

The Integrity of Lexical Acquisition Mechanisms in Autism Spectrum Disorders: A Research Review

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Research on autism spectrum disorders (ASD) has rapidly expanded in recent years, yielding important developments in both theory and practice. While we have gained important insights into how children with ASD differ from typically developing (TD) children in terms of phenotypic features, less has been learned about if and how development in ASD differs from typical development in terms of underlying mechanisms of change. This article aims to provide a review of processes subserving lexical development in ASD, with the goal of identifying contributing factors to the heterogeneity of language outcomes in ASD. The focus is on available evidence of the integrity or disruption of these mechanisms in ASD, as well as their significance for vocabulary development; topics include early speech perception and preference, speech segmentation, word learning, and category formation. Significant gaps in the literature are identified and future directions are suggested. *Autism Res* 2015, 00: 000–000. © 2015 International Society for Autism Research, Wiley Periodicals, Inc.

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Scientific summary for families with ASD

Research on autism spectrum disorders (ASD) has rapidly expanded in recent years, yielding important developments in both theory and practice. Many children with ASD struggle with vocabulary and vocabulary development. We survey the research on how vocabulary development and knowledge in ASD are similar to and different from typical development, with the goal of identifying contributing factors to the heterogeneity of language outcomes in ASD. Our focus is on available evidence about the cognitive processes that are thought to underlie language learning in typical development, and whether these processes are intact or disrupted in ASD. We also discuss the significance of these processes for vocabulary development. Topics include early speech perception and preference, speech segmentation, word learning and category formation. Significant gaps in the literature are identified and future directions are suggested.

In recent years, the study of autism spectrum disorder (ASD) has, in a word, exploded. The Interagency Autism Coordinating Committee reported in 2012 that the past three decades had seen a 12-fold increase in the number of annual ASD-related publications (<https://iacc.hhs.gov/publications-analysis/july2012>). Though this rapid expansion certainly marks important advances, there

remain gaps. Many researchers of human development have highlighted the importance of combining the study of typical and atypical development; in the words of Sroufe [1997]: “the same laws that govern normal development govern the pathological as well” (p. 266). That is, rather than conceptualizing “disorder” as manifesting qualitatively different patterns of development than what we observe in “typical” development, we should instead perceive it as a variant produced by different combinations of endogenous or exogenous factors (i.e., biology and/or environment). While ASD research conventionally includes comparison samples of children matched on chronological or mental age to identify how children with ASD differ from TD children, however, these studies often focus on profiling differences in children’s language knowledge rather than understanding why such differences arise—that is, whether the cognitive and learning mechanisms by which children develop language themselves differ. This is a marked shortcoming in our efforts to understand ASD; our aim should be to identify continuities and discontinuities in underlying mechanisms, not simply in observable features [Rutter & Sroufe, 2000].

In this review, we focus on mechanisms subserving language development, and specifically, lexical development (which we interchangeably term lexical, semantic, or vocabulary development). The five domains of

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language (phonology, morphology, syntax, semantics and pragmatics) have been studied to varying degrees in ASD. Pragmatic deficits have been well studied, but these are not the only impaired aspects of language and communication in ASD. Individuals with ASD often have language impairments ranging in severity, encompassing some or all of phonological, morphosyntactic, and lexical/semantic development [see Boucher, 2012 for a survey]. We focus our attention on the latter.

Though lexical knowledge (*per se*) in ASD is not the focus of this review—we focus primarily on the *processes* that allow children to acquire this knowledge—it is a suitable launching point. Most individuals with ASD acquire their first words later than their typically developing (TD) peers [Charman, Drew, Baird, & Baird, 2003; LeCouteur, Bailey, Rutter, & Gottesman, 1989; Lord, Rutter, & Le Couteur, 1994; Luyster, Lopez, & Lord, 2007], with language delay being one of the most commonly reported initial parent concerns [Chawarska et al., 2007; Herlihy, Knoch, Vibert, & Fein, 2013]. However, language outcome in early adulthood is extremely heterogeneous across the autism spectrum: current estimates suggest that nearly 70% of individuals will attain verbal fluency (e.g., use of sentences that are spontaneous, generative and communicative), and roughly 10% will have receptive and expressive language approximating age expectations [Pickles, Anderson, & Lord, 2014]. Studies have repeatedly found this variability in language outcome to be closely associated with nonverbal cognitive ability [Pickles et al., 2014; Anderson et al., 2007; Thurm, Lord, Lee, & Newschaffer, 2007]. As with all areas of development in ASD, individual differences are significant [e.g., Kjelgaard & Tager-Flusberg, 2001], but for individuals who do acquire phrase speech, vocabulary may be a relative strength [Mayes & Calhoun, 2003; Kjelgaard & Tager-Flusberg, 2001]. Nevertheless, lexical mastery—even if considerable—may not be “normal”: individuals with ASD often do not show a pronounced advantage in receptive relative to expressive language skills as TD children do [Weismer, Lord, & Esler, 2010; Charman et al., 2003; Luyster, Lopez, & Lord, 2007; but see Kwok, Brown, Smyth, & Cardy, 2015], though the extent to which these apparent deficits in comprehension are entangled with impairments in social response remains unclear.

This review aims to go beyond characterizing lexical knowledge to explore possible explanations for its diversity in ASD. Research on typical development has identified several mechanisms supporting lexical acquisition at multiple levels; for instance, from perceptual sensitivity to speech sounds, to parsing out word forms from the speech stream, determining their grammatical category, and morphosyntactic properties, and assigning a semantic representation. These capabilities have

been explored (to varying degrees) in individuals with ASD. Below, we summarize what is known about the integrity of lexical acquisition mechanisms in ASD, with the goal of “bridging the gap” between research on typical and atypical populations. The first section explores children’s attention to and processing of lexical input through a review of perceptual narrowing, preference for speech, and statistical learning. The second section reviews abilities supporting mapping to meaning, including the use of social cues, availability of word learning constraints, and formation of lexical categories.

