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Investigating Word Learning in Fragile X Syndrome: A Fast-Mapping Study

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Abstract Fast-mapping paradigms have not been used previously to examine the process of word learning in boys with fragile X syndrome (FXS), who are likely to have intellectual impairment, language delays, and symptoms of autism. In this study, a fast-mapping task was used to investigate associative word learning in 4- to 10-year-old boys with FXS relative to younger typically developing boys and age-matched boys with autism spectrum disorders (ASD). Task performance exceeded chance levels for all groups; however, boys with FXS outperformed boys with ASD, despite having lower levels of nonverbal cognition. Memory task demands significantly impacted performance only for boys with typical development. For boys with FXS or ASD, fast-mapping uniquely accounted for small but significant variance in concurrent levels of vocabulary comprehension as did chronological age and nonverbal IQ, but not autism severity. Understanding the fast-mapping process has implications for designing interventions to support word learning and language acquisition in these populations.

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Introduction

Fragile X syndrome (FXS) is the leading inherited cause of intellectual disability (Fernandez-Carvajal et al. 2009; Hagerman 2008) and the most common single-gene cause of autism (Feinstein and Reiss 1998). The phenotypic features of FXS result from expansion of a CGG nucleotide sequence in the *FMR1* gene on the X chromosome (Brown et al. 1982). Expansion to over 200 repeats (termed the full mutation) causes transcriptional silencing and repression of FMRP (Sutcliffe et al. 1992), a protein critical for synaptic plasticity (Soden and Chen 2010). On average, males with FXS are more affected than females; virtually all males with the FXS full mutation have IQ scores that fall in the range of intellectual disability (FSIQ <70; Hessl et al. 2009). More than 90 % of males with FXS also display behaviors that are characteristically observed in individuals with idiopathic autism, such as gaze aversion, repetitive motor behaviors, stereotyped speech, and social anxiety (Hagerman and Lampe 1999; Merenstein et al. 1996). Differences in the severity of autism symptoms contributes to variability on many other dimensions of the FXS behavioral phenotype (Bailey et al. 2000, 2001; Demark et al. 2003). The present study was designed to characterize one essential aspect of language learning in children with FXS, the ability to acquire new vocabulary, in relation to comorbid autism symptoms and intellectual ability.

Although many females with FXS have adequate language, language delays impact virtually all males with FXS (Abbeduto et al. 2007). In general, vocabulary

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comprehension is described as a relative strength for males with FXS and strongly associated with levels of nonverbal cognition (Abbeduto et al. 2001; McDuffie et al. 2012; Pierpont et al. 2011; Price et al. 2007); however, this is not true for all developmental periods or all measures of vocabulary (Abbeduto et al. 2007; Kover et al. 2012).

In examining language comprehension for a group of adolescents and young adults with FXS, Abbeduto et al. (2008) administered the three subtests (Vocabulary, Grammatical Morphemes, Elaborated Phrases and Sentences) of the Test for Auditory Comprehension of Language, Revised (TACL-R; Carrow-Woolfolk 1985). Based upon age-equivalent scores, no significant differences in total TACL-R scores were observed between participants with FXS and younger typically developing participants who were matched on nonverbal cognition (Abbeduto et al. 2008). Rather, these investigators observed a flat profile of subtest scores, indicating similar levels of performance across the domains of vocabulary and syntax comprehension.

In a longitudinal study, Price et al. (2007) also examined language comprehension in boys with FXS, Down syndrome and typical development using the third edition of the Test for Auditory Comprehension of Language (TACL-3; Carrow-Woolfolk 1999). Participants with FXS ranged in age from 4- to 16-years at the initial visit, were divided into subgroups based on diagnostic categories derived from the ADOS (nonspectrum, ASD, and autism), and were matched group-wise with participants with Down syndrome and typical development based upon nonverbal cognitive level. Typically developing participants ranged in age from 2 to 6 years. After controlling for nonverbal cognitive developmental level and maternal education, significant effects of receptive language domain did not emerge and the groups of boys with FXS did not differ from one another based on autism status. Participants with FXS scored lower in all domains of the TACL-3 (including receptive vocabulary) than did typically developing comparison boys matched on nonverbal cognition.

In contrast to performance differences obtained with the vocabulary subtest of the TACL-3, Roberts et al. (2007a) used the Peabody Picture Vocabulary Test, Third Edition (PPVT-3; Dunn and Dunn 2007) and found that boys with FXS, between 2 and 14 years of age, did not differ in vocabulary comprehension from nonverbal cognitive level-matched boys with typical development. The discrepancy in findings between Price et al. (2007) and Roberts et al. (2007b) may be attributed to the assessment measures used. In a direct comparison of the PPVT-3 and TACL-3, Chapman (2006) reported that performance on the PPVT-3, which samples vocabulary based on picturability and frequency of use, is likely to be superior to performance on the vocabulary subtest of the TACL-3, which samples vocabulary based upon conceptual difficulty.

Although the studies reviewed above examined vocabulary comprehension in boys with FXS who were, on average, older than the participants in the current study, several studies of younger boys with FXS demonstrate that receptive language is a strength for boys with FXS relative to expressive language performance. Roberts et al. (2001) examined growth in an omnibus measure of receptive and expressive language (i.e., Reynell Developmental Language Scales; Reynell and Gruber 1990) over time for a group of 2- to 7-year-old males with FXS and found that the growth rate for receptive language significantly exceeded that for expressive language, although absolute levels of the two language domains did not differ. Similarly, Philofsky et al. (2004) demonstrated that receptive language, again measured with a global assessment tool (i.e., Mullen Scales of Early Learning; MSEL, Mullen 1995), was a relative strength for young males with FXS without comorbid autism.

Taken as a whole, these studies suggest that males with FXS have receptive vocabulary ability that is generally commensurate with levels of nonverbal cognition. Several caveats to this conclusion, however, include the use of global measures of language ability that do not specifically reflect accomplishments in the domain of vocabulary and the use of discrete rather than continuous classification systems for representing autism status in FXS. Additionally, the learning processes underlying vocabulary acquisition in males with FXS are largely unexplored. In this study, we examined the acquisition of vocabulary, focusing on early learning processes that rely upon the establishment of an associative link between label and referent. Additionally, we focused exclusively on males given the ubiquity and severity of their language impairments.

Previous Approaches to Studying Language in FXS

In general, previous research on language development in FXS has primarily utilized standardized tests (Lewis et al. 2006; Price et al. 2007), expressive language sampling (Finestack and Abbeduto 2010; Kover and Abbeduto 2010; Roberts et al. 2007a), and experimental tasks (Abbeduto et al. 2006; Abbeduto et al. 2008) to arrive at a description of the levels of language ability characteristic of individuals with FXS at different ages or developmental levels (Kover and Abbeduto 2010; Murphy and Abbeduto 2003; Price et al. 2007, 2008). In addition, studies have examined within-syndrome variability by identifying linguistic (e.g., verbal working memory) and nonlinguistic (e.g., nonverbal cognition) predictors of levels of language ability (Pierpont et al. 2011).

