Tutorial

Distributional Cues to Language Learning in Children With Intellectual Disabilities

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Purpose: In typical development, *distributional cues*—patterns in input—are related to language acquisition processes. Statistical and implicit learning refer to the utilization of such cues. In children with intellectual disability, much less is known about the extent to which distributional cues are harnessed in mechanisms of language learning.

Method: This tutorial presents what is known about the process of language learning in children with language impairments associated with different sources of intellectual disability: Williams syndrome, autism spectrum disorder, Down syndrome, and fragile X syndrome.

Results: A broad view is taken on distributional cues relevant to language learning, including statistical learning (e.g., transitional probabilities) and other patterns that support lexical acquisition (e.g., sensitivities to sound patterns, cross-situational word learning) or relate to syntactic development (e.g., nonadjacent dependencies).

Conclusions: Critical gaps in the literature are highlighted. Research in this area is especially limited for Down syndrome and fragile X syndrome. Future directions for taking learning theories into account in interventions for children with intellectual disability are discussed, with a focus on the importance of language input.

This tutorial presents what is known about learning from distributional cues in children with intellectual disability as a starting place for driving clinically relevant research. Distributional cues in input—regularities among units—are intimately related to processes of typical language acquisition (Arciuli & Torkildsen, 2012; Gómez & Gerken, 2000; Graf Estes, Evans, Alibali, & Saffran, 2007; Lany & Saffran, 2011; Thiessen & Saffran, 2003). Because the use of distributional cues is thought to underlie language learning, research in this area has the potential to explain how or why language comes to be impaired and provide direction for how language learning could be supported in children with intellectual disability. Intellectual disability is defined as an IQ of 70 or below, associated with deficits in social, cognitive, and adaptive domains (Centers for Disease Control and Prevention, 2015). Here, a focus is taken on processes of language learning in children with specific (genetic) causes of intellectual disability: Williams

syndrome, autism spectrum disorder (ASD), Down syndrome, and fragile X syndrome. Each disorder is described in turn, pointing to features of development that are most central to language acquisition and distributional cue use, while addressing the extent to which children with these disorders can learn implicitly. Finally, taking into account the largest gaps in research, a framework for better understanding processes of language learning in individuals with intellectual disability is put forth, emphasizing the role of language input.

Evidence has been building that children with intellectual disability often learn language in the same manner as typically developing children, but at the same time, nuanced differences in learning from distributional cues could arise in different disorders associated with intellectual disability (Mosse & Jarrold, 2011; Vicari, Verucci, & Carlesimo, 2007). The use of distributional cues for language learning is important in cases of intellectual disability because (a) it relates to later language outcomes; (b) it can be predicted by child characteristics, including aspects of development such as existing linguistic knowledge; and (c) children with intellectual disability experience cognitive and language delays that could subtly impact the ways in which this type of learning occurs. That is, learning from patterns in input is expected to be as critical or more critical for language development in children with intellectual disability as in any other child.

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Distributional Cues to Learning in Typical Development and Language Impairment

Children are sensitive to patterns in language input in ways that shape what, how, and when language is acquired (Erickson & Thiessen, 2015; Romberg & Saffran, 2010). Examples of these regularities include patterns of sounds in language input, co-occurrence of a spoken word with its referent across different contexts, and the common grammatical sequence of words in English, in which a verb is preceded by a subject and followed by an object. Each of these patterns is present in the language input a child receives, identifiable based on the presence of units in relation to others. These distributional cues may help children find boundaries between words; link the label “fork” to a utensil with tines, rather than a spoon; and interpret a sentence in the face of ambiguity, even if the verb is unknown—all in support of language development.

Defined as auditory or visual regularities in input that are relevant to language acquisition processes, distributional cues are taken as far-reaching and inclusive of many developmental phenomena. This broad view on distributional cues allows parallels to be drawn across learning mechanisms that relate to similar processes that operate on different aspects, levels, or domains of language (e.g., sounds, words, grammatical patterns). Many researchers refer to the use of distributional cues as statistical learning or implicit learning: the extraction of distributional patterns or regularities from ambient input (Arciuli & Torkildsen, 2012; Perruchet & Pacton, 2006). “Procedural learning” is another term used to refer to this type of acquisition, especially with respect to syntax (Ullman & Pierpont, 2005). The common feature among these learning processes is the incidental (i.e., implicit, without instruction, conscious effort, or awareness) use of distributional cues for learning language. This type of learning is powerful because it leads to generalization of patterns beyond individual items (Gómez, 2002). As such, distributional cues support phonological, lexical, and syntactic development beginning in infancy and throughout development (Gómez & Gerken, 1999; Graf Estes et al., 2007; Thiessen & Saffran, 2003).

As context for research on distributional cue use in intellectual disabilities, exemplary studies on lexical and syntactic development in typical acquisition and developmental language disorder (DLD) are presented. Children with DLD have language impairments without intellectual disability or co-occurring sensory or social-emotional conditions (Bishop, Snowling, Thompson, Greenhalgh, & CATALISE-2 Consortium, 2017).

Distributional Cues Related to Lexical Development

Many aspects of lexical knowledge are supported by learning from distributional cues, including (a) word segmentation, (b) phonological patterns, and (c) tracking word meanings across ambiguous contexts (i.e., cross-situational learning). This work demonstrates that distributional cues relate to vocabulary size and language ability, hinting at a

role for distributional cues for understanding how language may come to be impaired.

