional reaction to guide word learning, we separately considered fast-mapping performance under each experimental condition. Within these conditions, we report performance for each group relative to chance level expectations (research question 1), followed by comparisons for differences between the groups (research question 2). During each test probe, participants were asked to select the examiner's intended referent from a total of four objects (i.e., one novel target object, one novel foil object, 2 familiar objects); thus, the probability of selecting the correct object by chance on any given test probe was .25.

Performance on the Successful Search Condition

Comparisons Relative to Chance

Examination of the data indicated that the distributions for performance on the Successful Search probes violated the parametric assumption of normality for all three participant groups; thus, one-sample Wilcoxon signed-rank tests were used to compare each group's performance on the Successful Search probes to a reference score of 1 ($np = 4 \times .25 = 1$). All three participant groups exceeded chance levels: TD participants, $T = 406.00$, $z = 4.79$, $p < .001$, $r = .85$; participants with FXS, $T = 426.00$, $z = 4.57$, $p < .001$, $r = .81$; and participants with nonsyndromic ASD, $T = 311.00$, $z = 3.54$, $p < .001$, $r = .62$; all large effect sizes.

Between-Group Comparisons

Mann–Whitney U test statistics were utilized to evaluate the presence of between-group differences in Successful Search performance. Performance at the group level was significantly better for participants with FXS than for participants with nonsyndromic ASD ($U = 366.00$, $z = -2.02$, $p = .04$, $r = .25$). However, this difference in performance may be due to the fact that, on average, boys with FXS demonstrate fewer symptoms of autism than do boys with nonsyndromic ASD, even when only considering boys with FXS and comorbid ASD. Thus, nonparametric regression analyses were conducted using the Serlin-Harwell Aligned Rank Procedure (Serlin and Harwell 2004) to compare Successful Search performance between the FXS and nonsyndromic ASD groups after controlling for autism symptom severity. These results indicated no significant difference between participants with FXS and participants with nonsyndromic ASD on the Successful Search condition after controlling for autism symptom severity $F(2,63) = 1.59$, $p = .21$).[1] Performance of TD participants was significantly better than for participants with nonsyndromic ASD ($U = 709.00$, $z = 2.78$, $p = .005$, $r = .35$) but did not differ significantly from participants with FXS ($U = 587.00$, $z = 1.07$, $p = .29$, $r = .37$).

Analyses utilizing Chi square test statistics also were conducted to evaluate whether group-level findings could be replicated when considering the number of individual participants in each group who successfully learned all label-object pairings. These follow-up analyses failed to yield any significant between-group differences: FXS versus nonsyndromic ASD ($\chi^2[1] = .067$, $p = .41$, $phi = -.10$); TD versus nonsyndromic ASD ($\chi^2[1] = 6.48$, $p = .02$, $phi = -.32$); and, TD versus FXS ($\chi^2[1] = 3.09$, $p = .13$, $phi = -.22$).

Performance on the Unsuccessful Search Condition

Comparisons Relative to Chance

One-sample Wilcoxon signed-rank tests again were used to compare performance on the Unsuccessful Search condition for each group to a reference score of 1 ($np = 4 \times .25 = 1$). Performance by all three participant groups exceeded chance levels in the Unsuccessful Search condition: TD participants, $T = 402.50$, $z = 4.09$, $p < .001$, $r = .72$, a large effect size; participants with FXS, $T = 230.00$, $z = 2.43$, $p = .015$, $r = .43$, a medium effect size; and participants with nonsyndromic ASD, $T = 327.00$, $z = 3.41$, $p = .001$, $r = .60$, a large effect size.

[1] Subsets of participants with FXS and with nonsyndromic ASD were created utilizing the same matching procedures described in the Method section to create a samples of participants with FXS and participants with nonsyndromic ASD matched on nonverbal cognitive ability, utilizing only the participants with FXS who met study criteria for a comorbid diagnosis of ASD (previously described). The same pattern of findings was obtained. When initially compared, performance at the group level was significantly better for participants with FXS + ASD than for participants with nonsyndromic ASD on Successful Search performance ($U = 137.00$, $z = 2.538$, $p = .011$, $r = .38$). However, there was no significant difference between the groups after controlling for autism symptom severity ($F(2,54) = 2.92$, $p = .09$).