Although it is important to delineate the extent and predictors of language delay in FXS, it is unfortunate that virtually no attention has been paid to investigating the (presumably) inefficient processes that individuals with

FXS syndrome actually bring to bear on the task of learning language. From a clinical perspective, information about the ways in which individuals with FXS acquire language knowledge could inform intervention planning and enable clinicians to support and facilitate the acquisition of fundamental language skills (Abbeduto et al. 2012). From a theoretical perspective, understanding the mechanisms that are disrupted during the course of development in particular neurodevelopmental disorders has the potential to advance our knowledge of cognitive phenotypes (Thomas et al. 2009). Thus, there is a pressing need for information about the learning processes that underlie the language impairments associated with FXS.

Language learning processes are likely to be shaped in important ways by other dimensions of the FXS behavioral phenotype. In this regard, autism symptom severity represents a particularly important source of within-syndrome variability in the FXS (Hall et al. 2010). For a group of verbal male adolescents with FXS, McDuffie and colleagues recently found that autism symptom severity was a significant predictor of receptive vocabulary, after controlling for nonverbal cognition and chronological age (McDuffie et al. 2012). Identifying another linguistic source of within-syndrome variability, Pierpont et al. (2011) reported that phonological and verbal working memory predicted unique variance in vocabulary growth over and above the contributions of both nonverbal cognition and autism symptom severity for males with FXS. How the process of language learning in FXS may be impacted by cognitive characteristics such as autism symptoms or memory has yet to be sufficiently addressed and many questions remain to be answered.

The present study was designed to improve our understanding of the process of language learning in FXS by studying fast-mapping in an interactive task in which an examiner provided numerous cues to word meaning. We utilized a typically developing comparison group and a comparison group of boys with idiopathic autism, an overlapping yet distinct neurodevelopmental disorder, to examine theoretically relevant dimensions of within-syndrome variability (i.e., nonverbal cognition, autism symptom severity, and memory) with respect to the learning processes underlying vocabulary acquisition.

Vocabulary Acquisition as Fundamental to Language Development

A focus on vocabulary acquisition is important because of the strong predictive association between early lexical acquisition and the later emergence of word combinations and the use of morphological endings that has been observed consistently for young typically developing language learners (Bates et al. 1988, 1995; Bates and Goodman 1997, 1999; Fenson et al. 1994). Typically developing children reliably begin to produce word combinations only when their vocabulary size is between 50 and 200 words, and growth in utterance length accelerates when vocabulary size exceeds 400 words (Bates et al. 1995). Such findings highlight the function of early lexical learning in providing a platform for the subsequent development of grammar and morphology. Thus, understanding the process by which initial lexical knowledge is acquired by young males with FXS, for whom this learning might be more challenging than for typically developing children, has the potential to provide a path for supporting later language development. Furthermore, vocabulary represents a language domain to which a process-oriented approach to acquisition has been applied in both typical and atypical development, thereby providing experimental methods that can be readily applied to the study of language in FXS. In this study, we extended a previously developed fast-mapping paradigm (McDuffie et al. 2006) to the study of word learning in FXS.

Fast-Mapping and Word Learning

The term fast-mapping was introduced by Carey and Bartlett (1978) in a classic study of word learning in preschool-aged typically developing children. Broadly speaking, fast-mapping describes an associative learning process by which children are able to rapidly infer a correspondence between a novel label and a speaker's intended referent. According to Rice et al. (1990), an experimental fast-mapping paradigm can provide a conservative metric of children's initial, albeit incomplete, comprehension of a novel word and, for a given child or group of children, can reveal the minimum input conditions necessary for the first stages of a word acquisition to occur (Rice et al. 1990). If not reinforced by repeated exposures to the novel label over time and in a variety of contexts, this type of quick, associative learning is likely to be temporary and may not generalize to different exemplars of the category represented by the novel word.

The preschool-aged typically developing children who participated in Carey and Bartlett's original fast-mapping study were required to make an inference about the speaker's intended referent in response to the examiner's request, "Bring me the chromium tray; Not the red one, the chromium one." In such a paradigm, accurate word learning depends upon the child's ability to resist assigning a novel label to an object for which a label is already known (i.e., mutual exclusivity; Markman and Wachtel 1988). The current study, however, utilized a more straightforward fast-mapping task during which the requirement for inference-making was intentionally minimized. In such a task, successful mapping relies predominantly on exposure to temporal co-occurrence between the novel label produced by a communicative partner and the object to which a child is attending when the label is provided (Baldwin 1995).

Numerous adaptations of behavioral fast-mapping paradigms have focused upon identifying the types of social, affective, and attentional cues required to support the initial process of word comprehension in very young children with little spoken language. In general, these types of cues function to highlight the explicit correspondence between label and object. Hollich and colleagues (Hollich et al. 2000), for example, found that successful fast-mapping in typically developing 12-month-olds required multiple cues presented in synchrony with one another in order for word learning to occur. These cues included increasing the salience of the object (i.e., object handling by the examiner and opportunities for exploration of the object by the child), temporal contiguity (i.e., labeling at the same time the object was presented), follow-in labeling (i.e., labeling that did not require the child to switch his focus of attention), multiple presentations of the novel label, extended duration of exposure to the labeled object, and presentation during testing on the same side as the labeled object had been presented originally.

By 18 months of age, however, typically developing toddlers are increasingly sophisticated word learners who are able to respond to and follow adult direction of gaze and learn a new word even when the adult's referential focus is discrepant from their own (Baldwin 1993). Children of this age also can learn a new word in contexts in which the target object is not visible to the child at the moment when the novel label is presented by the speaker (Tomasello et al. 1995). By 24 months of age, typically developing children can learn a new word by interpreting an adult's emotional reaction (Tomasello and Barton 1994) and by identifying what is novel in the discourse context from the speaker's perspective (Akhtar et al. 1996). Thus, there is a steady age progression in the ability of typically developing children to use a variety of social and contextual cues to infer the speaker's referential intent.

In the current study, however, we focused on the use of multiple synchronous cues, such as those used by Hollich et al. (2000), to evaluate fast-mapping in a highly supported context of follow-in labeling for a group of young boys with FXS, who are known to have cognitive, language, and behavioral challenges. The experimental task utilized in this study did not require participants to understand the linguistic relevance of the various cues that were provided; instead, the task provided a redundancy of cues simply as a way to scaffold the associative learning between label and object that provides the basis of fast-mapping. As discussed by Gliga et al. (2012), the ability to follow social and contextual cues (including points and gaze shifts) provided by a social partner may be a prerequisite for socially mediated learning in general and word learning in particular; however, this ability is not necessarily sufficient to ensure that word learning will occur even under a highly supportive context of follow-in labeling. This might be especially true of young boys with FXS who have moderate to severe cognitive delays as well as other behavioral characteristics that may interfere with associative learning in explicit contexts.