The heterogeneity associated with ASD introduces a number of questions that are beyond the scope of the present paper. For instance, what role does IQ play in the integrity of lexical mechanisms in ASD? Are these processes diminished in individuals with higher levels of symptom severity? How do underlying systems such as executive function or motor control, influence lexical development? Although these inquiries will not be addressed here, we argue that if mechanistic disruptions are defining—that is, universal—features of ASD, group-level differences should nevertheless emerge. As a first step towards answering these questions, however, we note relevant characteristics of the studied populations in the research we review. It is our hope that our synthesis of the literature will help clarify the defining features of ASD, and provide leads for future research efforts as well as evidence-based interventions.

Access to a Lexicon: Using language input

Tuning to native sounds

One of the earliest milestones in the long road of language development is the “tuning” of auditory perception to native speech sounds. Foundational research has indicated that, while infants younger than 6–8 months are equally sensitive to phonemic distinctions across native and non-native languages, older infants (~10 months) are much less sensitive to non-native sounds, showing reduced ability to discriminate similar phonemes [e.g., Werker & Tees, 1999]. This developmental shift, whereby the infant retains heightened discriminatory skill with native speech sounds relative to non-native ones, is called “perceptual narrowing,” and is thought to be one of the first signs that the child is specializing, both neurologically and functionally, in his or her native language. Indeed, individual differences in the timing of perceptual narrowing are associated with later lexical performance, such that children who remain sensitive to non-native speech contrasts past 8 months show slowed vocabulary development at 2 years of age [Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005].

Although perceptual narrowing in children later diagnosed with ASD has not yet been measured in developmentally appropriate longitudinal designs, several studies have explored related questions with the hope of extrapolating whether this process might be related to language outcomes in ASD. One vein of research has observed that auditory discrimination is an area of strength in ASD [Lepistö et al., 2005]. A commonly cited example is that a disproportionate number of individuals with ASD have absolute pitch [DePape, Hall, Tillman, & Trainor, 2012; Miller, 1999; Rimland & Fein, 1988] or heightened pitch discrimination ability [Bonnell et al., 2010; Stanutz, Wapnick, & Burack, 2014; O’Riordan & Passetti, 2006], leading some experts to suggest that “fundamental differences in the perception of sounds may be part of the autistic profile” [Jones et al., 2009, p. 2851]. Although this evidence is not about speech sounds specifically, pitch discrimination may play a pivotal role in early language acquisition, facilitating the identification of word boundaries and processing of syntactic structures [e.g., Eigsti & Fein, 2013; Goodsit, Morgan, & Kuhl, 1993; Jusczyk et al., 1992].

Several studies have suggested a link between enhanced pitch discrimination and lexical delays in individuals with ASD: infants with heightened sensitivity to auditory contrasts may be slower to focus on the particular contrasts most relevant for their native language [see Eigsti & Fein, 2013 for discussion], thus delaying the process of word segmentation. Jones et al. [2009] reported that exceptional skill in discriminating frequency differences in auditory stimuli was significantly more common in adolescents with ASD and a history of delayed first words than in children with no history of language delays; similar findings were reported by Bonnell et al. [2010]. In a study of children with ASD—some with “optimal outcomes” who had shed their diagnosis, and others still diagnosed on the autism spectrum—Eigsti & Fein, [2013] reported that individuals who had an early diagnosis of ASD *and* a history of delayed language (regardless of current symptom presentation) were better in one of three experimental measures of pitch discrimination than those who did not have a history of language delay. Interestingly, when averaging across all three tasks, the ASD group showed an advantage in pitch discrimination relative to the typical controls, whereas the optimal outcome group did not, pointing to a link between pitch discrimination and current symptomatology. Overall, the results addressing pitch discrimination are consistent with the aforementioned results in TD children [Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005] and together suggest that lexical delays may be linked with heightened sensitivity to sounds that continues beyond a “developmentally appropriate” time window.

Relatedly, Constantino et al [2007] measured the ability to perceive non-native phonemic contrasts in school-aged, verbal children with ASD, with the hypothesis that children with ASD might have retained this ability even through late childhood. The hypothesis was not supported; the ASD and TD groups performed similarly. However, it is worth noting that the authors consider their sample to be “high-functioning,” although they do not report on history of language delays or current level of language ability.

The perceptual abilities shaped through perceptual narrowing form the foundation for phoneme production. Consequently, another inroad to the question of whether children with ASD tune to their native language is to explore production—rather than perception—of speech sounds. Schoen, Paul and Chawarska [2011] measured the vocal productions of toddlers with ASD, as well as age- and language-matched controls. Groups were similar in their productions of some nonspeech sounds, like laughter and crying/fussing, but toddlers with ASD produced significantly more atypical vocalizations than their peers, primarily in the form of high-pitched squeals [see also Schoen, Paul, & Chawarska, 2009; but cf. Brisson et al., 2014]. The authors concluded that one feature of speech and language development in children with ASD may be a “failure to shape their production toward the sound parameters of the ambient language” [Schoen, Paul, & Chawarska, 2011, 2009, p. 186]. Although this is a promising path of investigation, it remains to be seen whether these perturbations in vocal production are sequelae of perceptual deficits.

Early speech preferences

From the earliest months of life, typically developing infants prefer to listen to speech over non-speech sounds [e.g., Vouloumanos & Werker, 2004, 2007; Shultz & Vouloumanos, 2010]. This preference predicts later vocabulary development in healthy, TD populations [Vouloumanos & Curtin, 2014]. In contrast, early speech preferences (relative to non-speech) are disrupted in infants at risk for ASD [Curtin & Vouloumanos, 2013], and other studies have reported a lack of preference for speech over non-speech in children with ASD in both behavioral [Kuhl et al., 2005; Watson, Roberts, Baranek, Mandulak, & Dalton, 2012] and event-related potential [Whitehouse & Bishop, 2008] paradigms.

The speech that infants hear from their mothers (and other primary caregivers) is often characterized by a particular style of speech called infant-directed speech (IDS), with higher pitch and exaggerated pitch contours compared to adult-directed speech. Infants generally prefer IDS over adult-directed speech [Fernald, 1985], and this preference facilitates language development in

TD children [Thiessen, Hill, & Saffran, 2005; Singh, Nestor, Parikh, & Yull, 2009; Saint-Georges et al., 2013].