Between-Group Comparisons

Results of a Mann–Whitney U comparison indicated that participants with FXS performed significantly worse than the TD participants ($U = 725.50$, $z = 2.94$, $p = .003$, $r = .37$). Performance by participants with nonsyndromic ASD did not differ significantly from either participants with FXS ($U = 622.50$, $z = 1.53$, $p = .13$, $r = .19$) or TD participants ($U = 620.50$, $z = 1.50$, $p = .13$, $r = .19$). Nonparametric regression analyses were conducted using the Serlin-Harwell Aligned Rank Procedure (Serlin and Harwell 2004) to compare Unsuccessful Search performance between the FXS and nonsyndromic ASD groups after controlling for autism symptom severity. Results indicated that, after controlling for autism symptom severity, participants with nonsyndromic ASD performed significantly better than did participants with FXS on the Unsuccessful Search condition $F(2,63) = 6.19$, $p = .02$.[2]

Analyses examining the data on an individual level demonstrated the same pattern of findings. Significantly fewer participants with FXS learned all the label-object pairings in the Unsuccessful Search condition relative to TD participants ($\chi^2[1] = 14.25$, $p < .001$, $phi = -.48$) and participants with nonsyndromic ASD ($\chi^2[1] = 5.41$, $p = .03$, $phi = .30$). Additionally, the number of participants with nonsyndromic ASD who learned all four words during the Unsuccessful Search trials did not differ significantly from that for TD participants ($\chi^2[1] = 2.88$, $p = .11$, $phi = -.22$).

Performance on the Successful versus Unsuccessful Search Conditions

Relative Profiles of Performance

To address the second research question, within-group analyses were conducted to determine if children with FXS, nonsyndromic ASD, or TD demonstrated differential levels of task performance between the Successful and Unsuccessful Search conditions. For the participants with FXS, performance on the Successful Search condition was significantly better than performance on the Unsuccessful Search condition, ($T = 45.00$, $z = -3.35$, $p = .001$, $r = .59$). No statistically significant between condition differences were observed for participants with nonsyndromic ASD ($T = 131.00$, $z = -.217$, $p = .83$, $r = .04$) or TD participants ($T = 54.00$, $z = -1.67$, $p = .09$, $r = .30$). Analyses indicated that even when considering performance on the individual level (i.e., the number of children in each participant group who successfully learned all of label-object pairings) the same pattern of findings were observed: FXS ($\chi^2[1] = 9.91$, $p = .001$, $phi = -.40$), nonsyndromic ASD ($\chi^2[1] = .02$, $p = .89$, $phi = -.04$), and TD ($\chi^2[1] = 1.00$, $p = .45$, $phi = -.12$).

Associations Between Successful and Unsuccessful Search Performance

To address the third research question, Spearman rank order correlations were used to examine concurrent associations between task performance during Successful and Unsuccessful Search trials. For the TD participants, a significant positive association was observed between performance on the Successful and Unsuccessful Search conditions ($r = .39$, $p = .026$); however, this association did not reach significance for participants with FXS ($r = -.10$, $p = .58$) or nonsyndromic ASD ($r = .26$, $p = .16$). Fisher's r-to-z transformation indicated that there was a trend for a stronger association between performance on the two conditions for the TD participants than for the participants with FXS ($z = -1.95$, $p = .05$). The strength of this association for participants with nonsyndromic ASD did not differ significantly from that for TD participants ($z = .55$, $p = .58$) or participants with FXS ($z = -1.40$, $p = .16$).

Pattern of Errors

To address the fourth research question, Chi square analyses were used to compare the likelihood of selecting a novel foil object in response to the novel label relative to selecting a familiar object as a function of Diagnostic Group (FXS, ASD, TD), Search Condition (Successful/Unsuccessful), and Test Probe Type (Comprehension/Generalization).

Errors that involved selecting the familiar object (instead of the target object) were made significantly more often by participants with nonsyndromic ASD than for TD participants ($\chi^2[1] = 5.85$, $p = .02$, $phi = -.17$). Object selection errors for participants with FXS did not differ significantly from errors observed for participants with nonsyndromic ASD ($\chi^2[1] = 1.65$, $p = .20$, $phi = .08$) or for TD participants ($\chi^2[1] = 1.79$, $p = .18$, $phi = -.10$).

The relation between Error Pattern and Search Condition was not significant for any of the participant groups: FXS ($\chi^2[1] = .55$, $p = .46$, $phi = -.07$), nonsyndromic ASD ($\chi^2[1] = .00$, $p = 1.00$, $phi = .00$), and TD

[2] The same pattern of findings was obtained when comparing participants with FXS + ASD to participants with nonsyndromic ASD matched on nonverbal cognitive ability. When initially compared, no between-group differences on Unsuccessful Search performance were observed ($U = 296.50$, $z = 1.33$, $p = .19$, $r = .20$); however, after controlling for autism symptom severity, participants with nonsyndromic ASD performed significantly better than participants with FXS + ASD ($F(2,54) = 7.39$, $p = .008$).

($\chi^2[1] = .80$, $p = .37$, $phi = .10$). Thus, participants did not vary in their tendency to incorrectly select a familiar or novel object regardless of whether the test probe followed a Successful or Unsuccessful Search.