Fast-Mapping by Children with Autism Spectrum Disorders

Fast-mapping paradigms have been utilized to examine the process of word learning in children with autism spectrum disorders (ASD). These studies provide evidence that, in a word learning task with no requirement to disambiguate the adult's intended referent, school-aged children with ASD are able to make an associative pairing between label and object as well as typically developing children matched on developmental level (Baron-Cohen et al. 1997; Preissler and Carey 2005). At the same time, however, children with ASD show substantial impairments, even relative to developmental level expectations, in using some types of social cues in word learning (Baron-Cohen et al. 1997). Importantly, fast-mapping performance has been shown to mediate the longitudinal relationship between attention-following and subsequent parent report of receptive and expressive noun vocabulary for young children with ASD (McDuffie et al. 2006), thereby documenting the developmental importance of the fast-mapping construct for these children. In the current study, we addressed the dual goals of examining level of fast-mapping performance in young boys with FXS and identifying concurrent associations with other developmental markers relative to children with ASD and children with typical development.

Research Questions

Although much has been learned about the language profiles of males with FXS in terms of absolute levels of language ability and relative profiles of achievements across language domains, there is little information about the underlying mechanisms that guide their language learning. In the current study, we investigated the process of fast-mapping in 4- to 10-year-old males with FXS utilizing the task developed by McDuffie et al. (2006). This task directly pairs novel labels and objects in an ostensive manner with no ambiguity about the referent the adult intends to name and thus, yields what might be considered to be a baseline measure of the associative learning at the core of fast-mapping.

While not requiring the learner to understand the speaker's referential intent, the fast-mapping task used in the current study did include a social-interactive component in that an examiner presented the cues necessary to link the label and object within a real-time or in vivo interaction. We, therefore, expected that task performance would be influenced by both level of cognitive development and degree of social impairment. We hypothesized that the performance of typically developing children would exceed that of participants with FXS given the attentional and executive functioning impairments characteristic of this disorder (Cornish et al. 2004). We further hypothesized that the performance of participants with FXS would exceed that of participants with ASD, given the more serious social impairments characteristic of ASD. Based on evidence for the contribution of phonological memory to language development for boys with FXS, we also hypothesized an influence of phonological memory on task performance. Thus, we addressed the following research questions:

1. After controlling for nonverbal cognitive developmental level, is there a difference in performance between participants with FXS, ASD, and typical development in word acquisition as indexed by fast-mapping?
2. Within each diagnostic group, is there evidence that participants fast-mapped the novel words?
3. Do memory task demands contribute to differences in fast-mapping performance?
4. Does fast-mapping performance relate to other markers of developmental status, particularly chronological age, vocabulary performance, and nonverbal cognition?
5. Does fast-mapping account for unique variance in predicting vocabulary ability?

Method

Participants

Participants were a subset of a larger group of 177 boys with FXS ($n = 57$), ASD ($n = 61$), or typical development ($n = 59$) who were recruited for a project on the social-affective bases of word learning and who were tested at one of two university sites (one in the Midwest, the other on the West coast). Participants were recruited nationally, with the exception of typically developing boys who were recruited locally by the two sites. Recruitment methods for participants with FXS or ASD included flyers and brochures posted in public places, magazine ads, postings to websites or internet listservs for families of children with neurodevelopmental disorders, and university and national research registries. Participants were enrolled if the parent reported that: (1) English was the primary language spoken at home; (2) the child could understand simple instructions (e.g., “Give me the ball”); (3) spoken language was the child’s primary means of communication; (4) the child had used approximately 10 different spoken words spontaneously within the prior month; and (5) the child lacked any uncorrected motor or sensory impairments that would preclude participation. Participants with FXS entered the study with positive results on genetic testing for FXS; participants with ASD had received community diagnoses of autism, ASD, or PDD-NOS prior to enrollment and had negative results on previous genetic testing for FXS. Typically developing children were not receiving special education services at the time of enrollment. This study was approved by the IRBs of the respective universities.

Participant Selection for the Current Study

Participants with FXS were included in the current study if they had nonverbal IQ scores under 85, as this cutoff is inclusive of essentially all males with FXS (Hessl, et al. 2009). This resulted in 54 participants with FXS. Participants with ASD were included in the present study if they achieved: (1) a calibrated autism severity score of at least four (Gotham et al. 2009) on the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1999); and, (2) a classification of autistic disorder according to the original algorithm of the Autism Diagnostic Interview—Revised (ADI-R; Rutter et al. 2003). Additionally, participants with ASD were included if they achieved a nonverbal mental age of less than 6.75 years and a nonverbal IQ of less than 85. These criteria were implemented to limit the range of nonverbal mental age and IQ scores for participants with ASD to those scores observed for participants with FXS. These criteria resulted in 35 participants with ASD.

Participants with typical development were selected for inclusion in the current study if they had nonverbal IQ scores between 85 and 115 (i.e., ±1SD from the test mean) and if their scores on the Social Communication Questionnaire (SCQ) did not exceed 11. A conservative cut-off score was used in the latter measure to ensure that children with possible ASD diagnoses were excluded (Corsello et al. 2007). This resulted in 30 participants with typical development.

Participants across all three groups were included in the analyses for the current study if they had completed four valid trials of the experimental word learning task. This final selection criterion resulted in the exclusion of three boys with typical development, six boys with ASD, and eight boys with FXS, yielding a final participant sample of 27 boys with typical development, 29 boys with ASD and 46 boys with FXS. Additional information regarding invalid trials is presented below in the section describing the experimental word learning task. Additionally, descriptive characteristics of the final participant sample are presented in Table 1.

Table 1 Descriptive characteristics of participants: means and (SDs)

Variable	Typical development ($n = 27$)		ASD ($n = 29$)		FXS ($n = 46$)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Chronological age	3.89	(0.88)	7.46	(1.82)	7.50	(2.00)
Nonverbal cognition						
IQ	102.07	(6.31)	64.74	(12.27)	59.20	(13.20)
Age-equivalent	4.07	(0.81)	4.43	(1.24)	4.08	(1.10)
Autism severity	NA	NA	8.03	(1.40)	6.30	(2.01)
Receptive vocabulary						
Standard score	116.65	(12.75)	57.82	(22.13)	68.13	16.66
Age-equivalent	5.08	(1.46)	3.67	1.28)	4.42	1.63
Raw score	81.07	(27.32)	52.29	28.69)	68.28	30.79
Expressive vocabulary						
Standard score	113.23	(9.20)	59.67	(23.59)	67.71	(15.04)
Age-equivalent	4.71	(1.11)	3.94	(1.35)	4.28	(1.50)
Raw score	58.48	(16.47)	43.15	(25.26)	50.36	(22.93)
	Frequency		Frequency		Frequency	
Caucasian	22		20		42	
Family income[a]	19		15		21	
Maternal education[b]	20		18		32	

[a] Family income >$50,000 per year

[b] Mothers who obtained a college degree or higher

Measures

Autism

The Social Communication Questionnaire (SCQ), a screening measure based upon the ADI-R and completed by a parent, was used to screen children with typical development. A cut off score of 11 was employed to provide maximum specificity and sensitivity when screening the typically developing children enrolled in the current study for a possible ASD (Allen et al. 2007; Corsello et al. 2007; Wiggins et al. 2007).