A small body of literature has explored the salience and developmental role of IDS to infants at risk for or diagnosed with ASD, but a methodological note is warranted: in the studies described below, there is considerable variation in the comparison stimuli employed (i.e., adult-directed speech, analogs of IDS, digitized musical tracks). Parents of infants with ASD use IDS at the same rate as comparison groups [Cassel et al., 2013; Cohen et al., 2013; Brisson et al., 2014], although parental utterances may be shorter [Brisson et al., 2014]. Nevertheless, infants at high-risk for ASD have a weaker preference for IDS than their low-risk peers, showing either a smaller preference for IDS over adult-directed speech [Droucker, Curtin, & Vouloumanos, 2013] or a slight preference, instead, for adult-directed speech [Nadig et al., 2007]. This lack of preference could be due, in part, to reduced attention or sensitivity to the features of IDS. For instance, Ference and Curtin [2013] found that high-risk infants did not differentially attend to contrasting lexical stress patterns highlighted in IDS [and also failed to recognize stress as a marker of word meaning, Ference & Curtin, 2015]. Toddlers and preschoolers with ASD showed a similarly damped preference for infant-directed speech [as compared to non-speech analogs of IDS speech, Paul, Chawarska, Fowler, Cicchetti, & Volkmar, 2007; Kuhl et al., 2005], but Paul et al. [2007] suggest that this effect could be due partly to degree of language impairment. Follow-up studies confirmed that, although toddlers with ASD showed a markedly diminished IDS preference relative to chronologically matched peers, they differed only from language-matched TD peers in the degree of IDS preference (as compared to nonsocial stimuli) under live speech (rather than videotaped) conditions [Watson et al., 2012]. Lack of preference for IDS and its exaggerated pitch contours is perhaps surprising given the enhanced pitch sensitivity reviewed above; it may be that heightened sensitivity to pitch makes IDS overly stimulating and thus dispreferred, or that the social nature of IDS is what makes it specifically dispreferred.

The ramifications of reduced IDS preference for language development are mixed. Two studies with infants at high risk for ASD [Droucker, Curtin, & Vouloumanos, 2013; Ference & Curtin, 2013] found no relationship between IDS preference and later vocabulary development. On one hand, these results might suggest that, for infants with a genetic liability for ASD, preference for IDS (or lack thereof) may not play a lasting role in language development. Conversely, however, other studies report lasting effects of reduced IDS preference. In a study of toddlers with ASD, preference for IDS was correlated with receptive language skills, both concurrently and at a 1-year follow-up [Paul et al.,

2007]. Watson et al. [2010] similarly reported that, for preschoolers with ASD, preference for IDS predicted concurrent and later expressive and receptive abilities, and Nadig et al. [2007] reported that, for 6-month-olds at risk for ASD, adult-speech preference was negatively associated with concurrent standardized expressive language scores [Nadig et al., 2007].

In sum, although children with ASD do not—at a group level—show a preference for speech (over non-speech) or IDS (over a range of comparison stimuli), associations with concurrent and later language attest to the lasting effects of heterogeneity in early preferences; in fact, Kuhl et al. [2005] measured response to a *native* contrast (/ba/and/wa/) in preschoolers with ASD, and found evidence for phonemic discrimination only for those children who preferred to listen to IDS over a non-speech analog signal. Clearly, then, there are meaningful individual differences in speech preferences for infants at risk for and children with ASD.

Identifying the words: Statistical and distributional learning

Statistical learning is the ability to extract statistical regularities from a stimulus. Though now widely considered a domain-general learning mechanism [e.g., Kirkham, Slemmer, & Johnson, 2002; Saffran, Johnson, Aslin, & Newport, 1999], it has been well studied in language acquisition, particularly with respect to children's identification of word boundaries and extraction of grammatical rules. In the first demonstration of statistical learning in human infants, Saffran, Aslin, & Newport [1996] presented 8-month-olds with streams of connected speech syllables. The distribution of the syllables was such that some strings of three syllables appeared together more often than others, and infants were tested to see if they recognized the cohesion between these syllable groupings. They did, demonstrating that they had segmented the ongoing speech stream into parts ("words") that frequently co-occurred. Many subsequent studies have replicated and extended this finding, and linked it to lexical development; for instance, Estes, Evans, Alibali, & Saffran [2007] found that 17-month-olds could map the "words" they segmented to novel objects [see also Lany & Saffran, 2010].

There are individual differences in segmentation ability, suggesting that this is an important place to seek predictive value for language outcomes. Newman, Ratner, Jusczyk, Jusczyk, & Dow [2006] found that performance on a segmentation task before age 12 months predicted expressive vocabulary at age 2 years and other language measures at ages 4–6 years (MacArthur Bates Communicative Development Inventory [Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994], Test of Language

Development [Newcomer & Hammill, 1997]). Further, statistical learning difficulties may be implicated in Specific Language Impairment (SLI); Evans, Saffran, & Robe-Torres [2009] showed impaired identification of word boundaries in a statistical learning task in children with SLI as compared to age- and IQ-matched comparison groups.

In individuals with ASD, the evidence about statistical learning is scant, and somewhat conflicting [see also Eigsti & Mayo, 2011, for review]. Scott-Van Zeeland et al. [2010], using a similar paradigm to Saffran et al. [1996], found different patterns of neural activation in high-functioning 9- to 16-year-olds with ASD than TD age- and IQ-matched controls. These atypical activation patterns were linked to communication domain scores on the Autism Diagnostic Interview-Revised, suggesting that disrupted speech segmentation abilities may underlie language and communication deficits. Mayo and Eigsti [2012], however, found similar performance in high-functioning 7- to 17-year-olds with ASD as TD controls on a similar task—although the exposure period was considerably longer than in Scott-Van Zeeland's (21 min, compared to 2 min)—and they found no links between task performance and language or cognitive measures.

Statistical learning with visual stimuli (e.g., shapes), instead of auditory or linguistic stimuli, may be intact in ASD [Jeste et al., 2015; Roser, Aslin, McKenzie, Zahra, & Fiser, 2014]. A recent meta-analysis also finds no evidence that sequence learning or other types of implicit learning for non-language stimuli are impaired [Foti, De Crescenzo, Vivanti, Menghini, & Vicari, 2014; see also Boucher, Mayes, & Bigham, 2008]. Thus, although statistical learning itself is considered domain-general, it may be intact for non-speech/language stimuli but not for language. This does not necessarily indicate that the mechanism is domain-specific in ASD; rather, it likely indicates difficulty processing language stimuli in a way that permits typical use of the mechanism, and may be related to the aforementioned reduced attention to speech.