Participants with nonsyndromic ASD committed significantly more errors by selecting the familiar object relative to the novel foil object in Comprehension probes relative to the Generalization probes ($\chi^2[1] = 4.62$, $p = .03$, $phi = -.20$). The relation between Error Pattern and Probe Type was not significant for participants with FXS ($\chi^2[1] = 1.20$, $p = .276$, $phi = -.10$) or TD participants ($\chi^2[1] = .02$, $p = .89$, $phi = -.02$).

Predictors of Fast-Mapping Performance

The fifth research question was addressed by examining bivariate associations between child characteristics and experimental task performance. A series of stepwise linear regression analyses was then conducted for each group of participants to determine if social avoidance and autism symptomatology accounted for unique variance in predicting experimental task performance over and above the contributions of chronological age and nonverbal cognitive ability. Separate within-group analyses were used to identify predictors that might differentially account for variance in the Successful and Unsuccessful Search conditions. Assumptions of linearity, normally distributed errors, and uncorrelated errors were met. One-tailed tests were used to evaluate the significance of the final step of each regression model as we predicted that CA and nonverbal cognitive ability would be positively related to, and social avoidance and autism symptomatology would be negatively related to, performance on the Successful and Unsuccessful conditions.

Successful Search Condition

For participants with FXS, means, standard deviations, and intercorrelations are reported in Table 3. Significant correlations between child characteristics and fast-mapping performance failed to emerge for this experimental condition. In the first step of the regression, inclusion of CA and Leiter-R nonverbal growth score did not result in a significant model ($F(2,29) = .35$, $p = .71$, adjusted $R^2 = -.04$). The addition of ADAMS Social Avoidance and ADOS Severity, in the next step, also failed to reveal significant predictors of performance for participants with FXS ($F(4,27) = .58$, $p = .68$, adjusted R^2 change $= -.06$).

The means, standard deviations, and intercorrelations for participants with nonsyndromic ASD are reported in Table 4. Nonverbal growth score was positively related and social anxiety was negatively related to performance in the Successful Search condition. Entering chronological age and nonverbal cognitive growth score into the regression model significantly predicted performance in this condition ($F(2,28) = 11.04$, $p < .001$, adjusted $R^2 = .40$), with only Leiter nonverbal growth score accounting for unique variance in predicting fast-mapping performance ($t = 4.22$, $p < .001$, one-tailed, semipartial $r = .35$). The addition of ADAMS Social Avoidance and ADOS Autism Severity at the next step of the regression significantly improved the predictive value of the model, ($F(4,26) = 6.92$, $p = .001$, adjusted $R^2 = .44$). Within this final model, Leiter-R nonverbal growth score ($t = 3.86$, $p < .001$, one-tailed, semipartial $r = .28$) and ADAMS Social Avoidance ($t = -2.00$, $p = .03$, one-tailed, semipartial $r = -.07$) each accounted for unique variance in fast-mapping performance.

Table 3 Means, standard deviations, and intercorrelations for experimental task performance and predictor variables for participants with FXS

Variable	*M*	*SD*	1.	2.	3.	4.
Successful condition	2.78	1.21	.07	−.02	−.02	−.16
Unsuccessful condition	1.50	1.08	.18	.19	−.08	−.12
Predictor variables						
1. CA	7.29	2.03	–	.82**	.24	.14
2. Leiter nonverbal growth score	456.16	11.56		–	.13	−.09
3. ADAMS social avoid	6.23	4.67			–	.24
4. ADOS Autism severity	5.66	2.10				–

** $p < .001$

Table 4 Means, standard deviations, and intercorrelations for experimental task performance and predictor variables for participants with nonsyndromic ASD

Variable	*M*	*SD*	1.	2.	3.	4.
Successful condition	2.03	1.38	.29	.65**	−.46*	−.001
Unsuccessful condition	2.10	1.38	−.07	.19	−.16	−.41*
Predictor variables						
1. CA	7.27	1.81	–	.64**	−.29	.28
2. Leiter nonverbal growth score	457.10	11.33		–	−.34*	.10
3. ADAMS social avoid	9.10	4.92			–	.09
4. ADOS Autism severity	8.03	1.49				–

* $p < .05$; ** $p < .001$

Table 5 Means, standard deviations, and intercorrelations for experimental task performance and predictor variables for TD participants

Variable	*M*	*SD*	1.	2.	3.	4.
Successful condition	3.10	1.17	.60**	.53*	–.008	–.19
Unsuccessful condition	2.52	1.53	.49*	.23	.19	–.06
Predictor variables						
1. CA	3.94	1.10	–	.83**	−.04	–.21
2. Leiter nonverbal growth score	456.97	12.94		–	−.06	–.26
3. ADAMS social avoid	.77	1.20			–	.22
4. SCQ total	4.26	2.94				–

* $p < .05$; ** $p < .001$

For TD participants, the means, standard deviations, and intercorrelations are reported in Table 5. Both chronological age and Leiter nonverbal growth score were significant bivariate correlates of performance in the Successful Search condition. Inclusion of both variables resulted in a significant model ($F(2,28) = 8.21$, $p = .002$, adjusted $R^2 = .33$), with only chronological age accounting for unique variance in predicting fast-mapping performance ($t = 1.98$, $p < .03$, one-tailed, semipartial $r = .09$). The addition of the ADAMS Social Avoidance and SCQ Total Score did not significantly improve the predictive model ($F(4,26) = 3.88$, $p = .01$, adjusted $R^2 = .28$). In the final model, chronological age ($t = 1.91$, $p = .03$, semipartial $r = .09$) was the only factor that accounted for unique variance in performance.

