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Individual Differences in First Language Acquisition

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Abstract

Humans vary in almost every dimension imaginable, and language is no exception. In this article, we review the past research that has focused on individual differences (IDs) in first language acquisition. We first consider how different theoretical traditions in language acquisition treat IDs, and we argue that a focus on IDs is important given its potential to reveal the developmental dynamics and architectural constraints of the linguistic system. We then review IDs research that has examined variation in children's linguistic input, early speech perception, and vocabulary and grammatical development. In each case, we observe systematic and meaningful variation, such that variation in one domain (e.g., early auditory and speech processing) has meaningful developmental consequences for development in higher-order domains (e.g., vocabulary). The research suggests a high degree of integration across the linguistic system, in which development across multiple linguistic domains is tightly coupled.

1. INTRODUCTION

Variation is a pervasive property of the natural world. The forces of evolution take advantage of genetic and environmental diversity to fine-tune populations of individuals (Darwin 1859). Brain sizes can vary as much as twofold (Reardon et al. 2018), and variations have been observed in both white and gray matter (Wilke & Holland 2003) that are associated with cognitive outcomes (Colom et al. 2009, Mabbot et al. 2006). These differences are observed at the behavioral level, where we systematically vary in basic processes like visual perception (e.g., Mollon et al. 2017), attention (e.g., Nunez et al. 2015), and memory [e.g., working memory (WM) (Jarrold & Towse 2006)].

Systematic and meaningful interindividual variation exists in both language acquisition and adult language processing (Bornstein et al. 2018, Kidd et al. 2018a). In this article, we review the current state of the art concerning individual differences (IDs) in first language acquisition; we concentrate on early development from speech through to grammar. While there is a large literature concerning variability as it relates to atypical language development, we concentrate on IDs in typically developing children because the topic has received less systematic attention (for past reviews, see Bates et al. 1995, Lieven 1994). We argue that the study of IDs across the spectrum of abilities has the potential to reveal key insights into the acquisition process and provide a fruitful method for theory testing and development.

This article is organized as follows. We first review theoretical approaches to language acquisition and consider how they predict patterns of IDs. We then systematically review the literature on IDs in acquisition; we begin with work on child-directed speech (CDS) and move through work on infant speech perception, lexical development, and grammatical development. In each case, we demonstrate the existence of IDs and discuss their sources and consequences. We end with a discussion of measurement issues in IDs studies.

First, however, we note some caveats. Given space limitations, we cannot review all studies, so we have been necessarily selective. Furthermore, while many studies of acquisition suggest individual-level effects, we prioritize the selection of studies that have an explicit IDs focus. For instance, many studies link corpus frequencies to vocabulary or syntactic development and suggest environmental effects on learning. We have chosen not to review these studies and instead concentrate on studies that link variability in a child's environment to the child's specific developmental outcomes.

2. FIRST LANGUAGE ACQUISITION: SOURCES OF VARIABILITY AND IMPLICATIONS FOR THEORY

Pretheoretically, all scholars of language acquisition share the common goal of explaining acquisition given (*a*) the properties of the input and (*b*) the biological learning mechanisms children bring to the problem. Thus, the field is in broad agreement that exogenous and endogenous variables both directly influence and necessarily interact to support language acquisition. However, different theoretical approaches make different assumptions about the sources of variability that lead to IDs.

One prominent dimension on which theories of acquisition have been traditionally divided is their degree of commitment to the assumption of representational innateness. Following Chomsky's (1980) poverty of stimulus argument, nativist approaches to development argue that the input is not sufficiently rich to allow the child to induce language from their immediate experience; because acquisition is seemingly rapid, the child must bring significant, innately specified knowledge to the problem of language learning. The most famous application of this argument is in the domain of grammar (see recent proposal by Yang et al. 2017), but there are comparable accounts in the domains of phonology (Hale & Reiss 2008) and semantics (Crain 2012). In each case, the innately specified linguistic knowledge is assumed to constitute the core component of the linguistic system: Universal Grammar (UG).