Forming a Lexicon: mapping words to meaning

When children with ASD do successfully segment a new word from the speech stream (even if they may require more input to do so than TD children), how do they assign it meaning? A first step is to recognize that word forms *have* meaning. This ability has been demonstrated in the first year of life: words, but not non-verbal sounds, promote object categorization and object individuation in infancy [e.g., Ferry, Hespos, & Waxman, 2010; Fulkerson & Waxman, 2007; Xu, 2002]. McDuffie, Yoder, & Stone [2006a] reported similar behaviors in 2-year-olds with ASD (and comprehension-

matched TD children), who show increased attention to novel objects when they hear a novel label.

But because there are likely to be multiple objects, people, ongoing actions, and spatial relations evident in the child's environment, assigning the correct meaning to a word is an important challenge, requiring the child to identify which referent is being labeled. Even if only one referent is salient, it may be construed in multiple ways (e.g., a puppy might be labeled *dog* or *animal*, and a game of catch as *throwing*, *catching*, or *playing* a game). Research with TD children has delineated several linguistic/cognitive mechanisms they bring to the word-learning task. Here, we outline the evidence about these mechanisms in typical development and ASD in three domains: social cues, word learning constraints, and linguistic cues.

Using social cues. An important set of social cognitive skills is thought to drive language learning, such as inferring what a speaker intends to refer to (e.g., a speaker is likely to label something she appears interested in at the moment), and using the speaker's direction of gaze, pointing, or affect to determine his or her attentional state [e.g., Baldwin, 1993; Baldwin & Tomasello, 1998; Nappa et al., 2009; Poulin-Dubois & Forbes, 2002; Tomasello & Barton, 1994]. To capitalize on such cues, the child must have some prerequisite social-cognitive abilities. A review of this rich literature is beyond the scope of this review; however, it is essential to note the heterogeneity of ability in these areas for children with ASD. As a group, individuals with ASD show deficits in gaze following [Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997; Leekam, Hunnisett, & Moore, 1998; Gillespie-Lynch, Elias, Escudero, Hutman, & Johnson, 2013], joint attention [Osterling & Dawson, 1994; Mundy, Sigman, & Kasari, 1990; Leekam & Ramsden, 2006; Dawson et al., 2004], and understanding others' internal states [Happé, 1994, 1995; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997]; but these gross differences belie remarkable individual differences in each of these areas. Not surprisingly, these social cognitive skills strongly predict language ability (both concurrent and at later points) for children with ASD [Brooks & Meltzoff, 2015; Yoder, Watson, & Lambert, 2015; Luyster, Kadlec, Carter, & Tager-Flusberg, 2008; Adamson, Bakeman, Deckner, & Ronski, 2009; Anderson et al., 2007], suggesting that they may be "gate-keepers" for children's access to essential linguistic input [e.g., Bono, Daley, & Sigman, 2004; Thurm, Lord, Lee, & Newschaffer, 2007]. Indeed, Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg [2007] found that understanding of social intention predicted vocabulary size in children with ASD (but not TD children). Similarly, McDuffie, Yoder, and Stone

(2006b) found that attention-following at 2.5 years of age predicted success in a fast-mapping task, as well as vocabulary size 6 months later.

The literature addressing use of social cues in word learning in children with ASD has primarily focused on two questions: (1) can children with ASD use speaker's gaze to guide mapping of new words to their intended referents; and (2) what role does attention modulation play in successful mapping? We address each of these issues in turn.

In a seminal study, Baron-Cohen, Baldwin, and Crowson [1997] adapted Baldwin's [1993a, 1993b] word learning paradigm asking whether children would map a novel word to the object that the speaker was currently attending to, or to the object they themselves were holding at the time. Baron-Cohen et al. demonstrated that children with ASD do not typically use the speaker's direction of gaze to assign word meanings; Preissler & Carey [2005] reported similar results. Note that both samples included children who were quite a bit older than Baldwin's typically developing sample and had marked language deficits. In a follow-up study using the same experimental design with younger, higher-functioning children with ASD, Luyster and Lord [2009] found that children with ASD *were* able to use the speaker's direction of gaze in a word-learning task. This ability has since been confirmed across a range of paradigms, with a range of age groups and language abilities, though most studied individuals have been relatively high-functioning [Akechi et al., 2011; Akechi, Kikuchi, Tojo, Osanai, & Hasegawa, 2013; Aldaqre, Paulus, & Sodian 2015; Franken et al., 2010; Hani, Gonzalez-Barrero, & Nadig, 2013; McGregor, Rost, Arenas, Farris-Trimble, & Stiles 2013; Norbury, Griffiths, & Nation, 2010].

Some researchers have suggested that children's use of social cues is more based on attention than social understanding *per se* [e.g., Akechi et al., 2011; Hani et al., 2013; McGregor et al., 2013], and that social cues work insofar as they increase the perceptual salience of an object. Akechi et al. [2013], for example, using a similar paradigm to Baron-Cohen et al., but adding eye-tracking to identify children's locus of visual attention, found that 6- to 12-year-old TD children looked longer at the object the speaker was gazing at than the object they themselves were holding, while children with ASD showed no difference; however, children with ASD reversed this pattern and successfully mapped a novel label to an object in the speaker's gaze when that object was more perceptually salient than their own object. Even high-functioning adults with ASD may be affected by perceptual salience in a word-learning task requiring attention to speaker gaze [Aldaqre et al., 2015]. Also supportive of this is evidence that attention to gaze direction does not *necessarily* lead to word learning;

Gliga, Elsabbagh, Hudry, Charman, & Johnson [2012] found that 3-year olds with a family history of ASD followed a speaker's direction of gaze but those who scored poorly on social and communication domains on the Autism Diagnostic Observation Schedule [ADOS; Lord et al., 2000] did not use that information to assign a referent to the novel word. Importantly, in many of the studies documenting successful learning in children with ASD, multiple converging social cues and/or increased repetitions were provided, scaffolding performance in valuable ways [Akechi et al., 2013; Hani et al., 2013; Luyster & Lord, 2009; Norbury et al., 2010]. These findings point to the importance of attention and memory in word learning [e.g., Norbury et al., 2010; Bedford et al. 2013].