Unsuccessful Search Condition

For participants with FXS, the means, standard deviations, and intercorrelations with performance on the Unsuccessful Search condition are reported in Table 3. No significant bivariate relationships emerged between child characteristics and performance on the Unsuccessful Search condition. Additionally, entering chronological age and Leiter-R nonverbal growth scores failed to yield a significant model of performance on the Unsuccessful Search condition, ($F(2,29) = .55$, $p = .58$, adjusted $R^2 = -.03$). The addition of ADAMS Social Avoidance and ADOS Severity also failed to result in a significant predictive model ($F(4,27) = .45$, $p = .77$, adjusted $R^2 = -.08$).

For participants with nonsyndromic ASD, means, standard deviations, and intercorrelations for performance on the Unsuccessful Search condition are reported in Table 4. ADOS Autism Severity emerged as a significant negative correlate of performance on this condition. Inclusion of CA and Leiter-R nonverbal growth score did not result in a significant model ($F(2,28) = 1.61$, $p = .22$, adjusted $R^2 = .04$). Addition of ADAMS Social Avoidance and ADOS Severity also failed to result in a significant model (F $(4,26) = 2.13$, $p = .11$, adjusted $R^2 = .13$). Examination of the intercorrelations presented in Table 4, however, revealed that the only predictor correlated with performance in the Unsuccessful Search condition was ADOS severity. Follow-up analyses revealed that performance on the Unsuccessful Search trials was significantly negatively correlated with both severity of Social Affective symptoms ($r(32) = -.36$, $p = .02$, one-tailed) and severity of Restricted Repetitive Behavior ($r(32) = -.33$, $p = .03$, one-tailed), the two domains of symptoms within autism symptomatology.

Finally, for TD participants, the means, standard deviations, and intercorrelations are reported in Table 5. Chronological age emerged as a significant bivariate correlate of fast-mapping performance in the Unsuccessful Search Condition. When CA and Leiter-R nonverbal growth score were entered into a regression equation, they significantly predicted fast-mapping performance, ($F(2,28) = 6.83$, $p = .004$, adjusted $R^2 = .28$), with both CA ($t = 3.39$, $p = .001$, one-tailed, semipartial $r = .28$) and Leiter-R nonverbal growth score ($t = -1.96$ $p < .03$, one-tailed, semipartial $r = -.09$) accounting for unique variance in predicting fast-mapping performance. Once again, although the final model was significant, the addition of the variables ADAMS Social Avoidance and SCQ total did not significantly improve the prediction ($F(4,26) = 3.81$, $p = .01$, adjusted $R^2 = .27$). In the final model, chronological age ($t = 3.41$, $p = .001$, one-tailed, semipartial $r = .27$) and Leiter-R nonverbal growth score ($t = -1.93$, $p = .03$, one-tailed, semipartial $r = -.09$) each accounted for unique variance in predicting performance.

Relations Between Fast-Mapping and Receptive Vocabulary

The final research question was addressed by examining partial Spearman's rank correlations between fast-mapping performance in the Successful and Unsuccessful Search condition and receptive vocabulary ability, after controlling for the influence of nonverbal cognitive ability. Separate within-group analyses were used to determine if, in each participant group, children who had larger receptive vocabularies more readily acquired new words than children with smaller receptive vocabularies; one-tailed tests were utilized. For participants with FXS, after controlling for nonverbal cognitive ability, no significant correlations were observed between fast-mapping performance and receptive vocabulary in either the Successful ($r_s = -.008$, $p = .49$) or Unsuccessful ($r_s = -.001$, $p = .50$) Search conditions. For participants with nonsyndromic ASD, fast-mapping performance in the Successful Search condition was significantly correlated with receptive vocabulary ability, after controlling for nonverbal ability ($r_s = .45$, $p = .006$). No significant association was observed between fast-mapping performance in the Unsuccessful Search condition and receptive vocabulary after controlling for nonverbal cognitive ability ($r_s = .13$, $p = .25$). Finally, the relation between receptive vocabulary and fast-mapping performance in both the Successful ($r_s = .34$, $p = .03$) and Unsuccessful Search ($r_s = .51$, $p = .002$) conditions was significant for TD participants.