Word Segmentation: Finding Forms

Before attaching meaning to words, a learner must identify the word form itself. The quintessential example of distributional cue use related to lexical development is for segmentation of the speech stream. Saffran, Aslin, and Newport (1996) studied this phenomenon by presenting 8-month-old typically developing infants with a 2-min stream of artificial language, in which the only cues to syllable boundaries were transitional probabilities. A transitional probability is the likelihood that a given sound follows another, taking into account how often the sounds occur (Saffran et al., 1996). The likelihood that a given syllable follows another particular syllable is greater for those that occur together within words than for syllables that are adjacent but belong to different words. For example, in the phrase “*sleeping puppy*,” the sequence *pu-ppy* has a higher transitional probability than *ing-pu*, which crosses a word boundary. Using such distributional information, infants discriminated between words and nonwords. Overall, this work has demonstrated use of distributional cues very early in development with rapid learning based on minimal, but informative, input.

Word segmentation in language impairment. Evans, Saffran, and Robe-Torres (2009) found 6- to 14-year-olds with DLD required twice as much input (42 min) as typically developing children to use transitional probabilities for word segmentation. Furthermore, their performance was correlated with receptive vocabulary. For children with DLD, general cognitive ability or developmental level does not explain weak implicit learning, but inefficient processing and difficulty tracking regularities in sequential input seem to contribute to their language abilities (Haebig, Saffran, & Ellis Weismer, 2017; Tomblin, Mainela-Arnold, & Zhang, 2007).

Phonological Patterns: Word Forms in Natural Language

Other distributional cues for lexical development are seen through the lens of phonological patterns (e.g., how sounds co-occur in words or are distributed in a language). Infants and toddlers are sensitive to the distributions of speech sounds of their native language, using phonotactic legality and co-occurrence to identify candidate words (Graf Estes, Edwards, & Saffran, 2011; Graf Estes et al., 2007; Saffran & Thiessen, 2003). In addition, word learning can be altered by changing distributional features of novel labels, such as phonological neighborhood density, which is the number of words in ambient input that differs by only a single phoneme—perhaps relating to differences in vocabulary size between those with and without language impairment (Gray, Pittman, & Weinhold, 2014).

Cross-Situational Word Learning

Cross-situational learning explicitly addresses the creation of a link between a form and its meaning. Here, the distribution of presentations of a label and its referent across

contexts is utilized to assign meaning to an object, such that cross-situational statistics are tracked across multiple exposures to novel label-referent pairs (Yu & Smith, 2011). For example, the word “cup” is linked with its referent across mealtimes when sometimes a cup and knife are present and sometimes a cup and bowl are present. Even within the lexical domain, the range of patterns children track in support of acquisition is remarkable.

Distributional Cues Related to Syntactic Development

Distributional cues are also related to grammatical aspects of language, including through (a) dependencies and categories and (b) syntactic bootstrapping. These are aspects of learning from distributional cues that either result *in* or result *from* syntactic development.

Dependencies and Categories: Word Order

Analogous to transitional probabilities computed over sounds, predictive dependencies can refer to regularities among categories. These dependencies relate to word order patterns for types (i.e., categories) of words; for example, noun phrases are composed of a word from one category (e.g., a determiner) that predicts the presence of a word from another category (e.g., Saffran, 2001). Indeed, typically developing children can extract “rules” and generalize auditory grammatical strings (e.g., word order) from a native language or artificial grammar, sometimes with very little exposure (e.g., less than 2 min; Gertner, Fisher, & Eisengart; Gómez & Gerken, 1999). This implicit acquisition of word sequences can be achieved with predictive dependencies among sequential adjacent units (Saffran, 2001, 2002), as well as nonadjacent units (Gómez, 2002). Learners make use of the most reliable cue, such as nonadjacent relationships among units, when others (e.g., adjacent relationships) are not informative. In one study, toddlers and adults learned nonadjacent dependencies (e.g., an *aXb* structure, where *a* and *b* are dependent, akin to auxiliaries and inflectional morphemes: *is running*), but only when the number of middle “X” elements that varied across occurrences was high (i.e., 24 different “X”s; Gómez, 2002). Here, the characteristics of the input lead a learner to make use of different distributional cues, with the natural complexity and variability of language supporting learning (Erickson & Thiessen, 2015).

Dependencies and categories in language impairment.

Use of nonadjacent dependencies is impaired in individuals with DLD (Hsu, Tomblin, & Christiansen, 2014). Because of this weakness, even more variability in input may be needed for successful learning (Grunow, Spaulding, Gómez, & Plante, 2006; Torkildsen, Dailey, Aguilar, Gómez, & Plante, 2013). Grunow et al. (2006) manipulated the number of intervening units in *aXb* strings (12 vs. 24 “X” elements). They found that participants without language impairment took advantage of the additional variability to demonstrate above-chance learning of nonadjacent dependencies whereas the participants with language impairment showed no such

learning. This is likely to have implications for intellectual disability in terms of the amount of input or extent of variability required to extract a pattern.

Syntactic Bootstrapping: Form With Meaning

Typically developing children extend knowledge about word order and categories to meaning through syntactic bootstrapping. Although the result of syntactic bootstrapping is lexical, the basis of that learning is dependent upon syntactic knowledge. Syntactic bootstrapping is a learning mechanism that allows inferences about the meaning of a novel word from semantic–syntactic cues, such as transitivity (i.e., that transitive structures imply causality; Naigles, 1990). That is, when heard in a transitive sentence, typically developing children tend to assign a novel verb to a causative action (Naigles, 1990). Overall, sensitivity to distributional cues is hypothesized to facilitate language development, with the amount or features of input required differing for those with impairments.