Participants with FXS or ASD completed the ADOS and parents (typically the biological mother) completed the ADI-R. The ADOS is a gold-standard measure of current symptoms of autism and can be used to generate a continuous metric of autism symptom severity based on algorithms provided by Gotham et al. (2009). All ADOS and ADI-R examiners were research reliable and cross-site reliability was assessed over the course of the study by independent coding of 10 % of the ADOS and ADI-R assessments for each group (i.e., FXS or ASD) by all active examiners (a total of 4 examiners for the ADOS and 5 examiners for the ADI-R). Reliability was generally good, although as expected, it was somewhat lower for participants with FXS than for those with ASD, because the latter were the "normative" sample. For the 5 participants with FXS selected for the cross-site reliability assessment, overall reliability on the ADOS and ADI-R was 74 and 89 %, respectively. For the 6 participants with ASD selected, overall reliability on the ADOS and ADI-R was 83 and 86 %, respectively.

The presence of autism symptoms in participants with FXS is accounted for in the present study by using autism severity scores from the ADOS. We did not create categorical subgroups of individuals with FXS based on comorbid autism status. This decision was based on previous research suggesting that using a dichotomous approach to assign diagnostic categories of autism within a group of individuals with FXS syndrome masks important heterogeneity among these individuals as well as potential differences relative to idiopathic ASD cases (McDuffie et al. 2012; Hall et al. 2010).

Nonverbal Cognition

The Brief IQ subtests of the Leiter International Performance Scales—Revised (Roid and Miller 1997) were administered: Figure Ground, Form Completion, Sequential Order, and Repeated Patterns. Raw scores, age-equivalents, growth scores, and standard scores (minimum 36) were obtained from the Leiter-R. In four cases (1 FXS, 2 ASD, 1 typical development), a failure to achieve basal scores on the Leiter led us to administer the Visual Reception and Fine Motor subtests of the Mullen Scales of Early Learning (MSEL; Mullen 1995). For these four participants, we used age equivalent and standard scores from the MSEL in the analyses for the current study rather than eliminating these participants from the sample. Use of these MSEL subtests is common in children with ASD and shows convergent validity with other measures, such as the Differential Ability Scales (Bishop et al. 2011). In another case, a participant with FXS completed only three Leiter subtests and thus, a standard score could not be computed. For this participant, a mean age-equivalent score was computed from the three subtests and used in the analyses for the current study.

Vocabulary

Receptive and expressive vocabulary were assessed with two standardized measures: the Peabody Picture Vocabulary Test, 4th edition (PPVT-4; Dunn and Dunn 2007) and the Expressive Vocabulary Test, 2nd edition (EVT-2; Williams 2007). The PPVT-4 contains four color pictures on each page and the child is asked to select the picture that matches the vocabulary word spoken by the examiner. The EVT-2 contains a single color picture on each page and the child is asked to label or provide a synonym for each item. Approximately half of the participants in each group received Version A or Version B of these measures. Both the PPVT-4 and the EVT-2 yield raw scores, standard scores relative to age-normed performance, and growth scores. Raw scores were used as the dependent measure in all analyses.

Procedures

Fast-Mapping Task

Participants completed a fast-mapping task modeled after that of McDuffie et al. (2006). The task, which took less than 6 min to administer in most cases, was presented by a trained examiner. The task included four trials, with each trial divided into two phases: object presentation and comprehension testing. One pair of objects was presented during each trial. During the object presentation phase, two objects within a pair were sequentially introduced to the child. The same object pairs were used for all participants. One object within the pair (designated as the target) was labeled with a nonsense word (i.e., *modi, dawnoo, koba, tooko*). The other object (designated as the distracter) was talked about with an equivalent amount of connected speech but without any labeling of the object. Although the order of novel word presentation remained the same, the object assigned as the target, side of presentation (left, right), and order of presentation (target first, target second) were counterbalanced.

During the task, participants were seated or stood behind a curved table that was positioned near a wall in the testing room. For a minority of participants, a research assistant sat behind the child and encouraged the child to stay in the area behind the table during the task. However, this individual was instructed not to influence the child's performance by talking or directing the child's attention during the task. The task was video recorded and the images from two cameras positioned on either side of the child were combined with a digital video mixer.

Object Presentation

During the presentation phase, each object was presented individually such that only one object was visible to the child at a time. Prior to presenting each object, the examiner attempted to get the child's attention, then introduced the object from the designated side by bringing the object up from under the table edge. As the object was raised into view, the examiner directed the child's attention to the object with an exaggerated head turn, a point, and by saying "Look!" The examiner then moved the object diagonally across the table until the object was centered in front of the child and close enough for the child to reach it.

While presenting each object, the examiner used proximal gestures, head turns, gaze shifts, and movement of the object to scaffold and redirect the child's object-focused attention. The examiner attempted to establish a game-like interactive routine and the child was encouraged to manipulate and examine each object. After directing the child's attention to the object for approximately 15 s, the object was removed and the second object of the pair was presented in a similar manner.

Presentation of the target object was accompanied by 5 repetitions of the novel CVCV word embedded in child-directed speech in sentence-final position (*Look! It's a modi! A modi! You can see my modi! I like how you are playing with the modi! It's a great modi!*). Presentation of the distractor object was accompanied by an equivalent amount of child-directed talking without labeling (*Look, wow! See what I have? It's mine! And you can play with it! You're looking at a great one!*). Once both objects in a pair had been presented, comprehension testing began.

Comprehension Testing

Presentation of each object pair was followed immediately by comprehension testing of the novel word. The examiner first attempted to gain the child's attention and prepare him for the testing phase by saying,"Ready? We're going to find the ____!". The examiner held one object in either hand, with the objects out of sight under the table edge and on the same side as the objects originally had been presented. While looking at the child, the examiner then slowly raised both objects above the edge of the table saying, "Here comes the ____!" and held the objects at shoulder height for approximately 5 s. Next, the examiner slowly and simultaneously placed both objects on the table

Table 2 Description of invalid trials and derivation of final study sample

Group	Typical development	ASD	FXS
Original study sample	59	61	57
Participants meeting study eligibility criteria	30	35	54
Number of invalid trials			
Due to child noncompliance	2	8	5
Due to examiner error	5	7	4
Participants with invalid trials			
Due to child noncompliance	1	4	5
Due to examiner error	2	3	0
Individual participants with invalid trials[a]	3	6	8
Final study sample (participants with no invalid trials)	27	29	46

[a] Some participants had invalid trials attributable to both child noncompliance and examiner error

in front of the child saying, "Where's the ____?" Finally, the examiner extended an open hand slightly behind and directly between the two objects and asked the child to select the target object, saying "Give me the ___".