Discussion

The present study was designed to evaluate the ability of children with FXS, nonsyndromic ASD, or typical development to learn new words when such learning depended on interpreting and using a speaker's emotional reaction within a nonostensive word learning context. Efficient word learning requires the use of multiple strategies across a variety of contexts and many of these strategies are social in nature (Tomasello 2001). In addition to deficits in language, individuals with FXS or nonsyndromic ASD often demonstrate some level of difficulty in the ability to notice, interpret, and respond to other people's social signals (e.g., American Psychiatric Association 2013; Cordeiro et al. 2011; Harris et al. 2008). Thus, there are multiple avenues through which efficient word learning could be compromised in these populations. Furthermore, although the similarities observed between the FXS and nonsyndromic ASD phenotypes suggest that similar treatment approaches could be used in both conditions (e.g., Klusek et al. 2014; Philofsky et al. 2004; Roberts et al. 2001), there is a growing body of research documenting important differences in the manifestations and correlates of ASD in FXS relative to nonsyndromic ASD (McDuffie et al., in press; Thurman et al. 2014; Wolff et al. 2012). Thus, understanding the ability of children with FXS or nonsyndromic ASD to utilize different types of interpersonal cues to disambiguate a speaker's intended referent is crucial to developing optimal treatment approaches to enhance the language development of affected individuals. By comparing between-group patterns of performance as children with FXS or nonsyndromic ASD acquire new vocabulary words under controlled experimental conditions, we were able to obtain insight into the extent to which the behavioral symptoms shared by these neurodevelopmental disorders reflect similar or differing neurocognitive mechanisms and thereby begin to elucidate the circumstances in which the same or different treatment approaches should be used in each condition .

The experimental paradigm used in the present study measured children's ability to utilize an adult's positive or negative emotional reaction, indicating either a successful or an unsuccessful search, to disambiguate the novel object that the speaker intended to label. In the Successful Search condition, the target object was found in one of four buckets and the examiner reacted with excitement upon locating the intended referent. For those trials in which the examiner did not find the intended object (e.g., the Unsuccessful Search condition), the examiner reacted with disappointment to each object as it was removed from its hiding place. In addition to interpreting the speaker's expression of disappointment, Unsuccessful Search trials also required participants to infer that because the adult never found the intended object a previously unseen novel object on the test probes represented the intended referent.

Word Learning Performance

In the Successful Search condition, all groups of participants were, on average, able to learn novel words at a rate greater than expected by chance, as indicated by their selection of the target object during test probes. Despite the fact that performance exceeded chance in this condition, however, significant between-group differences in fast-mapping performance were observed. TD participants performed significantly better (at both the group and individual levels of analysis) than did participants with nonsyndromic ASD when matched on level of nonverbal cognitive ability. This suggests a particular difficulty for children with nonsyndromic ASD, even relative to nonverbal cognitive level expectations, in utilizing the emotional reaction of excitement to guide a label-object pairing. Other researchers have posited that early impairments in attending to social information deprive children with ASD of vital learning experiences and that these impairments cascade over time, disrupting both brain and behavioral development (Mundy and Neal 2001). The present findings are consistent with this theoretical model and suggest that an early impairment in the ability to use social cues may contribute to more global language delays, which are commonly observed within the ASD phenotype. Other studies have observed lower levels of performance in children with nonsyndromic ASD relative to developmental level-matched TD children on word learning tasks that require the use of gaze direction to disambiguate the speaker's intended referent (Baron-Cohen et al. 1997; Preissler and Carey 2005). Our results extend these findings and suggest that challenges to the process of word learning extend beyond difficulty in utilizing the speaker's direction of eye gaze to include difficulty interpreting the communicative significance of the speaker's socio-affective reactions.

As a group, participants with FXS were able to more successfully utilize the speaker's emotional reaction of excitement than were participants with nonsyndromic ASD of similar chronological age and nonverbal cognitive ability. That is, the participants with FXS significantly outperformed those with nonsyndromic ASD during the Successful Search condition. Additionally, no statistical differences in performance were found between participants with FXS and TD participants. The total number of individual participants with FXS who successfully learned all label-object pairings in the Successful Search condition, however, did not significantly differ from participants with nonsyndromic ASD. Thus, as a group, children with FXS performed better in the Successful Search condition relative to children with nonsyndromic ASD; however, they still demonstrated variable levels of individual performance across trials. These results are consistent with recent studies suggesting that, although the FXS and ASD phenotypes are associated with difficulties navigating social interactions, in many cases the level of impairment is less severe in FXS (McDuffie et al., in press; Wolff et al. 2012).

One could argue that, assuming cognitive ability was equivalent across diagnostic groups, the advantage for children with FXS in utilizing social cues during word learning should translate to a more general advantage in vocabulary comprehension relative to children with nonsyndromic ASD. In fact, there is some limited evidence supporting this argument. McDuffie et al. (2013) found that, for two groups of participants with nonverbal IQs less than 85, participants with FXS earned significantly higher receptive vocabulary standard scores than did participants with nonsyndromic ASD. More research is needed on between-syndrome differences in specific domains of language development and to identify associated factors (e.g., anxiety, attention, nonverbal cognitive ability) that may account for developmental differences between diagnostic groups.