Distributional Cues: Why They Matter for Intellectual Disability

Learning based on distributional cues highlights the role of the input, the existing linguistic knowledge brought to the learning task, and the learning capabilities of the child (e.g., ability to extract patterns from input). With this understanding, research has attempted to address whether learning in intellectual disabilities proceeds as it does for typical development, but more slowly, or using an entirely different process (Mosse & Jarrold, 2011). One particular issue of debate has been whether individuals with intellectual disability can implicitly extract patterns from input at all, leading researchers to ask if learning from distributional cues can occur regardless of one’s IQ (Fletcher, Mayberry, & Bennett, 2000; Vinter & Detable, 2003). For example, some research has shown that individuals with intellectual disability learn nonverbal patterns as well as would be expected for their level of nonverbal cognitive abilities (Atwell, Conners, & Merrill, 2003; Vinter & Detable, 2003). In a general sense, then, implicit learning (extracting patterns from input) is possible for individuals with intellectual disability. If using regularities in language input proceeds with as much success as would be predicted based on the developmental level of an individual with intellectual disability, capitalizing on distributional cues could be a viable avenue for supporting language development.

Even with the capacity for implicit learning, delayed cognition and weak language skills in individuals with intellectual disabilities could be expected to relate to learning from distributional cues. The basis of this reasoning is informed by research on individual differences (i.e., variability in performance and correlates of that variability) among typically developing children and children with DLD. This research points to pertinent linguistic knowledge and learning abilities on which distributional cue use relies—bridging to the case of intellectual disability, in which cognition is

significantly delayed and yet some amount of language is acquired, albeit more slowly. First, evidence from typical development and DLD shows that distributional cue use predicts concurrent and later language outcomes (e.g., vocabulary size, syntactic comprehension; Evans et al., 2009; Graf Estes et al., 2007; Kidd & Arciuli, 2016; Mainela-Arnold & Evans, 2014; Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006; Torkildsen et al., 2013). This suggests that this learning can cascade over time, influencing speed of growth and level of ability.

Second, acquired language (i.e., how much language has already been learned) predicts further learning from distributional cues in typical development and DLD (Graf Estes, Gluck, & Grimm, 2016; Krogh, Vlach, & Johnson, 2013; Lany, 2014; Lany & Saffran, 2011). For example, infants with smaller vocabularies learn illegal phonotactic patterns that conflict with English, whereas infants with large vocabularies do not, possibly due to the way already-acquired linguistic knowledge directs future learning (Graf Estes et al., 2011, 2016). Although these relationships are less well defined for intellectual disability, they demonstrate the significance of distributional cue use to trajectories of language acquisition. Just as in typical development, future learning depends on previously acquired knowledge (e.g., syntactic development requires sufficient vocabulary) among children with intellectual disability, so it would be expected that these relationships would also apply to distributional cue use in intellectual disabilities (van der Schuit, Segers, Balkom, & Verhoeven, 2011). As such, the child's existing language knowledge and learning capabilities are likely to affect the ability to exploit regularities and, thus, the linguistic outcome over time. These effects on learning could occur by way of weighting or the efficiency of the learning process.

In typical development, learning on the basis of distributional cues can change over time, as cues combine or are weighted differently during phases of development or depending on the current linguistic knowledge of the learner (Lany & Saffran, 2011; Romberg & Saffran, 2010; Saffran, 2003). Cues are considered to be weighted when multiple cues are available in the input, but the learning of an individual reflects the use of one cue rather than another or one cue to a greater extent. For children with intellectual disability, these weightings might differ from typical development if, for example, use of a particular distributional cue relies on linguistic knowledge that has yet to be acquired. Because learning from distributional cues can be guided by acquired language, a lack of a linguistic foundation or slowed language development may constrain the extent to which cues can be used without additional support (Thiessen, 2010). The likelihood that a particular cue is utilized for learning could also differ if it requires a type or amount of processing (e.g., holding certain kinds or amounts of information in mind) that is challenging to the learner. If the weight given to different cues varies from typical language acquisition, processes of learning using distributional cues could be vitally important to understanding the course of language development in intellectual disability.

Developmental change in learning and outcomes can also be accounted for by changes in efficiency or the effectiveness of learning processes due to developmental changes (e.g., improving cognitive skills) and experience (e.g., accrued exposure to input; Thiessen, Girard, & Erickson, 2016; Vihman, 2017). This is related to intellectual disability because, overall, development is delayed, and experiences may differ from those of typically developing children. For instance, an individual with intellectual disability might have more experience or input exposure as measured by chronological time, but less accumulated knowledge due to poorer learning efficiency. This may be apparent in that certain distributional cues only come into play when a child has processed "enough" input to have extracted the pattern, such that certain cues thereafter become less informative and less heavily weighted (Thiessen et al., 2016). In the syntactic domain, in some circumstances, toddlers with higher grammatical skills use distributional cues to support word learning, whereas those with lower skills do not (Lany, 2014). In this case, only toddlers who often produced multiword utterances connected novel labels with their referents based on the distributional cue of grammatical category. Likewise, children with intellectual disability might experience different access to weighting of or efficiency of distributional cue use based on aspects of their development.

Furthermore, learners with less language experience and knowledge (and presumably those with weaker cognitive processing skills or those who are younger) are accruing data that are noisier, resulting in slower, less efficient learning (Thiessen et al., 2016; Thiessen & Pavlik, 2016). For all learners, "noise" in extracting a pattern from language input can occur due to disturbances in the input, such as speech errors by adults or exposure to younger children who themselves are developing language and may omit grammatical morphemes, for example. However, noise may also impact learning when a smaller amount of relevant input is tracked or retained, when irrelevant instead of relevant input is tracked or retained, or when relevant input is tracked but not held in mind long enough (or with a strong enough representation) for the pattern to be extracted. For example, noisier learning might occur by tracking regularities about a speaker or a repeated pronoun instead of nonadjacent dependencies in the context of grammatical learning (e.g., *You are dancing. You are singing.*). Noise in the input or in the learning process could result in slower learning, which might require an increased amount of input or increased frequency and salience of the target through variability of nontarget units (Alt, Meyers, & Ancharski, 2012; Gómez, 2002; Plante & Gómez, 2018).