Using word learning constraints/biases

In typical development, learners are thought to use certain constraints or biases to inform word learning—in other words, cognitive heuristics that aid the formation of links between word forms and meanings. Among these are the whole object assumption [Markman, 1990], the taxonomic assumption [Markman, 1990], the noun bias [Gentner, 1982], the noun-category bias [Waxman, 1991], and mutual exclusivity [Markman, 1990] or the Principle of Contrast [Clark, 1987]. It is still a matter of debate whether these constraints or biases are innate or learned, domain-specific or domain-general [e.g., Hollich et al., 2000; Samuelson, 2011]. For current purposes, we ask to what extent children with ASD appear to use these same constraints or biases, regardless of their source; we hope that with continued study, findings from TD and disordered populations will inform each other with respect to the specific processes underlying these constraints.

Several of these word learning constraints or biases have been studied in children with ASD. The noun bias, or a preference to map a novel word to an object rather than an action, appears intact in 2- to 3-year olds with ASD [Swensen, Kelley, Fein, & Naigles, 2007]. Mutual exclusivity is the assumption that only one word applies to each object, and therefore that unfamiliar words label objects for which children do not yet have a label [Markman, 1990]; several studies have found that this, too, is intact [de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011; Parish-Morris et al., 2007; Preissler & Carey, 2005; Wilkinson, 2005]. De Marchena et al. [2011], studying high-functioning children and adolescents with ASD, specifically addressed the issue of whether the ability to use mutual exclusivity in word learning is more closely related to lexical or pragmatic development, and found that it was the former. The same is true with TD children: Bion, Borovsky, and Fernald [2013] found a positive relationship

between accuracy at looking to an unfamiliar object when hearing a novel word and vocabulary size for TD 2-year-olds. We take these studies as evidence that these constraints are not in themselves absent or notably impaired in ASD.

Using linguistic cues

The linguistic context in which a word appears can also provide cues to its meaning. Verb acquisition is most studied in this context, because verb meaning is tightly linked to the sentence structures in which it appears [e.g., Baker, 2001; Grimshaw, 1984; Levin, 1993; Pinker, 1984]. The ability to use these syntax-semantics links to acquire the meanings of unfamiliar verbs is known as syntactic bootstrapping [Gleitman, 1990; Landau & Gleitman, 1985], and has been documented beginning at about 1.5 years of age [e.g., Arunachalam, Escovar, Hansen, & Waxman, 2013; Fisher, 1996, 2002; Fisher, Hall, Rakowitz, & Gleitman, 1994; Messenger, Yuan, & Fisher, 2015; Naigles, 1990]. In a classic demonstration, Naigles [1990] presented 28-month olds with novel verbs in either transitive sentences (e.g., “The duck is gorping the bunny”) or intransitive sentences (e.g., “The duck and the bunny are gorping”), accompanied by a visual scene depicting two simultaneous events (e.g., the duck pushed the bunny, and the duck and bunny waved). At test, these two events displayed on different screens, and children were asked to “find gorping!” Children who had heard the transitive sentence preferred the scene in which the duck pushed the bunny, revealing their knowledge that transitive syntax can be mapped to causative events in which one event participant acts on another.

Prerequisite abilities for syntactic bootstrapping include knowledge of some nouns and comprehension of basic linguistic structures [e.g., Gleitman et al., 2005]. This latter ability was partly demonstrated by children with ASD by Swensen et al. [2007], who found that 2- to 3-year-old English-acquiring children with ASD understood that word order in English dictates the assignment of event participants to semantic roles. With this prerequisite skill empirically established, two studies went on to document syntactic bootstrapping in children with ASD using Naigles’s [1990] task: Shulman and Guberman [2007] in Hebrew-acquiring 5-year olds, and Naigles, Kelty, Jaffery, & Fein [2011] in English-acquiring 3-year olds. Naigles et al. [2011] further found that syntactic bootstrapping performance was related to vocabulary and sentence processing abilities as measured 8 months earlier.

Methodologically, an interesting feature of experimental paradigms for studying syntactic bootstrapping is that they are remarkably non-social, only requiring children to attend to linguistic cues, with little social

context or cuing (see also Arunachalam [2013] for an even less social version of Naigles’s [1990] task). The minimal social demands involved in these tasks suggest that they may be promising for understanding children’s lexical and syntactic abilities while bypassing confounding social impairments. We suspect that pursuit of this line of research will reveal which learning mechanisms require social attention and social understanding and which proceed without these skills.

Interestingly, one category of verbs that originally motivated the study of syntactic bootstrapping does appear to be poorly learned in ASD: mental state verbs. Mental state verbs are ideal for examining syntactic bootstrapping because they represent abstract concepts that would be difficult to learn by observing the world, such as *think*, *remember*, and *know*; however, they often appear in a syntactic structure in which they take a complement clause (e.g., “I think that...”), which serves as an indicator of the verb’s meaning. Nevertheless, children with ASD have difficulty understanding mental state verbs [e.g., Baron-Cohen et al., 1994; Kazak, Collis, & Lewis, 1997; Kelley, Paul, Fein, & Naigles, 2006; Tager-Flusberg, 1992; Ziatas, Durkin, & Pratt, 1998], suggesting an interaction between semantic and syntactic ability: While syntactic knowledge can support acquisition of a broad meaning category, it cannot override difficulties children may have with particular concepts. Taken together, the literature indicates that syntactic bootstrapping is relatively intact in ASD but (unsurprisingly) relies on the earlier acquisition of prerequisite linguistic skills and is constrained by conceptual understanding.

Generalizing words to the appropriate category

Of course, the brief exposure to a new word that is typically presented in word-learning tasks does not itself result in robust or precise representations of word meaning. In Carey and Bartlett’s [1978] seminal “fast mapping” study, 3-year-olds successfully chose an olive green tray rather than a red tray when asked to “Bring me the chromium tray, not the red one,” indicating that they inferred that the unfamiliar word *chromium* (a) referred, (b) referred to a color, and (c) referred to a color for which they did not have a name. However, they were only slightly more successful than a control group of children in subsequently picking out the same color in a memory task. To truly learn a word’s meaning, children must engage in a process of extended mapping during which they refine and consolidate their lexical representation. At least two specific abilities have been tested in ASD: extension to appropriate category members, and integration into existing lexical knowledge and semantic networks.