Importantly, symptoms of autism, on average, are less severe in children with FXS than in children with nonsyndromic ASD, even when only considering those children with FXS who have a comorbid diagnosis of ASD (McDuffie et al., in press; Thurman et al. 2014). In the present project, after controlling for autism symptom severity, performance on the Successful Search condition no longer differed significantly between the children with FXS and the children with nonsyndromic ASD; this was also the case when analyses were restricted to include only children with FXS who met research criteria for a comorbid diagnosis of ASD. These findings potentially indicate that the between-group differences in autism severity account for why children with FXS outperform children with nonsyndromic ASD in the Successful Search condition. Though, given the fact that autism symptom severity is negatively associated with nonverbal cognitive ability in FXS (Lewis et al. 2006), this finding should be examined longitudinally to evaluate its stability across development and elucidate the contributions of autism symptom severity and nonverbal cognition.

In the unsuccessful search condition, children in all groups were able to infer label-object pairings at a rate greater than expected by chance. Nevertheless, significant between-group differences in fast-mapping performance emerged. In this condition, however, it was participants with FXS who demonstrated difficulty relative to nonverbal cognitive level expectations, as they performed significantly less well than the TD participants, both at the group and individual levels of analysis. Furthermore, although a significant difference in group-level performance between the participants with FXS and those with nonsyndromic ASD initially failed to emerge, after controlling for autism symptom severity participants with FXS demonstrated significantly lower performance on the Unsuccessful Search condition than did participants with nonsyndromic ASD. Follow up analyses indicated that this finding was supported by analyses at the individual level and was replicated when including only participants with FXS who met research criteria for a diagnosis of ASD.

For the TD participants, performance across the two search conditions did not differ significantly and was significantly correlated. Results for the Successful Search condition confirm previous findings (Tomasello and Barton 1994; Tomasello et al. 1996) that TD children do not simply map a novel label to the first nameless referent they see after hearing the label, but can delay this mapping until the speaker provides a nonverbal cue (in this case, an exclamation of excitement) that indicates that intended referent has been found. Results of the current study extended previous research by demonstrating that, in addition to using the speaker's positive emotional reaction to guide word learning, TD children—by early school age—are also able to utilize an adult's expression of disappointment to infer the identity of an intended object referent (Tomasello et al. 1996). Our results also indicate that, during this developmental period, children's ability to form label-object mappings is comparable across Successful and Unsuccessful Search conditions and related to chronological age. This finding is reasonable given that cognitive skills and chronological age are highly correlated in typical development making it difficult to separate the unique variance contributed by each characteristic. Furthermore, one would expect that success in forming label-object mappings would lead to an advantage in adding words to one's lexicon; this hypothesis was confirmed for TD children as, after controlling for nonverbal cognitive ability, word-learning performance in both conditions was associated with receptive vocabulary ability.

For the participants with FXS, we found that word learning performance on Successful Search trials was significantly better than word learning performance on Unsuccessful Search trials. In addition, performance across the two experimental conditions was not significantly correlated. These findings suggest that word learning in FXS relies on differing underlying processes during Successful and Unsuccessful trials. None of the predictor variables included in the present study, however, accounted for significant variance in predicting fast-mapping performance in either experimental condition for those with FXS. Clearly, future studies must attempt to identify and measure other characteristics that may be associated with the behavioral phenotype of FXS and theoretically likely to be necessary to support word learning in social contexts.

Examination of the data for participants with FXS at the individual level revealed that, although 11 children with FXS learned all of the mappings in the Successful Search condition, only 1 learned all the mappings in the Unsuccessful Search condition. There are two potential explanations for why children with FXS had particular difficulty learning words in the Unsuccessful Search condition. First, one could argue that comprehending the communicative significance of an expression of disappointment is a more complex skill than comprehending the communicative significance of an expression of excitement. Some support for this argument is provided by the literature on the developmental progression of emotion understanding in TD children. In particular, multiple studies have demonstrated that, on social referencing tasks as well as tasks requiring recognition of facial emotions, young TD children demonstrate higher accuracy when interpreting positive expressions (e.g., happiness or excitement) than when interpreting negative expressions, such as sadness (see Gross and Ballif 1991). Second, it is also possible that an extra step is required for successful word learning in the Unsuccessful Search condition and that this additional cognitive challenge was problematic for the children with FXS. In the Unsuccessful Search condition, not only must the child refrain from mapping the label to any of the novel foil objects as they are removed from their buckets, they also must determine which of the objects presented during test probes has not previously been seen and rejected as a potential target. This combination of steps may have been particularly challenging for children who are likely to have issues with sequential processing, impulsivity, executive control, sustained attention, and working memory (Cornish et al. 2001, 2004; Dykens et al. 1987; Hodapp et al. 1992; Kemper et al. 1988; Lanfranchi et al. 2009; Munir et al. 2000). In the present study, it may be that the dual requirement, in the Unsuccessful Search condition, of remembering the identity of the four novel foil objects as well as understanding that the examiner never found the intended target object overloaded available executive capacity. Future studies should evaluate the potential contributions of attentional demands, visual and auditory working memory, and executive functioning to fast-mapping performance by individuals with FXS.