From this view, individuals with intellectual disability have impaired language that may result from difficulty implementing learning from distributional cues, different weighting of cues, different efficiency of learning (requiring more input), insufficient language knowledge to support learning from a particular cue, or inefficient learning from cues due to weaker cognitive skills (e.g., memory, attention) that support pattern extraction. Given the cognitive and

language delays experienced by individuals with intellectual disability and the slow rate of growth in these domains, consideration of learning from distributional cues is essential. For remediation, understanding the processes by which language is acquired could inform how to support it.

Language Learning in Children With Intellectual Disability

With these factors in mind, four disorders are described in terms of associated features, general implicit learning, and use of distributional cues for language learning (see Table 1).

Williams Syndrome

Williams syndrome is characterized by mild-to-moderate intellectual disability caused by microdeletion of genes on chromosome 7 (Hillier et al., 2003). It occurs in one in 7,500 births (Strømme, Bjørnstad, & Ramstad, 2002). In Williams syndrome, several aspects of visual and auditory cognitive processing (e.g., memory, attention) are impaired (Brown et al., 2003; Jarrold, Baddeley, & Phillips, 2007). Although phonological memory is, on average, aligned with developmental level, memory and language (e.g., receptive syntax) are correlated (Robinson, Mervis, & Robinson, 2003). Language skills are usually no stronger than developmental level, with vocabulary not as delayed as syntax (Brock, Jarrold, Farran, Laws, & Riby, 2007; Mervis et al., 2000; Mervis, Robinson, Rowe, Becerra, & Klein-Tasman, 2003). In general, implicit and procedural learning may be weak in Williams syndrome as evidenced by performance on serial reaction time tasks (i.e., motor tasks of implicit learning in which reaction times decrease as participants learn a pattern; Vicari et al., 2007).

Distributional Cues Related to Lexical Development

Two studies have examined distributional cues for word segmentation in Williams syndrome. Nazzi, Paterson, and Karmiloff-Smith (2003) found that 15- to 48-month-olds with Williams syndrome could segment the speech stream (i.e., recognize individual English words that had been presented in a continuous speech stream) for words with a strong-weak pattern (predominant in English), but not weak-strong words. Conversely, typically developing infants could segment based on both stress patterns. Impaired performance of young children with Williams syndrome on word segmentation and recognition of English words provides evidence of difficulty with distributional cues (Nazzi et al., 2003).

In contrast, Cashon, Ha, Graf Estes, Saffran, and Mervis (2016) demonstrated that 8- to 20-month-olds with Williams syndrome could statistically segment the speech stream using transitional probabilities, just as shown for typically developing infants (Saffran et al., 1996). Performance was not related to age, and children accomplished this despite having extremely small receptive vocabularies (i.e., less than fifth percentile; Cashon et al., 2016). Cashon et al. suggest that the primary language delays in Williams syndrome are not due to difficulties with distributional cues

to segment the speech stream, but this does not rule out the role of other distributional cues for language learning in Williams syndrome. In light of these conflicting findings, there is a need for additional research on distributional cues for lexical acquisition in children with Williams syndrome, especially later in childhood and for linking form to meaning.

Distributional Cues Related to Syntactic Development

Don, Schellenberg, Reber, DiGirolamo, and Wang (2003) studied implicit learning in 9- to 49-year-olds with Williams syndrome using an artificial grammar composed of letter strings. Of those participants, seven out of 27 performed better than chance, leading the authors to conclude that individuals with Williams syndrome are capable of implicit learning. Indeed, differences with a typically developing comparison group disappeared when controlling for working memory and nonverbal intelligence, implying that the overall difference in performance could be accounted for by the large difference in IQ between groups. This does not mean that implicit learning reaches typical expectations in Williams syndrome, but simply that it is no more impaired than nonverbal IQ or memory ability. Finally, in this study, learning performance for the individuals with Williams syndrome was correlated with working memory, indicating that individual differences in learning may arise due to cognitive processing skills.

Along those lines, Stojanovic et al. (2018) examined artificial grammar learning in 4- to 18-year-olds with Williams syndrome and participants with typical development of similar age or nonverbal abilities. Auditory grammatical strings of words (*AC* or *ABC* patterns of words from *A*, *B*, and *C* categories) were presented with the visual support of objects and events on a screen. Learning by children with Williams syndrome was weaker relative to typically developing children, but not when limiting the comparison to those with more similar nonverbal cognitive skills. Even so, there were several specific differences in learning between groups. The children with Williams syndrome made judgments about grammaticality of sequences based on familiarity with particular stimuli, rather than generalization. Furthermore, unlike the typically developing children, the children with Williams syndrome required prosodic cues in addition to the distributional cues. Because their learning seemed to be more item-based, rather than based on the structure of the input, Stojanovic et al. suggested that children with Williams syndrome, relative to their developmental levels, may use lower-level cues, rather than pattern-based ones, to learn language. From this work, it is apparent that children with Williams syndrome can show evidence of learning implicitly. The notion that children with Williams syndrome weight cues differently from typically developing children will be an important area for future research.

Williams Syndrome: Summary

Research on distributional cues to learning has focused on word segmentation and rule-based dependencies, showing evidence of implicit learning with some differences from typical development. The capability to learn from input

Table 1. Sources of intellectual disability (ID) and distributional cue use for language learning.