Extension involves generalizing words beyond a specific referent to the entire category to which they apply: The noun “dog” refers not just to the family pet but to all dogs, and the verb “kick” refers not only to a girl kicking a football, but also a boy kicking a soccer ball, a baby kicking a mobile, and so on. It has long been suggested that children with ASD have difficulty generalizing information (though the precise mechanisms underlying this difficulty are poorly understood) [e.g., Happé & Frith, 2006; Plaisted, 2001]. However, studies examining generalization of new words in ASD have yielded mixed findings [McGregor & Bean, 2012; Menyuk & Quill, 1985; Tager-Flusberg, 1988; Vaginoudoukas, Papageorgiou, & Vostanis, 2003]. In particular, when children with ASD who have low expressive language levels [Hartley & Allen, 2014, 2015] and/or IQs below 70 [Preissler, 2008] are targeted, studies suggest impairments in extension to appropriate category members. One specific type of extension that may be impaired in ASD is extension via the shape bias [Field, Allen, & Lewis, 2015; Potrzeba, Fein, & Naigles, 2015; Tek, Jaffery, Fein, & Naigles, 2008], which informs children’s generalizations of nouns from one category exemplar to others: TD children prefer to generalize nouns by shape, rather than by other attributes such as color or texture, by about 2 years of age [Landau, Smith, & Jones, 1988]. Tek et al. [2008] and Potrzeba et al. [2015] found that children with ASD as a group did not use the shape bias to categorize novel nouns even at 4 years, although Field et al. [2015] found that children with a relatively high verbal mental age did use the shape bias (and children with a lower verbal mental age did not), and Potrzeba et al. [2015] reported intriguing associations between vocabulary size and fine motor skill in a subset of children with ASD who did show evidence of the shape bias. Tek et al. [2008] suggest that difficulty using the shape bias in children with ASD might be related to the pervasive difficulties with generalization evidenced in ASD. However, the shape bias is also reported to be deficient in late-talking children [Jones, 2003] and children with SLI [Collisson, Grela, Spaulding, Rueckl, & Magnuson, 2014], suggesting that the interaction between language learning and (visual) attention may be implicated [Vales & Smith, 2015], rather than ASD itself.

A few studies have examined the composition of the lexicon more broadly to ask whether children with ASD know the same *kinds* of words as TD children. Rescorla and Safyer [2013] found that though children with ASD had smaller vocabularies than TD children, there were no significant differences in the kinds of words they knew whether by grammatical category (e.g., noun, verb), or semantic category (e.g., animal names, toy names). Similar results have been reported using the MacArthur-Bates Communicative Development Inven-

tory [Charman et al., 2003; Luyster et al., 2007], and in comparison to late-talking toddlers [Weismer et al., 2011], although nonsemantic properties like word length do appear to matter [Kover & Ellis Weismer, 2014].

However, other studies have highlighted differences in semantic knowledge. Learners must discover relationships between words, for example, that *kick* is hierarchically related to verbs like *move* and *punt* but taxonomically related to *ball* and *foot*. Although children with ASD perform similarly to TD children on tasks probing their arrangement of words into superordinate and basic levels [Tager-Flusberg, 1985, 2001], they nevertheless appear less sensitive to the semantic relationships among words in some tasks [e.g., Battaglia, 2012; Bowler, Gaigg, & Gardiner, 2008; Gastgeb, Strauss, & Minshew, 2006; Hermelin & O’Connor, 1970; Norbury, 2005]. Schafer, Williams, & Smith [2013] found that children with ASD have sparser semantic networks, such that they know fewer words that are highly connected in the lexicon than their TD counterparts. Relatedly, Kelley et al. [2006] and Naigles, Kelley, Troyb, & Fein [2013] found that “optimal-outcome” children struggled with tasks tapping into conceptual knowledge and semantic networks, such as categorical induction. These authors suggest that pervasive difficulties with generalization, as well as pragmatic/social abilities to infer semantically relevant relationships may be to blame; we agree that this is an area ripe for future research.

We do not yet know what underlies group differences, but the fact that children with and without ASD seem to know the same *kinds* of words suggests that they may have access to the same mechanisms to acquire these words. Indeed, we believe that assuming similarity at first is more useful than starting with the assumption that learning mechanisms are fundamentally different. A starting hypothesis, for example, is that children with ASD are capable of forming robust and robustly connected semantic networks that are similar to those evident in TD children, but that they need more time and input to do so, or that the input must be presented in a way that is easier for them to take in and integrate, or that takes into account their characteristically restricted interests. We return to this latter notion of “intake” of the input below, but one intriguing finding in support of this possibility is that children with ASD with poor language skills have difficulty with cross-situational learning [McGregor et al., 2013], or more specifically, the ability to use information from multiple trials when positing a representation for a new word. If this is the case it could be that retention of information about new words is compromised in ASD, resulting in sparser or more poorly integrated lexical semantic knowledge. Indeed, two studies have found

poorer retention of word meanings in children and siblings of children with ASD [Bedford et al., 2013; Norbury et al., 2010].

Summary and directions for future research

We have presented several mechanisms underlying lexical acquisition in TD children and reviewed the evidence for the integrity of these processes in ASD. Below, we synthesize our findings in each area and identify the most pressing needs for future research.

Perceptual narrowing is relatively understudied. Although there is suggestive evidence for disruption in terms of timing or completeness, ASD is not characterized by an absence of perceptual narrowing. Indeed, Yi et al. [2015] reported intact perceptual narrowing for faces in individuals with ASD, suggesting that, at least as a domain-general process, narrowing to environmental input proceeds typically in ASD. Future research, particularly prospective designs in high-risk infants, should focus on replicating results from traditional paradigms addressing sensitivity to speech sounds in the first year of life. This work could confirm the unfolding of this process in children later diagnosed with ASD and explore whether it is delayed or occurs in a more “piecemeal” fashion; research should also address how individual variability in perceptual narrowing to speech sounds predicts language development.