Novel Objects

Eight novel stimulus objects were constructed by gluing together a variety of small wooden shapes. Each object was 5- to 7-inches tall and was attached to a 4-in diameter circular wooden base, enabling the object to stand upright on a table. Each object, including the base, was painted a glossy, bright color. The objects were constructed so that they did not resemble any objects that would be familiar to young children. The objects were sorted into four pairs based on maintaining a color and shape contrast between each pair member.

Scoring and Fidelity

The examiner who tested the participant scored performance on the experimental task by watching the video of task administration. This examiner also verified validity of the experimental task trials. Trials could be considered invalid due to examiner error or child noncompliance. Examples of child noncompliance resulting in an invalid trial included, for example, the child leaving his seat or disengaging from the task such that he did not participate in portions of the trial. Examiner administration errors that resulted in an invalid trial included, for example, production of an incorrect number of labels for the target object, failure to provide an equivalent amount of talking during presentation of the distractor object, failure to adhere to the script during object presentation, and/or failure to adhere to the prompting protocol during comprehension trials. In order to verify scoring decisions, a second trained examiner independently coded each experimental session from videotape. Any scoring discrepancies were resolved through consensus discussion with a third trained examiner. Data were included only if the participant had completed four valid trials of the experimental task. A description of participant selection based upon invalid trials is presented in Table 2.

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. Across sessions selected for fidelity coding, each primary examiner completed fidelity for all other examiners. The fidelity measure included 40 items querying adherence to rules for: (1) object presentation (16 items; e.g., presentation script, number of labels, equivalent talking about target and distracter); (2) randomization (12 items; e.g., side of presentation, order of presentation, and target object assignment); and, (3) comprehension testing (12 items; e.g., probe script, object placement, prompting of child response). Mean overall percentage of agreement across diagnostic groups and sites was 95.22 % (Range = 80–100, SD = 4.05).

Results

Participant and Experimental Task Characteristics

Establishing Comparability of Groups on Age and Nonverbal Cognitive Level

To ensure that comparisons among the groups on the dependent measures of interest would be interpretable, between-group differences in chronological age, nonverbal mental age, and nonverbal IQ were examined using a one-way ANOVA. Participants with FXS and ASD were well matched on chronological age ($p = .918$), as expected given that chronological age had been a criterion for study eligibility. Typically developing participants were well matched on nonverbal mental age with participants with FXS ($p = .959$). Participants with ASD, however, had somewhat higher, although not significantly different, nonverbal mental ages than both typically developing participants ($p = .208$) and those with FXS ($p = .172$). As p values for these latter comparisons did not reach the recommended alpha level of .50 (Mervis and Robinson 2005), we controlled for nonverbal mental age in all analyses involving the three groups of participants. As expected, typically developing participants had significantly higher nonverbal IQ scores than participants with either FXS or ASD (both $ps < .001$). Additionally, participants with FXS displayed somewhat lower nonverbal IQ scores (M = 59.20, SD = 13.20, Range = 40–83) than those with ASD (M = 64.74, SD = 12.27, Range = 36–83), $p = .051$. Thus, we also controlled for nonverbal IQ and chronological age in the regression analyses involving the FXS and ASD groups.

Group Comparability on Vocabulary Measures

The current study was designed to examine how, when compared at similar cognitive developmental levels, children with different neurodevelopmental profiles (e.g., TD, FXS, or ASD) used a particular learning strategy or capitalized on similar learning opportunities to acquire linguistic knowledge, in this case, an initial representation of a vocabulary word. Thus, the aim of the study was to identify and measure one potential construct (fast-mapping) that could account for between-syndrome differences in performance on measures of vocabulary acquisition. Given this rationale, we did not choose to match participants on the standardized language measures. In fact, because we would expect that measures of accumulated vocabulary knowledge (i.e., PPVT and EVT) would be correlated with fast-mapping ability, such matching would have obscured the relationship of interest. As mentioned previously, however, we did control for nonverbal cognitive developmental level in the analyses. For receptive vocabulary standard scores, a one-way ANOVA revealed significant differences between all of the groups (TD vs ASD and TD vs FXS, p's = .000; ASD vs FXS, $p < .016$). Thus, TD participants outperformed participants with FXS who outperformed participants with ASD. For receptive vocabulary raw scores, a one-way ANOVA revealed a marginally significant difference between TD and FXS participants ($p < .075$), whereas TD and FXS participants differed significantly from participants with ASD (TD vs ASD, $p < .000$, ASD vs FXS, $p < .025$). For expressive vocabulary standard scores, a one-way ANOVA revealed significant differences between TD participants and participants with both ASD and FXS (p's $< .000$) and a marginally significant difference between participants with ASD and FXS ($p < .051$), in favor of participants with FXS. For expressive vocabulary raw scores, a one-way ANOVA revealed a significant difference between TD and ASD participants ($p < .012$); however, TD participants did not differ significantly in raw scores from participants with FXS ($p < .134$) who did not differ significantly from those with ASD ($p < .183$). Two-tailed p values were used in all of these analyses.

Differential Effects of Object and Order on Experimental Task Performance

To ensure that the experimental task operated in the same manner among groups, we tested for differences in performance among object sets and trial order for each group. A nonparametric McNemar's test was used to evaluate potential effects of the four different object sets used during the experimental task. McNemar's test is based upon a 2×2 contingency table and is suitable for use when individual participants have been assessed with respect to two dichotomous variables. The question of interest was whether task performance systematically differed within the participant groups based upon the object set used for a particular trial. For each group of participants, all pairwise comparisons of object sets were examined yielding six pairwise comparisons (i.e., sets 1–2; sets 1–3; sets 1–4; sets 2–3; sets 2–4; and, sets 3–4). Thus, an adjusted p value of $.05/6 = .008$ was used to control for multiple significance testing. None of the comparisons exceeded this adjusted p value. For participants with typical development and ASD, p values ranged from .453 to 1.00 and from .180 to 1.00, respectively. For participants with FXS, p values ranged from .057 to 1.00.