Disorder	Prevalence	ID	Common features relevant to language acquisition	General language	General implicit learning	Distributional cue use: Lexical	Distributional cue use: Syntactic
Williams syndrome	1/7,500	Mild-to-moderate ID	Weak visual–spatial and auditory processing	Strength in expressive language	Some weaknesses	Understudied, mixed findings	Understudied, some weaknesses
Autism spectrum disorder	1/68	30% ID	Weak executive function and memory	Weak social communication	On par without ID; some weaknesses for ID	Understudied for ID	Understudied for ID
Down syndrome	1/750	Mild-to-moderate ID	Weak verbal memory	Weak expressive language	Some weaknesses	Understudied	Understudied
Fragile X syndrome	1/2,500	Mild-to-moderate ID	Weak verbal memory; ASD symptoms	Weak syntax	Understudied, some weaknesses	Understudied	Understudied

Note. Mild intellectual disability usually refers to an IQ of 50–70, moderate refers to an IQ of 35–50, and severe or profound refers to an IQ below 35 (World Health Organization, 2001).

is present, but more research is needed to understand what aspects of learning need support and how distributional cues relate to patterns of language learning over time in individuals with Williams syndrome. How these skills change over time or whether certain distributional cues are better suited to the cognitive skills of children with Williams syndrome has yet to be established.

ASD

ASD is behaviorally defined, with core deficits in social interaction and restricted behaviors (Diagnostic and Statistical Manual of Mental Disorders–5; American Psychiatric Association, 2013). Its prevalence is approximately one in 68 (Centers for Disease Control and Prevention, 2015), with an estimated rate of intellectual disability of 25%–30% (Baio, 2014; Chakrabarti & Fombonne, 2001; Kim et al., 2011; Matson & Shoemaker, 2009). Research on ASD both without and with intellectual disability is included here, as specified. Across ASD in general, cognitive processing (e.g., memory, attention) is delayed, with visual processing differences related to language (Lai et al., 2017; Macizo, Soriano, & Paredes, 2016; Venker, 2017). Developmental level (overall cognitive ability) is an important predictor of language in children with ASD, meaning that language is likely to be more impaired in cases of intellectual disability (Bal, Katz, Bishop, & Krasileva, 2016; Ellis Weismer & Kover, 2015). Overall, phonology tends to be a strength, whereas many with ASD experience delays in vocabulary and syntax (Arunachalam & Luyster, 2016; Ellawadi & Ellis Weismer, 2015). What little research has focused on ASD with intellectual disability indicates that language lags behind nonverbal expectations (Kover et al., 2014; Maljaars, Noens, Scholte, & van Berckelaer-Onnes, 2012; Thurman, McDuffie, Hagerman, Josol, & Abbeduto, 2017).

In terms of general implicit learning, skills are on par with comparison groups for those with ASD without intellectual disability (Foti, De Crescenzo, Vivanti, Menghini, & Vicari, 2015; Obeid, Brooks, Powers, Gillespie-Lynch, & Lum, 2016; Zwart, Vissers, Kessels, & Maes, 2017); however, there is some variability among findings (Brown, Aczel, Jimenez, Kaufman, & Grant, 2010; Jeste et al., 2015; Scott-Van Zeeland et al., 2010). A major limitation of this work is a focus on high-functioning individuals with average-range IQ (Obeid et al., 2016). Only a single study has addressed those with lower developmental levels and language impairment, reporting weaknesses in implicit learning (Gordon & Stark, 2007).

Distributional Cues Related to Lexical Development

Research on ASD has addressed multiple cues related to lexical development. Haebig et al. (2017) found that word segmentation and object–label association performance in 8- to 12-year-old children with ASD did not differ from typically developing children matched on age and nonverbal IQ. In this study, the only reliable cue to word boundaries was the transitional probability across syllables (Graf Estes et al., 2007). Even for those with ASD and language

impairment, only fast mapping (linking a novel word to a referent), but not distributional cue use, was impaired. This aligns with other research demonstrating successful word segmentation using distributional cues in ASD (Mayo & Eigsti, 2012); however, it does not directly address individuals with ASD and intellectual disability.

Evidence for other types of learning using distributional cues is mixed. Some research has examined phonological patterns of words in the context of vocabulary or word learning (Henderson, Powell, Gareth Gaskell, & Norbury, 2014; Kover & Ellis Weismer, 2014). For example, toddlers with ASD with small vocabularies tend to have lexicons that contain words with high phonological neighborhood density (i.e., that sound like many other words) and that are short, with only word length uniquely predicting vocabulary size (Kover & Ellis Weismer, 2014). It could be that the phonological distribution of input is less strongly weighted for toddlers with ASD or that cognitive processing demands (e.g., memory) might be at play (Stokes, 2014; Swingley, 2005).

Related specifically to word meanings, a weakness in shape bias (i.e., the propensity to extend novel labels to objects of the same shape in the face of ambiguity) in ASD has also been identified (Potrzeba, Fein, & Naigles, 2015). The premise of the shape bias is that children have acquired sufficient lexical knowledge to utilize the pattern that labels tend to extend to objects of similar shape, rather than on the basis of other features, such as color. Finally, school-age children with ASD with average-range cognition have been shown to use cross-situational information for word learning (McGregor, Rost, Arenas, Farris-Trimble, & Stiles, 2013). These children performed better than chance at mapping an unfamiliar word to its referent by tracking the co-occurrences of the label and possible referents. Furthermore, cross-situational word learning was associated with receptive vocabulary, which means that this type of learning could be more challenging for those with language impairments, pending further study. It is notable that none of these studies have spotlighted ASD with intellectual disability. Additional research on this subpopulation is in great need.