Finally, in males with FXS receptive vocabulary was not associated with fast-mapping performance on either condition once we controlled for nonverbal cognitive ability. Although, we hypothesized that children with larger vocabularies would more readily acquire new words, it is important to note that fast-mapping is only one of many tasks a child must perform in order for a word to become a known lexical item (Horst and Samuelson 2008; Rice et al. 1990). Studies examining working memory in FXS suggest that males with FXS have a working memory deficit associated with the attentional resources taxing their central executive capacity (Munir et al. 2000). Thus, in males with FXS it is plausible that the mechanism underlying the subsequent retention of label-referent mappings and the integration of novel words into the larger lexicon may be stronger predictors of receptive vocabulary size than the initial associative learning process, at least in situations in which children must rely on socio-affective information to determine referential intent.

When we compared the group-level performance by children with nonsyndromic ASD across the two experimental conditions, we found that the relative profiles of performance did not differ. Examination of the data at the individual level indicated that 8 children with ASD learned all of the label-object pairings in the Successful Search condition and 7 children learned all of the label-object pairings in the Unsuccessful Search condition. Six children performed the same across the two conditions. However, performance on the Successful Search condition was not significantly related to performance on the Unsuccessful Search condition. As was the case for FXS, these findings suggest that different learning processes may be necessary for success in different word learning contexts, a proposal that is strongly supported by social cognitive theories of word learning (cf., Baldwin 2000). Nonetheless, it is interesting that we observed a bimodal distribution of performance in our sample of children with nonsyndromic ASD; it might be that testing younger children with less language competence might have revealed more variability in performance.

Despite these comparable levels of performance, the predictors of word learning performance and the relations between word learning performance and receptive vocabulary differed across the two word learning conditions for the participants with nonsyndromic ASD. Both nonverbal cognitive ability and social avoidance accounted for unique variance in predicting performance in the Successful Search condition. In the Unsuccessful Search condition, although the overall regression model failed to reach significance, severity of autism symptoms was observed to be a significant bivariate correlate of word learning task performance; importantly, little shared variance was observed between autism severity, as measured by the ADOS, and social avoidance, as measured by the ADAMS. Furthermore, word learning performance in the Successful Search condition, but not the Unsuccessful Search condition, was associated with receptive vocabulary ability. Taken together, these findings suggest that different neurocognitive mechanisms underlie word learning in the Successful Search and the Unsuccessful Search conditions for children with nonsyndromic ASD. In the relatively more straightforward Successful Search condition, children with nonsyndromic ASD may have been able to successfully form a link between label and object to the extent that their level of social avoidance did not negatively impact their ability to attend to and interpret the word learning context. In the relatively more challenging Unsuccessful Search condition, children with nonsyndromic ASD may have been able to perform successfully to the extent that they were able to recognize the speaker's social cues as relevant to the interactive context, interpret the examiner's expression of disappointment, notice which object had not been seen previously, and infer that this novel object was the speaker's intended referent.

In an attempt to determine whether social-affective or restricted, repetitive behaviors were differentially related to performance in the Unsuccessful Search condition for the participants with nonsyndromic ASD, we examined bivariate correlations between task performance and ADOS severity scores computed separately for each domain (Hus et al., in press). Interestingly, significant negative concurrent associations continued to be observed between performance on Unsuccessful Search trials and severity of impairments in both the Social Affective and Repetitive Behavior domains. Based on the lack of intercorrelations and differential associations with fast mapping, it appears that social anxiety, as measured by the ADAMS, and both social reciprocity and repetitive behaviors, as separately represented calibrated severity scores that have been newly established for the ADOS, represent different constructs that are important for fast-mapping performance under different contextual conditions. In a previous study examining a sample of boys with nonsyndromic ASD which overlapped substantially with the present sample, we observed a strong positive correlation between Social Anxiety and Obsessive Compulsive Behavior subscales of the ADAMS. It is possible that the items in the ADAMS Social Avoidance subscale reflect insistence on sameness behaviors, whereas ADOS severity scores for the Repetitive Behavior domain primarily reflect repetitive sensory motor behaviors (Bishop et al. 2013). Future research should continue to investigate which participant characteristics influence fast mapping performance and should direct efforts toward understanding the underlying constructs represented by various assessment tools. Such knowledge can help to identify component skills that can serve as intervention targets.