Differential effects of label and order of presentation could not be separately considered as the order of novel label presentation was fixed. Thus, the novel label *modi* was always the word presented in Trial 1, *dawnoo* was always presented in Trial 2, followed by *koba* and *tooko* in Trials 3 and 4, respectively. To examine potential effects of label/order on fast-mapping task performance for each group, we used a Related Samples Cochran's Q Test, a nonparametric version of a repeated measures analysis of variance. Cochran's Q was not significant for either the typically developing participants ($Q = 1.39$, $p = .708$, $df = 3$) or those with ASD ($Q = 1.33$, $p = .722$, $df = 3$). Because Cochran's Q approached significance ($Q = 6.39$, $p = .092$, $df = 3$) for participants with FXS, we examined post hoc comparisons for this group using an adjusted p-value of $.05/6 = .008$ to control for multiple significance testing. The comparison of Trial 1 (*modi*) vs. Trial 4 (*koba*) approached significance ($p < .015$), with a decrement in performance from Trial 1 to Trial 4. This may be attributable to the phonetic characteristics of the novel word assigned to the fourth trial but, alternatively, may be due to participants' response to characteristics of the task (i.e., fatigue, inattention, or strained memory load due to being exposed to four novel words in quick succession).

Although it is not possible to disentangle label/order effects in the current study, this will be an important area to investigate in future studies of word learning in FXS.

After Controlling for Nonverbal Cognitive Developmental Level, Is There a Difference Between Participants with FXS, ASD, and Typical Development in Word Acquisition as Indexed by Fast-Mapping Task Performance?

This research question was addressed with an ANCOVA using group as the independent factor, nonverbal mental age as the covariate, and raw scores on the fast-mapping task (i.e., number of trials out of four on which the correct object choice was made) as the dependent variable. Results revealed a significant main effect of group, $F(2,98) = 10.92$, $p < .001$, *partial* $\eta^2 = .182$, representing a medium effect size. The covariate, nonverbal mental age, also was significant, $F(1, 98) = 6.50$, $p < .012$, *partial* $\eta^2 = .062$, a small effect size. Pairwise comparisons, using one-tailed significance levels, indicated that experimental task performance by typically developing participants was superior to that of participants with either ASD or FXS (all ps $< .001$, one tailed) and that performance by participants with FXS was superior to that of participants with ASD ($p = .02$, one tailed). The difference in fast-mapping between participants with FXS and those with ASD was significant even when nonverbal mental age was not entered as a covariate. Covariate-adjusted mean scores for the experimental fast-mapping task are displayed in Table 3.

Within Each Diagnostic Group, Is There Evidence That Individual Participants Fast-Mapped the Novel Words?

During the comprehension phase of each fast-mapping trial, participants were offered a dichotomous choice between two novel objects; thus, the probability of selecting the correct object by chance on any given trial was .5. Across all four trials, participants could achieve a score of 2 ($np = 4*.5 = 2$) by chance alone. Thus, a one-sample t test was used to compare mean levels of fast-mapping task performance for each group to a reference score of 2. On average, performance by all three participant groups exceeded chance levels: typically developing participants, $t(27) = 11.72$, $p < .001$, two-tailed, $d = 2.25$, a large effect size; participants with FXS, $t(46) = 5.54$, $p < .001$, two-tailed, $d = .81$, a large effect size; and participants with ASD, $t(29) = 2.29$, $p = .03$, two-tailed, $d = .42$, a medium effect size.

Although results indicated that participants had fast-mapped the novel words at the group level, patterns of individual performance were then examined in an attempt to further understand between-group variability in fast-mapping. The number of children within each group that successfully learned all four words was compared using Pearson's Chi square (see Table 3). Results indicated that significantly more typically developing children learned all four words relative to participants with ASD, $X^2(1) = 7.47$, $p = .006$, $phi = -.37$, a medium effect size, and participants with FXS, $X^2(1) = 4.93$, $p = .026$, $phi = -.26$, again a medium effect size. Despite the significant difference in the average number of words learned, participants with FXS and ASD did not differ significantly from one another in the number of individuals achieving perfect word learning performance, $X^2(1) = .794$, $p = .373$, $phi = .1$.

Do Memory-Related Task Demands Contribute to Differences in Fast-Mapping Performance?

In the experimental task, participants were exposed to two trials in which the novel label was paired with the first object presented (target first condition) and two trials in which the novel label was paired with the second object presented (target second condition). During target-first trials, therefore, the participant would be required to hold the label-object pairing in mind throughout the presentation

Table 3 Fast-mapping task performance: adjusted mean scores[a] and unadjusted number of correct trials

	Participant groups					
	Typical development ($n = 27$)		ASD ($n = 29$)		FXS ($n = 46$)	
	Mean	(SE)	Mean	(SE)	Mean	(SE)
Fast-mapping performance	3.47	.167	2.40	.162	2.76	.128
Number of trials correct	Frequency (%)		Frequency (%)		Frequency (%)	
0	0 (0)		1 (3)		0 (0)	
1	0 (0)		4 (14)		2 (4)	
2	2 (7)		10 (35)		20 (44)	
3	11 (41)		9 (31)		12 (26)	
4	14 (52)		5 (17)		12 (26)	

[a] Nonverbal mental age evaluated at the mean value: 4.18

of the distracter object until the time that the comprehension probe was administered. Presumably, this situation could place a larger demand on phonological memory and tax a weak phonology–referent association to a greater extent than during target-second trials in which the target object was presented immediately prior to the comprehension probe.

McNemar's test, a nonparametric test suitable for matched-pair samples, was used to evaluate within-group differences in performance on trials during which the target object/novel label pairing was presented either first or second. In this analysis, the dependent variable was ordinal, as it was possible to obtain a score of 0, 1, and 2 for each condition. Scores for the boys with typical development ranged from 1 to 2, whereas scores for participants with FXS or ASD ranged from 0 to 2. Results revealed that significantly more typically developing children were able to learn the novel word on trials on which the labeled object was presented second compared with trials on which the novel word was presented first ($p < .03$, one-tailed). There were no significant differences in performance based on target presentation order for boys with ASD or FXS.

Does Fast-Mapping Performance Relate to Other Markers of Developmental Status?

In order to evaluate the construct validity of the experimental fast-mapping task, we examined concurrent bivariate associations between fast-mapping task performance and other constructs to which novel word learning should be positively related; specifically, chronological age, nonverbal cognition, and vocabulary scores from standardized tests. Positive associations were expected between fast-mapping and all of these variables. In addition, autism severity was expected to be negatively correlated with fast-mapping scores for boys with FXS or ASD.

For typically developing participants, fast-mapping task performance was significantly related to chronological age, $r(27) = .48$, $p = .006$, one-tailed, receptive vocabulary, $r(27) = .50$, $p = .006$, one-tailed, and expressive vocabulary $r\ (27) = .41$, $p = .018$, one-tailed. For participants with FXS, significant bivariate associations were observed between fast-mapping task performance and nonverbal mental age, $r(46) = .364$, $p = .006$, one-tailed, receptive vocabulary, $r(46) = .43$, $p < .001$, one-tailed, and expressive vocabulary, $r(45) = .347$, $p = .01$, one-tailed. Autism severity was not a significant correlate of fast-mapping task performance for participants with FXS, $r(46) = -.10$, $p = .25$, one-tailed. No significant associations with fast-mapping task performance were observed for participants with ASD, although observed patterns of associations were in the expected direction. These analyses were repeated using growth scores, instead of raw scores, for the PPVT and EVT and comparable results were obtained.