Distributional Cues Related to Syntactic Development

With respect to distributional cues that build on syntactic knowledge, children with ASD have been shown to utilize word order for comprehension and use syntactic bootstrapping to extend syntactic knowledge to word meaning (Naigles, Kelty, Jaffery, & Fein, 2011; Shulman & Guberman, 2007; Swensen, Kelley, Fein, & Naigles, 2007). Naigles et al. (2011) found that young children with ASD interpreted novel verbs as causative when appearing in transitive sentences; that is, children looked more toward a causative scene (one animal doing something to another) rather than a noncausative scene (two animals performing the same action side-by-side simultaneously) in response to a transitive sentence (e.g., “The duck is *gorping* the bunny.”), relative to baseline when simply asked to look at the scenes. This study demonstrated that, like typically developing children, young children with ASD have generalizable

knowledge about transitive subject–verb–object sentences in English. Furthermore, this ability was associated with both lexical (vocabulary size) and syntactic (word order interpretation) knowledge in the children with ASD. See also Horvath, McDermott, Reilly, and Arunachalam (2018). Again, the extent to which children with ASD with intellectual disability use distributional cues in the same way requires further research.

ASD: Summary

The literature suggests that children with ASD (not necessarily with intellectual disability) can learn implicitly and make use of distributional cues for learning. What is not known is how children with ASD with intellectual disability perform on such tasks, especially for the yet unstudied use of nonadjacent dependencies (directly relevant to grammatical morphemes, such as “*is X-ing*” and “*she X-s*” in English), and how distributional cues are weighted across development. There is particular need for greater attention to the overlap between ASD, intellectual disability, and language impairment (Bal et al., 2016).

Disorders With Limited Research: Down Syndrome and Fragile X Syndrome

Relative to Williams syndrome and ASD, even less research has addressed learning from distributional cues in Down syndrome and fragile X syndrome. What is known is reviewed here, with emphasis on the greatest needs for future research.

Down Syndrome

Down syndrome is caused by a third copy of the 21st chromosome and occurs in about one in 750 births (Parker et al., 2010). Primary areas of weakness in Down syndrome include attention, spatial memory, and auditory short-term (phonological) memory (Brown et al., 2003; Edgin, 2013; Jarrold, Baddeley, & Phillips, 2002). On average, receptive vocabulary is stronger, whereas syntactic knowledge and expressive syntax are weaknesses (Martin, Klusek, Estigarribia, & Roberts, 2009). As with Williams syndrome, phonological memory predicts language abilities as well as word learning (Jarrold, Thorn, & Stephens, 2009; Laws, 2004). In terms of general implicit learning, serial reaction task performance aligns with developmental level (Vicari et al., 2007). However, several areas of weakness relative to developmental expectations have also been identified, including vulnerability to distraction and rule-based category learning (Bussy, Charrin, Brun, Curie, & des Portes, 2011; Phillips, Connors, Merrill, & Klinger, 2014; Tovar, Westermann, & Torres, 2018).

The research on language learning in Down syndrome is sparse, with minimal mention of distributional cues, with two exceptions. Word segmentation has been tested using a task similar to Nazzi et al. (2003). Performance did not relate to later language in children with Down syndrome, whereas it did for typically developing infants (Mason-Apps, Stojanovik, Houston-Price, & Buckley, 2018). Mason-

Apps et al. concluded that word segmentation was not a limiting factor for development, meaning it could possibly be harnessed to increase learning. Demonstrating an area of impairment, children with Down syndrome showed a weaker noun bias (referred to by the authors as syntactic bootstrapping) than expected for developmental level (Mosse & Jarrold, 2011). Given its weakness in Down syndrome and lack of research, the most critical areas for future work are linking distributional cue use to individual differences in trajectories of language development, especially related to syntactic development (Edgin, 2013).

Fragile X Syndrome

Fragile X syndrome, with a prevalence estimated at one in 2,500, is an inherited source of intellectual disability, caused by an expansion mutation on the X chromosome (Hagerman, 2008; Mila, Alvarez-Mora, Madrigal, & Rodriguez-Revenga, 2017). Almost half of individuals with fragile X syndrome have symptoms of ASD pervasive enough to warrant a co-occurring ASD diagnosis (Klusek, Martin, & Losh, 2014). Cognitive processing skills are weak in terms of visual and auditory memory and attention (Baker et al., 2011; Ballantyne, Nunez, & Manoussaki, 2017; Sullivan et al., 2007). Auditory memory, in particular, predicts growth in aspects of language development (Pierpont, Richmond, Abbeduto, Kover, & Brown, 2011). On average, language delays appear early and persist, with weakness in syntax and strength in vocabulary (Abbeduto, Brady, & Kover, 2007; Kover, McCary, Ingram, Hatton, & Roberts, 2015). One study on implicit learning has reported some success, as well as weaknesses, in a serial reaction task relative to developmental expectations (Bussy et al., 2011).

No data have been published on the use of distributional cues for language learning in individuals with fragile X syndrome. Even without the need to track distributional information, word learning is weaker than developmental expectations (McDuffie, Kover, Hagerman, & Abbeduto, 2013). It has been noted that individuals with fragile X syndrome have difficulty with sequential processing, which could have implications for distributional cue use to the extent that it interferes with tracking input for learning (Freund & Reiss, 1991). This needs to be tested directly; however, there is initial evidence that children with fragile X syndrome can engage in syntactic bootstrapping, interpreting a novel verb in an intransitive frame as noncausative rather than causative (Kover, Saffran, & Abbeduto, 2015). Distributional cue use may be vulnerable to impairment in fragile X syndrome because of weaknesses in attention, memory, and sequential processing, with a need to examine both lexical and syntactic learning. Considering that profile, priorities for future research include connecting distributional cue use to concurrent language ability and later language growth.