Error Patterns

Finally, we explored the factors influencing the pattern of errors demonstrated by participants during the experimental task. These analyses indicated that children with nonsyndromic ASD were more likely to err by selecting a familiar object than were TD participants. In addition, participants with nonsyndromic ASD also were significantly more likely to err by selecting the familiar object on comprehension trials than on the generalization trials. In response to a nonsense label, selecting a familiar object for which the child already has a label might be considered "more" immature or less adaptive than selecting a novel foil object for which the child does not know a label at all. This pattern of performance is surprising given recent findings suggesting that children with nonsyndromic ASD are able to use nonsocial lexical constraints, in the form of mutual exclusivity, to guide successful word learning in social contexts (cf., Preissler and Carey 2005). Although participants with nonsyndromic ASD in the Preissler and Carey (2005) study were in the same age range and developmental level as participants in the current study, the former study presented learning trials that were less cognitively demanding and that did not involve a search procedure.

Limitations

The current study has at least four limitations. First, the sample of boys with nonsyndromic ASD included in analyses for the present study is not representative of the larger population of boys with nonsyndromic ASD because matching required a focus on those with lower IQs. Second, the sample size in the present study was slightly smaller than might be considered optimal when evaluating four predictors in a regression model. Our results indicated that autism severity was the only factor correlated with unsuccessful search performance for participants with nonsyndromic ASD; however, our overall regression model predicting unsuccessful search performance failed to reach significance in this population. Third, the current study examined only word learning performance in males; future research efforts should be directed toward exploring these same abilities in females affected by fragile X syndrome or nonsyndromic ASD. Finally, the ADOS was not administered to the TD participants in the present study; therefore, we relied on the SCQ data to evaluate the relations between word learning performance and autism symptomatology. Replication of the project findings for the TD participants using ADOS data in relation to word learning performance is warranted to ensure that the differences in findings across groups is not an artifact of this measurement difference.

Summary and Future Directions

Different between- and within-group patterns emerged across the Successful and Unsuccessful Search conditions, indicating the likelihood that different underlying processes influence word learning from social cues, depending on context, in children with FXS and in children with nonsyndromic ASD. Additionally, differences were observed between children with FXS and children with nonsyndromic ASD in the relations between word learning performance and receptive vocabulary ability. Clinically speaking, transformation of an experimental paradigm into an intervention activity may provide practitioners with a way to support the process of word learning in children with neurodevelopmental disorders. Review and practice with newly learned words during subsequent intervention sessions might serve to hone the skills needed to retain new vocabulary words within everyday learning contexts, such as home and school. Additionally, as understanding the emotional reactions of others is often considered a developmental goal for these children, utilizing a task in which the child is taught to attend to and use the speaker's emotional reaction to inform learning could provide a naturalistic activity during intervention sessions relative to an activity in which the child is required to label a passive facial expression.

There is a clear need for longitudinal data on developmental relationships between child characteristics and children's later ability to use a speaker's emotional reaction in the service of word learning. Our cross-sectional data indicate that absolute levels as well as predictors of word learning performance differ between boys with FXS and boys with ASD, giving us reason to expect that longitudinal studies will reveal a more nuanced version of this pattern of performance. We propose that sustained attention, impulse control, executive function, working memory, and sequential processing be explored as putative predictors of word learning performance in FXS. Observation of differential predictors of word learning performance would add to the literature suggesting important differences in the cognitive/linguistic profiles of individuals with FXS relative to nonsyndromic ASD. The identification of underlying characteristics that may differ across syndromes is especially important if effective pharmacological and behavioral interventions targeting these characteristics are to be developed. In addition to identifying predictors of word learning performance, it is also the case that experimental word learning paradigms may ultimately serve as sensitive measures of changes in cognitive processes during targeted treatments for the core deficits of FXS.

Acknowledgments This research was supported by Grant R01 HD054764 from the National Institute of Child Health and Human Development. We wish to thank the children and their families for their participation in this study. We also thank David Benjamin, Susan Harris, Beth Goodlin-Jones, Claire Hauser, Sara Lifson, Eileen Haebig, Ashley Oakes, and Cecilia Compton for assisting with data collection and Susen Schroeder for coordinating all study visits. Leonard Abbeduto has received financial support to develop and implement outcome measures for fragile X syndrome clinical trials from F. Hoffman-LaRoche, Ltd., Roche TCRC, Inc. and Neuren Pharmaceuticals Limited. Randi J. Hagerman has received funding from Novartis, Roche Pharmaceuticals, Curemark, Forest, and Seaside Therapeutics to carry out treatment studies in fragile X syndrome and autism. She has also consulted with Roche/Genetech and Novartis regarding treatment studies in fragile X syndrome. No other authors have financial disclosures to make.

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