Does Fast-Mapping Performance Account for Unique Variance in Predicting Vocabulary Ability?

This question was addressed using two separate linear regression analyses predicting raw scores for each vocabulary measure within each group. The following variables were entered simultaneously into each analysis: Chronological age, nonverbal IQ, autism severity, and fast-mapping task performance (number correct out of four possible).

For participants with ASD, the overall models predicting receptive vocabulary, $F(4,22) = 1.85$, $p = .158$, two-tailed, $adjusted R^2 = .114$, and expressive vocabulary, $F(4,22) = 2.34$, $p = .088$, two-tailed, $adjusted R^2 = .177$, failed to reach significance, a result suggested by the lack of significant bivariate associations obtained for this participant group. In this series of analyses, only the contribution of nonverbal cognition trended toward significance, accounting for 13 % ($p = .063$, two-tailed) and 22 % ($p = .018$, two-tailed) of the variance in receptive and expressive vocabulary, respectively, when entered into the regression along with the other predictors.

For participants with FXS, the overall models for both receptive vocabulary, $F(4,39) = 20.87$, $p < .001$, two-tailed, $adjusted R^2 = .649$,and expressive vocabulary, $F(4,39) = 25.26$, $p < .001$, two-tailed, $adjusted R^2 = .698$, reached significance. For receptive vocabulary, three variables emerged as significant and unique predictors of vocabulary performance: chronological age, $t = 7.46$, $p < .001$, two-tailed, *semipartial* $r = .674$, nonverbal IQ, $t = 5.14, p < .001$, two tailed, *semipartial* $r = .46$, and fast-mapping task performance, $t = 2.26$, $p = .032$, two tailed, *semipartial* $r = .201$. The effect sizes for chronological age and nonverbal IQ were moderate, whereas the effect size for fast-mapping performance was small. For the regression predicting expressive vocabulary, only chronological age, $t = 9.11, p < .001$, *semipartial* $r = .772$, and nonverbal IQ, $t = 5.24$, $p < .001$, *semipartial* $r = .45$, emerged as significant and unique predictors. Again, comparable results were obtained when growth scores for the PPVT-3 and EVT-2 were used as the dependent measures.

Discussion

In the current study, we addressed the extent of delay in fast-mapping ability in boys with FXS and ASD, the factors that contribute to difficulty with fast-mapping, and the concurrent correlates of fast-mapping ability. Although many studies have examined the process of fast-mapping for other populations of children, no previous study has examined fast-mapping in boys with FXS. We used an interactive word learning task during which an examiner provided a variety of attention-directing cues to highlight the explicit and unambiguous pairing between a novel label and an object referent. An additional goal of the current study was to establish a baseline level of fast-mapping performance against which future studies could compare word learning in response to more challenging experimental tasks that require participants to utilize subtle, abstract, or complex social and affective cues to disambiguate the speaker's intended referent during the process of acquiring new words.

Participants in the current study were not required to overtly respond to the examiner's cues in any way; these cues were provided simply to scaffold the child's visual attention to the target object during the presentation of the novel label. Thus, although a combination of social and contextual cues supported the establishment of an associative link between label and object, the task did not require that the child understand the linguistic relevance of the cues or to make inferences about the examiner's intended referent. This enabled us to isolate the associative word learning process. It should be noted that the contribution of the examiner to the word learning process in the current experimental paradigm cannot be evaluated, however, due to the absence of a direct comparison to a task in which referential cues from a speaker are totally absent during word learning (e.g., Scofield et al. 2007).

Although the fast-mapping performance of all three groups exceeded chance levels, typically developing participants matched on nonverbal cognition performed better than both groups of boys with neurodevelopmental disorders according to two different performance indices: mean number of correct object selections in response to the forced choice comprehension probes and the number of individuals who learned all four words. These results indicate that the initial process of associative learning—one which supports the development of vocabulary comprehension—is impaired in boys with FXS and boys with ASD relative to typically developing boys, even after controlling for the contribution of nonverbal cognitive level.

The results also revealed evidence of syndrome specificity in that, for boys with FXS, mean levels of fast-mapping task performance exceeded that of boys with ASD. This finding is particularly interesting given that boys with ASD had nonverbal cognitive scores that exceeded those of boys with FXS. The finding that boys with FXS had raw and standardized scores for receptive and expressive vocabulary that exceeded those of boys with ASD, who generally had higher nonverbal cognitive developmental levels lends, support to the notion that the process of word acquisition may be less impaired for boys with FXS than for boys with ASD. However, the two groups of boys did not differ in terms of the number of boys who learned all four words; thus, it is important to identify factors that may impact sustained performance on the experimental task. It is noteworthy that approximately half of boys with ASD or FXS performed successfully on two or fewer trials, whereas all but two typically developing boys passed either three or four trials. Moreover, the proportion of boys with typical development who had perfect performance on the fast-mapping task significantly exceeded that of boys with ASD or FXS, who did not differ in this regard. Although the experimental task did not require overt inference-making about the examiner's referential intent, the task did require the child to interact with the examiner (e.g., responding to the examiner's attentional cues, relinquishing the stimulus objects at the conclusion of each presentation phase, responding by pointing to or giving the object during the testing phase). Relative to the typically developing boys, it is possible that these interactive task demands adversely affected the performance of boys with ASD or FXS.

Although not measured directly, the experimental task was structured in a way that allowed us to examine the potential contribution of phonological memory (i.e., the temporary storage and rehearsal of phonological forms; Baddeley 1986) to word learning performance. Thus, we expected that performance would be better for those test trials in which the target object was presented immediately prior to comprehension testing. Contrary to our expectation, only the performance of the typically developing boys was influenced by order of object presentation, with significant improvement when the target object was presented second. Thus, it may be that the influence of phonological memory in the boys with FXS was over-shadowed by more severe impairments in other domains, which remain to be identified.

We chose to evaluate fast-mapping ability because it is a construct with theoretical and clinical relevance to later receptive and expressive language ability for typically developing children. Children who are more successful at establishing initial word-object associations should have an advantage in adding new words to their lexicons over time. Thus, for all participants, we expected to observe significant concurrent associations between performance on the experimental task and chronological age and standardized measures of vocabulary. Additionally, we expected correlations between fast-mapping and nonverbal cognition. We also examined concurrent correlations between fast-mapping and autism symptom severity for the boys with ASD and FXS. Finally, we examined which variables might function as unique predictors of receptive and expressive vocabulary performance for boys with FXS or ASD.