There is strong evidence that IDS evokes a less robust preference (relative to adult-directed speech, IDS analogs or nonsocial stimuli, depending on the study) in children with ASD than in TD children; however, because IDS is not required for healthy language development [as evidenced by cross-cultural research, e.g., Ochs & Schieffelin, 1984; Rogoff, Mistry, Göncü, & Mosier, 1993], their lack of preference should not by itself result in language deficits. Much more concerning is evidence that human speech does not ensnare the attention of children with ASD (as a group) to the extent that it does in TD children; this is likely to have downstream effects for many of the mechanisms we have reviewed. We suspect that the core issue for speech preference, then, is less about IDS and more about the degree to which children later diagnosed with ASD prioritize speech *of any kind* over other environmental input.

Consequently, in addition to investigating the neurobiological underpinnings and mutability of dampened speech preferences in ASD and the directional relationship between these biases and children’s ability to capitalize on linguistic information from the speech signal, future research should consider ways to heighten infant attention to speech. For instance, is it as simple as markedly increasing the amount of input (e.g., bombardment)? Is it helpful to reduce visual distractions

(e.g., movement, color, contrast) or lessen social demands (e.g., overheard rather than child-directed speech)? Or, on the other hand, is it useful to pair speech with another reinforcing sensory experience (e.g., parental touch, actions with objects)? There is much to be gained from exploration of these questions.

With respect to statistical learning, the literature suggests that it is available to children with ASD, but that they may require more input to use it, perhaps especially so for linguistic stimuli compared to non-linguistic stimuli. Reported difficulties with statistical language learning may thus be tied to the difficulties with attention to and preference for speech discussed above, a hypothesis demanding research. Future work should also probe statistical learning abilities in prospective studies starting in infancy, using now well-established paradigms to establish foundational empirical data on similarities and differences in statistical learning associated with the ASD phenotype.

To identify word meanings, children with ASD apparently rely on the same kinds of biases and cues as TD children. Word learning constraints such as mutual exclusivity are largely intact. With respect to social cues, there is now a general consensus that children with ASD can use gaze cues to learn words. However, a number of questions remain about the role of domain-general abilities like memory and learning, as well as the extent to which learners can interpret the deeper meaning of these gaze cues. Indeed, when children with ASD are asked to move beyond gaze cues to use non-visible cues of speaker reference or intention, including perspective-taking and Theory of Mind [e.g., Jing & Fang, 2014], performance suffers. This suggests that there is much to learn from studies requiring children to invoke higher order social cognitive skills or navigate different kinds of word-learning situations (e.g., when nonostensive cues are used, when the language is being addressed to someone other than the child, etc.).

With respect to linguistic cues, and syntactic bootstrapping in particular, children who have the prerequisite syntactic and lexical skills (which are often delayed in ASD) show successful use of this mechanism. Children with intellectual disability *and* ASD are expected to struggle, however [Kover et al., 2014]. Future work should address the degree to which bootstrapping can be “turned on” earlier by increasing early lexical and syntactic knowledge, as this could have exponential consequences for lexical development. Importantly, in addition to prerequisite lexical and grammatical abilities, syntactic bootstrapping also requires rapid language processing skills; in order to benefit from the information available in a linguistic context, children must be able to quickly process it [e.g., Fernald, Marchman, Hurtado, 2008; Trueswell & Gleitman, 2007].

Indeed, language processing speed—or the speed with which children look to a picture in a display after hearing it named—predicts language and cognitive outcomes in both TD children [Marchman & Fernald, 2008] and children with ASD [Venker, Eernisse, Saffran, & Weismer, 2013], and so future research should focus on this issue. However, the research on online language processing in young children with ASD is new; while there may not be systematic differences between TD children and children with or at risk for ASD, there are large individual differences [Brock, Norbury, Einav, & Nation 2008; Chita-Tegmark, Arunachalam, Nelson, & Tager-Flusberg, 2015; Venker et al., 2013].

An important gap in the literature on mapping words to meaning is that most studies are limited to noun learning, and even further, to highly concrete and imageable concepts that can be depicted easily. Some work has been done on verbs, prepositions, and adjectives, for example, but even within these categories, easily imageable referents have been the primary targets. Varied techniques must be used to improve our understanding of the lexicon, including less imageable referents and function morphemes that serve grammatical functions but convey little content.

Children with ASD do have difficulty extending word meanings appropriately and situating them in semantic networks. Notably, the shape bias appears perturbed. But because shape bias difficulties are also evident in late talkers and SLI, this is unlikely to be related to ASD specifically. Future research should address the extent to which language impairment is characterized by weaknesses in shape bias and other kinds of extension, as well as what kinds of learning situations might promote children's abilities to generalize word meanings appropriately—such as situations that do not rely on social understanding, or simply present more repetitions/exemplars than TD children require.

Another question demanding additional study is *why* semantic networks appear to be different in ASD. It is not yet clear whether the differences are qualitative or quantitative, conceptual or linguistic. One possibility is that poor memory for and integration of new word meanings into children's existing knowledge is partially to blame. (Henderson, Powell, Gareth, & Norbury [2014] argue that word *form* integration is impaired in ASD; whether word meaning integration is as well remains to be seen.) Memories, including memories for words, undergo consolidation over time, and during this memory consolidation process they become integrated with existing lexical knowledge [e.g., Dumay & Gaskell, 2007]. If this is impaired, it will be important to study the role of sleep in learning and memory in ASD. Although sleep is important for memory consolidation [e.g., Stickgold & Walker, 2005], sleep problems are pervasive in ASD [e.g., Goodlin-Jones, Tang, Liu, &

Anders, 2008; Hollway & Aman, 2011; Malow et al., 2006; Richdale, 1999], suggesting that memory consolidation may proceed differently in these children. Although no studies have yet investigated this issue, it is promising that slow-wave sleep, which promotes consolidation of semantic memories like word knowledge [e.g., Gais & Born, 2004], may be relatively intact in children with ASD [Buckley et al., 2010] (but maybe not in adults with ASD, [Limoges et al., 2005]). Unfortunately, research on the role of sleep in word learning even in typical development is only just beginning [e.g., Werchan & Gómez, 2014; Williams & Horst, 2014].