Pivotal Directions for Theory and Practice

The research reviewed here suggests that individuals with intellectual disability can use distributional cues for language learning. That is, children with intellectual disability

should not be counted out for use of distributional cues as a learning mechanism. However, even when distributional cue use is possible, learning still has the potential to be improved with appropriate supports. Thus, leveraging learning using distributional cues could be a viable strategy to improve trajectories of language development.

Of course, weaknesses in implicit learning have implications for delays in many aspects of language development, including lexical and syntactic acquisition and language form and meaning. Among both children with intellectual disability and typical development, developmental level and cognitive processing (e.g., memory) relate to language development, and acquired language relates to future learning (Lany, 2014; Misyak & Christiansen, 2012; van der Schuit et al., 2011). Even with all of these factors at play, the most central element of the learning problem is the language input a child receives, followed by the optimization of that input for the individual's developmental and linguistic needs.

A critical barrier to applying research on distributional cues to intervention is the sparsity of data. More work is needed to elucidate the role of distributional cue use for language learning in understanding pathways to outcomes. Theory and practice can be advanced with respect to the role of distributional cues for learning among children with intellectual disability using a framework focused on (a) features of language input, (b) developmental timing and weighting, (c) individual differences due to memory and attention, and (d) the opportunity to tailor interventions to disorders or individuals.

Input-Based Intervention

Distributional cues illuminate the structure of language input as critical for learning: Having the right kind of input and a sufficient amount of that input is required for learning from distributional cues. Research on individuals with DLD provides evidence that it is possible to increase learning from distributional cues through control of the input, in terms of salience of structure or amount (Evans et al., 2009; Grunow et al., 2006). Indeed, the case of DLD can serve as a model for applying research on weaknesses in distributional learning to clinical practice in intellectual disabilities, stressing opportunities for detection of regularities in input (Lammertink, Boersma, Wijnen, & Rispens, 2017). As in the case of children with DLD, thinking carefully about the type and amount of input children with intellectual disability receive may be key to facilitating their language development (Aguilar, Plante, & Sandoval, 2017; Plante et al., 2014).

The “right kind” of natural language input is informed by what we know about how learning from distributional cues occurs. The research base suggests that input should be characterized by regularity, complexity, and variability. In terms of regularity, the target or relevant pattern should be frequent and consistent, such that it is the most salient aspect of the input (e.g., highlighting subject–verb agreement by making it the most frequent and most consistent set of

morphemes; Plante & Gómez, 2018). At the same time, noise in the input should be minimized to avoid detracting from learning (e.g., uninflected verbs that lack the relevant distributional cues; Plante & Gómez, 2018). In terms of complexity, input should be grammatically complete and reflective of the natural elements of language. This involves providing input in phrases and sentences that include the full context in which distributional cues occur (e.g., *The cow is running. The girl is eating.*; Alt et al., 2012). Lastly, variability induces extraction of relevant patterns, rather than a focus on individual items, leading to generalization (Grunow et al., 2006). It is against the backdrop of variability that a relevant pattern can be extracted by the learner (e.g., variety in nouns and verbs to demonstrate subject–verb agreement).

These principles for providing good input appear in several existing approaches to treatment for individuals with DLD or other sources of language impairment. Many current parent-implemented interventions and grammatical treatments bring input, its variability, and its complexity to the forefront (Leonard & Deevy, 2017; McDuffie et al., 2018). Parental input that is grammatically complete predicts gains in language over time for young children with ASD (Venker et al., 2015), underlining how natural complexity might help the language learner. Likewise, target selection in grammatical treatments can capitalize on natural complexity to maximize generalization (Owen Van Horne, Curran, Larson, & Fey, 2018).

Similarly, research on a learning process referred to as recombinative generalization—instances when familiar stimuli are combined in novel ways—is a useful example of how implicit learning based on probabilistic input allows learning and generalization (Bernstein & Treiman, 2001, 2004; Treiman & Kessler, 2006). Recombinative generalization is relevant to spoken language acquisition because language requires generalization across linguistic units, communicative contexts, and time (Suchowierska, 2006). A classic demonstration of recombinative generalization comes from written language, in which, for example, exposure to reading *cat* and *mop* leads to success with *mat* (i.e., a novel combination of onsets [initial consonants] and rimes [rest of the syllable]; Saunders, O'Donnell, Vaidya, & Williams, 2003). This type of learning has been demonstrated in adults with intellectual disability, who showed the ability to generalize recombined onsets and rimes after exposure to practice words (Saunders et al., 2003). This area of work has implications for how basic research can be applied to intervention for children with intellectual disability who have yet to demonstrate detection of certain patterns in the input, including in spoken language (e.g., subject–verb agreement generalizing to new verbs). For distributional cues, the emphasis is on providing experience with input that brings relevant patterns to the forefront and builds from existing knowledge, without explicit instruction.

Beyond the right kind of input, the amount of input individuals require for successful learning needs further attention. Children with language impairment and intellectual disability might need much more input or more

variability to highlight regularities than do typically developing children (Evans et al., 2009; Grunow et al., 2006). Although it is a reasonable assumption that children with intellectual disability benefit from more input or better optimized input for learning, the research to support specific interventions has yet to be completed. Intervention research has the ability to demonstrate how language outcomes or learning capabilities can be improved by targeting learning using distributional cues, thereby informing theory—as well as providing an evidence base.