For typically developing boys as well as boys with FXS, significant and positive bivariate associations with fast-mapping task performance were observed for receptive and expressive vocabulary. Fast-mapping performance was significantly correlated with chronological age for typically developing boys and with nonverbal cognition for boys with FXS. For participants with FXS, chronological age, nonverbal IQ, and fast-mapping performance all emerged as significant and unique predictors of receptive vocabulary, whereas chronological age and nonverbal IQ uniquely predicted expressive vocabulary. Although examining longitudinal associations will provide additional insight into these relationships, the current results support the construct validity of the experimental task, at least for typically developing boys and boys with FXS.

Limitations

The experimental task implemented in the current study represents the simplest case of word-referent mapping in which an associative link is established between a label and an object based upon temporal contiguity alone; that is, the child hears a novel label at the same time a nameless object is within their field of vision. This type of experimental paradigm corresponds, in a stripped down fashion, to the real-life situation in which a caregiver provides a label that follows into the child's focus of attention, presumably limiting the cognitive resources that the child must direct toward disambiguating the adult's intended referent (Tomasello and Todd 1983). Studies of language acquisition in typically developing children suggest new words are acquired most efficiently when the parent scaffolds the child's attention to an object while a novel label is provided, even when the child makes no active contribution to the achievement of joint reference (e.g., Adamson et al. 2004). However, it is also known that an experimental paradigm such as the one used in the current study does not accurately reflect what happens in the natural environment where parents often do not label the objects within the child's focus of attention (e.g., Harris et al. 1983) and in which children may have to rely on understanding a variety of cues to infer the speaker's intended referent (Sabbagh and Baldwin 2005). Cross-situational theories of language learning, in particular, posit that children learn new words based upon the statistical probabilities experienced during repeated and consistent exposures to a label-object pairing across different daily activities and routines (e.g., Plunkett et al. 1992; Smith and Yu 2008). Clearly, the task administered in the current study did not delve into the word learning process in terms of specifying the extent of previous exposure needed to support word learning, the stability and retention of the word-object mappings, or the ability of the participants to make use of social and affective cues indicative of referential intent.

Unlike a looking-time study in which it is possible to examine how patterns of visual attention change based upon the time course of word presentation, this study was not designed to evaluate real time changes in direction of gaze. Thus, it is not possible to determine whether the phonological characteristics of the nonsense words influenced performance on the fast-mapping task. We did, however, intentionally construct the nonsense labels using earlier developing consonant phonemes (m, b, t, d, k) with the intent of minimizing differential effects on performance that might be attributed to the use of phonemes that might not be present in the participants' speech repertoires. Furthermore, with only one trial for each novel object, we are unable to systematically examine phonological characteristics of the novel labels.

It must be acknowledged that what the participants learned as a result of exposure to the experimental task was a temporary and fragile link between one label and one object presented in a single context. According to Carey (2010), the initial process of fast-mapping provides the child with a partial interpretation of the novel word based upon both the linguistic context and the child's representation of the nonlinguistic context. Fast-mapping is then followed by an extended process (sometimes termed "slow mapping") during which the child continues to consolidate the full meaning of the novel label.

The fast-mapping task utilized in the current study had several limitations. The task did not include a test of production in which the child's ability to generate the novel label could have been evaluated. Including only four trials on the fast-mapping task limited our ability to truly understand within-individual differences in word learning and limited our power to detect group differences. In addition, a lack of control trials in which the participant selected familiar objects limited our ability to evaluate participant compliance with task demands. Finally, use of generalization trials, in which the child selects another exemplar of the novel object in response to the novel label, would have provided a more stringent test of word learning. These limitations, however, reflected our desire to limit the duration of the experimental task and enable us to maintain the engagement of children in the developmental ranges of the populations of interest.

An additional limitation is the existence of potentially important predictors that were not included or measured in the current study, such as phonological memory. Although the initial fast-mapping process may be intact for individuals with cognitive delays, the process of retaining label-object associations over time is likely to be impaired (Wilkinson 2007), suggesting problems with working memory or consolidation and retrieval from long term storage. Studies of typically developing word learners have provided insights into the kinds of adult pragmatic and attentional cues necessary to support stable vocabulary acquisition in young children (Booth et al. 2008; Horst and Samuelson 2008). Measuring these types of variables might have informed the results and added important information to the description of the behavioral phenotypes of ASD and FXS. Finally, the current study reported only concurrent associations. Longitudinal data would allow a more rigorous examination of the contribution of fast-mapping to vocabulary learning.

Future Directions

The current study represents an initial inquiry into the process of word learning for boys with FXS or ASD. Future studies should pursue this line of research by focusing on the identification and measurement of specific cognitive skills that may impact the ability to learn new words early in development. One potential explanation for the differential task performance of boys with FXS in the current study relative to cognitive ability-matched boys with typical development or ASD is that factors other than nonverbal cognitive ability, such as attention and memory, affected word learning performance for this group of participants.

Males with FXS are known to display severe deficits in attention that are reflected at both the behavioral (Cornish et al. 2004; Scerif et al. 2012) and physiological (Van der Molen et al. 2012) level. Thus, boys with FXS can be expected to have particular difficulty with tasks demanding high levels of attention and the need for active planning, manipulation or organization of items in working memory (Pierpont et al. 2011).

Cornish et al. (2004) attribute behavioral characteristics such as inattention, hyperactivity and impulsivity to a core inability of males with FXS to modulate arousal. ERP studies of neural activity in males with FXS may shed light on the ways in which these individuals process auditory information. For example, Castrén et al. (2003) compared auditory N1 responses of school aged boys with FXS to age-matched controls and found increased amplitude and decreased habituation of this component; a finding interpreted as indicating abnormal stimulus processing in the auditory cortex. Similarly, Scerif et al. (2012) found that males with FXS attended less well than mental-age matched typically developing boys, experienced greater difficulties with auditory compared to visual stimuli, and did not benefit from multimodal information, which is the type of information that must be processed in the initial fast-mapping process.

In a recent examination of event-related cortical activity in response to both auditory and visual stimuli, Van der Molen et al. (2012) found both modalities to be affected in males with FXS, with more behavioral errors in response to auditory than visual stimuli. It is not yet known if a deficit in processing social and referential cues contributes to the language problems of males with FXS or if these problems can be accounted for by other aspects of the cognitive phenotype (e.g., phonological and verbal working memory; Pierpont et al. 2011). Thus, consideration of the contributions of attention, working memory, fast-mapping performance, and other cognitive skills in future studies would allow researchers to develop a more nuanced model of word learning in young boys with FXS. Continued investigation of the processes by which language is acquired in males with FXS has the potential to inform behavioral and pharmacological treatments with the goal of assisting these individuals to respond more successfully and consistently to language learning opportunities.

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