Much of the research we have reviewed on the underlying structure and use of lexical categories in ASD suggests that it is relatively intact [e.g., Charman et al., 2003; Lyster et al., 2007; Rescorla and Safyer, 2013]. One caveat is that lexical entries that are highly embedded in complex social cognitive skills (such as perspective-taking and Theory of Mind) may be impaired, including deictic terms [Hobson, Garcia-Perez, & Lee, 2010] and mental state and emotion words [e.g., Hobson & Lee, 1989; Tager-Flusberg, 2000]. However, we suggest that any observed lexical differences in these domains are secondary to a primary difficulty in social cognition [e.g., Boucher, 2012; Pelphrey, Shultz, Hudac, & Vander Wyk, 2011].

To evaluate this hypothesis rigorously it will be necessary to accrue evidence on relationships between social cognition and language development from a variety of domains. One intriguing new vein of research documenting language development in native-signers (that is, deaf children of Deaf parents exposed to a sign language from birth) with ASD [Shield, 2014; Shield & Meier, 2012; Shield, Meier & Tager-Flusberg, 2015] serves as a useful example. An important finding from this research is that although native signers with ASD do not reverse pronouns in the same way as children with ASD who use spoken language [Shield, 2014], they do use sign language pronouns less often than TD deaf children, even though sign pronouns are semantically transparent in that they point in the direction of their referent [Shield et al., 2015]. They further show unique patterns of sign formation, such as reversal of the palm while signing [Shield & Meier, 2012], which suggest a different approach to gesture imitation and sign learning. Although there is no obvious analog to palm reversal in speech, the authors hypothesize that “the same underlying deficit (in the understanding of the relationship between self and other) results in two different modality-dependent linguistic phenomena: pronoun reversals in speech, and reversals of the palm in sign” [Shield et al., 2015, p. 2141]. Future work on signing and speaking children will clarify the relative contributions of linguistic and social cognition to lexical development in ASD.

Conclusions

We suggest that while children with ASD have the same fundamental machinery for lexical development as typically developing children, there are apparent differences in the efficacy of these learning mechanisms due to (1) disruptions in supporting systems; and (perhaps causing) (2) differences in children's *intake* of the language input they receive. With regard to the former, even for typically-developing children, attendant cognitive systems like attention, memory, cognitive control, and processing speed develop throughout early childhood [e.g., Courage & Cowen, 2009; Fernald et al., 1998; Mazuka, Jincho, & Oishi, 2009; Trueswell, Sekerina, Hill, & Logrip, 1999], and therefore the representations that children form from the input are "filtered" through these systems [e.g., Omaki & Lidz, 2015]. An array of other systems also moderate the relationship between input and lexical acquisition; for instance, variations in lexical development are linked to individual differences in social attention [Morales et al., 2000; Morales, Mundy, & Rojas, 1998] and motor function [Iverson, 2010; He, Walle, & Campos, 2015]. Not surprisingly, parallels are observed in children with ASD, for whom cognitive function consistently predicts language development [e.g., Luyster et al., 2007; Thurm et al., 2007; McDuffie, Yoder, & Stone, 2005; Venker, 2013]; however, additional research is necessary to determine definitively whether this is because higher nonverbal IQ allows children access to 'normative' language learning, or to compensatory strategies like rote learning or association [Boucher, 2012]. Social attention [Charman, 2003; Luyster & Lord, 2009] and motor control [Gernsbacher et al., 2008] are also predictive of language development in children with ASD.

Therefore, children's intake of the input signal will be affected by these other abilities. We suggest that individual differences in these factors may go a long way toward explaining individual differences in language behavior—and more specifically in lexical development—in ASD; that is, children use the same learning mechanisms and are able to attend to the same aspects of the input, but they differ both in the degree to which they access this input and in how they process and integrate it into their developing semantic knowledge. A stronger focus on individual differences in future research may help to clarify these issues.

Importantly, despite the social impairments associated with ASD, children are sensitive to many of the same reciprocal aspects of parental language as TD children. In general, parents of children with ASD provide a similar quantity and quality of language input as parents of TD children in naturalistic play interactions [Bang & Nadig, 2015] and when presenting new words

[Adamson, Bakeman, Deckner, & Nelson, 2014; Hani et al., 2013], and just as with TD children, quantity and quality of input predict language skill [Bang & Nadig, 2015]. In fact, as Naigles [2013] points out, "What is most remarkable about the extant research ... is how similar the role of input seems to be for children with ASD, demonstrating effects of maternal responsiveness, effects of the child's role in establishing and maintaining joint attention, and effects of specific components of maternal speech on subsequent language development" (p. 245). The mechanisms by which these features support language development include not only social-pragmatic mechanisms that children with ASD may struggle with, but also high rates of contingency and contiguity (e.g., parents tend to label objects that infants are looking at) as well as multimodal features (e.g., parents often simultaneously label and touch objects) that increase salience [Tamis-LeMonda, Kuchirko, & Song, 2014]. Nevertheless, there is evidence that (as with TD children), the benefits of parental responsiveness differ depending on the child's language level [Haebig et al., 2013a, 2013b], with low-language children benefitting more from general responsiveness and high-language children benefitting more from specific linguistic features of the input [Naigles, 2013]. Apparent differences between children with ASD and TD children in this regard could be due to a larger discrepancy between chronological age, language ability, and an array of other cognitive/social/motor skills, thus making it more difficult for parents to identify the best ways to provide high-quality developmentally-appropriate input.

An important issue for future research, then, is *how we can increase children's intake from the input*—that is, we must identify under what conditions children with ASD benefit from information available in their environment, and how we can maximize those conditions. An overarching theme from the research reviewed above is that children with ASD may simply require more exposure to language. However, there may also be malleable aspects of how exposure is presented, such as reducing social interaction demands, separating auditory and visual input (minimizing the need for online integration), introducing highly motivating contexts, and modifying instructional settings to capitalize on personal interests or strengths. Situations that integrate these features are likely to be most successful in increasing children's access to linguistic information, thereby setting the stage for optimal lexical development.

We hope this review represents a step forward in clarifying the ways in which lexical acquisition in ASD is similar to and different from what is seen in typical development. Throughout we have aimed to view differences through Sroufe's [1997] lens, initially assuming that the mechanisms governing lexical development in

ASD are fundamentally the same as those in typical development. We hope that future research will continue to take this approach, and to explore the roles of related non-linguistic systems in contributing to the profiles of children with ASD.

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