Developmental Timing and Weighting

To use what is known about distributional cue use for language learning to develop treatments, research that addresses learning processes, sources of variability among individuals, and trajectories of development will be imperative (Arciuli & Torkildsen, 2012). That work will also guide questions about developmental timing and the weighting of cues (Monaghan, Chater, & Christiansen, 2005; Paterson, Parish-Morris, Hirsh-Pasek, & Golinkoff, 2016). Ideally, it would be possible to recognize which distributional cues for language acquisition are most important for a child's development at any given time. That would include the developmental ordering of mechanisms that utilize distributional cues, as well as an understanding of how to give access to (i.e., how to weight) distributional cues, so they can be best utilized by a child in the context of their existing linguistic knowledge and cognitive skills. Research is needed to support decisions about which cues should be highlighted, before building to others, or which cues should be combined (i.e., presented simultaneously). Furthermore, it is unknown what specific linguistic foundations or cognitive processing skills (e.g., memory) relate to when, how, and what extent learning from distributional cues occurs. Nonetheless, the current evidence suggests that providing input that reflects the natural complexity of language and its co-occurring cues, with variability among units to accentuate patterns, is worthwhile (Alt et al., 2012). Eventually, it may be possible to align developmental needs (timing, weighting) with child characteristics (linguistic knowledge, cognition). In the meantime, evidence from typical development and DLD guides intervention toward an input-minded approach (Alt et al., 2012).

Individual Differences: Memory and Attention

One theme among disorders associated with intellectual disability is weakness in memory, attention, or both. Furthermore, for individuals with intellectual disability, memory and attention are associated with language ability (Kover, McCary, et al., 2015; Pierpont et al., 2011; van der Schuit et al., 2011). Memory processes are related to learning from distributional cues because units from the input must be held in mind and stored in short-term memory for a regularity to be detected (Thiessen, Kronstein, & Hufnagle, 2013). For example, segmentation based on transitional probabilities requires remembering, at some level and to

some degree, sequences of syllables. Similarly, the ability to track certain patterns, like nonadjacent dependencies, could be reliant upon developmental advances in attention (de Diego-Balaguer, Martinez-Alvarez, & Pons, 2016). Memory is intimately linked to statistical learning processes and could ultimately tie learning from seemingly diverse cues together by explaining how they work (Thiessen, 2017). Across domains and modalities, attention to the relevant input is necessary for learning (Treiman, 2018).

Despite clear bearing on the learning process, even in typical development, such sources of individual differences in distributional cue use have been understudied (Erickson & Thiessen, 2015). It could be that memory and attention could enhance learning by *limiting* intake of the input to only its most important or salient aspects (i.e., the Less is More hypothesis; Newport, 1990); on the other hand, it has been shown that memory and attention *support* learning from distributional cues, even in adults (Ludden & Gupta, 2000; Pacton & Perruchet, 2008). From either stance, memory and attention may be sources of variability for language learning for individuals with intellectual disability. Understanding individual differences will be important for aligning interventions with individuals' needs. It will be the task of future research to investigate how memory and attention relate to learning from distributional cues in children with intellectual disability and how those abilities can be supported to improve outcomes.

Tailored Interventions

The learning needs of individuals with different sources of intellectual disability could differ in ways that can be addressed in interventions tailored to specific disorders (Foti et al., 2017; Lemons et al., 2017; Reilly, 2012). Information about common strengths and weaknesses among individuals with the same disorder could be harnessed by clinicians to aid in initial decision making about how to support language learning, pending a stronger evidence base. One approach is to target underlying processing skills likely to be impacted by a disorder (Fidler, Philofsky, & Hepburn, 2007). For example, research on treatment approaches using distributional cues that also take into account the phonological memory weaknesses of children with Williams syndrome, Down syndrome, and fragile X syndrome (Pierpont et al., 2011; Robinson et al., 2003) or the visual processing tendencies of children with ASD (Venker, 2017) would be instructive. This future work might come in the form of reducing demands on phonological memory by increasing the amount of input provided and the frequency of the target, while simultaneously presenting input that is fully grammatical, but without unnecessary syntactic complexity, to highlight patterns among sounds or words. Likewise, the strategies for organizing the visual environment to limit the need to shift attention to or between relevant aspects of the input would be worth studying. Alongside that research, clinicians may benefit from direct guidance on particular disorders and the features that are usually associated with them (Faught, Connors, Barber, & Price, 2016).

One might also consider strengths and weaknesses across modalities. Although work on distributional cues tends to emphasize recognition and comprehension, for individuals with especially impaired expressive language (e.g., Down syndrome), the effects of any weak implicit learning might be even more pronounced in that modality, requiring additional support from input (Plante & Gómez, 2018).

Hailing from other perspectives, treatments that take into account learning needs of specific disorders (e.g., use of visual supports for Down syndrome, given weaknesses in memory) are already being explored (Finestack, O'Brien, Hyppa-Martin, & Lyrek, 2017; Lemons et al., 2017; McDaniel & Yoder, 2016). Of course, balance is needed among (a) foundational aspects of treatment that support all children, (b) anticipating learning needs that are common to a particular disorder, and (c) allowing flexibility for individuality (Fidler et al., 2007; Reilly, 2012). Differences among disorders and among individuals can play a special role in identifying causal relationships among learning, cognition, and language in the context of intervention (McDaniel, Yoder, & Watson, 2017).

Conclusions

The input a child receives and its alignment to the child's preparedness to learn are expected to have consequences for language outcomes (Arunachalam & Luyster, 2016). For children with intellectual disability, developmental delays could impact use of distributional cues, such that hypotheses can be made about the need for more input or optimized input to support learning. A better understanding of how distributional cues in language input support acquisition in typical development and cases of language impairment will set a foundation of knowledge for intellectual disabilities (Alt et al., 2012). For intellectual disability, distributional cues to language acquisition provide a framework from which to inform treatment and further refine theories on language development.

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