These nativist accounts make specific predictions about the nature and structure of IDs in language acquisition. They generally assume that while the input is necessary for language-specific components of the linguistic system (e.g., vocabulary), those components of language that are part of UG are less dependent on input and so can be acquired early through fairly minimal exposure (though exposure is still deemed important; see Yang et al. 2017). A less discussed outcome of the assumption of representational innateness is that, in its strongest form, it makes specific predictions about the structure of IDs—namely, that children will operate with innately specified categories once triggered by the input. Thus, inter-IDs in the formal systems governed by UG can be categorical in nature (e.g., see Crain & Thornton 1998). That is, either a child recognizes that /θ/ is a phoneme in their language or they do not, and likewise, either a child operates with a grammar that requires V2 word order or they do not. In practice, this prediction is a property of the child's competence rather than their performance—a notoriously difficult distinction to disentangle because human behavior always reflects performance. However, in principle, different approaches to language acquisition predict different distributions even when performance factors are taken into account (see Kidd et al. 2018a); thus, a focus on IDs may allow theory testing.

Theories that do not assume representational innateness come in many varieties and are perhaps most straightforwardly termed emergentist. This umbrella term denotes their unifying purpose: to explain how linguistic representations emerge in development if the assumption of representational innateness does not hold (MacWhinney 1998). As such, this is an ecumenical church with as many differences as similarities (for an insightful discussion of different theories of phonological development, see Cristia 2018). In terms of IDs, what unites them is (*a*) a greater focus on the role of exogenous variability in acquisition and (*b*) the acknowledgment that multiple cognitive systems interact to support the acquisition process, which themselves may be subject to interindividual variability. Thus, assuming the absence of innate linguistic knowledge places a higher importance on the information available in the input because the representations must be induced from the input signal using learning mechanisms that likely also vary among individuals. Accordingly, emergentist approaches predict that IDs should pervade the linguistic system and will be intimately related to measurable differences in exogenous variables, such as input quantity and quality, and endogenous variables linked to language [e.g., memory, executive function (EF), statistical learning (SL)]. In contrast to the nativist approach, emergentist approaches predict IDs in formal linguistic subsystems (e.g., phonology, grammar) that the nativistic approach considers innate and therefore less prone to IDs.

Inevitably, these are broad brushstrokes that represent only the extreme ends of the possible hypothesis space. The extent to which the dichotomy is useful has been questioned (Frank et al. 2019), but it remains relevant insofar as it continues to frame acquisition research. Following Kidd et al. (2018a), the study of IDs highlights three important empirical observations for which any theory of acquisition must account. First, our theories must allow for and predict the existence (and absence) of IDs (the existence imperative). Second, our theories must account for the relationship between exogenous variables and language acquisition (the environmental imperative). Finally, our theories must account for the observed developmental relationships between linguistic subsystems and between language and other cognitive systems (the architectural imperative).

This final point is important because it demonstrates how the study of IDs provides a methodology for theory testing and development and points us toward mechanisms and architectural constraints on the acquisition process. Bates et al. (1988, p. 11) wrote that IDs reveal "the seams and joints of the language processor." That is, studies that use the correlational method can identify patterns of association and dissociation across linguistic subsystems and between cognitive mechanisms and linguistic skill. In doing so, these studies can reveal the architectural properties and developmental dynamics of the language system. Thus, if properties of the linguistic system hang together in acquisition, such as the attested though somewhat ambiguous coupling of vocabulary and grammar in early development (e.g., Dixon & Marchman 2007, Hoff et al. 2018), we have evidence for a common underlying mechanism supporting the acquisition of both.[1] If vocabulary and grammar are not coupled, then we have evidence for independent learning mechanisms. Likewise, if we find that mechanisms that we can define independent of language (e.g., memory, attention) also predict language proficiency, we have evidence for domain-independent mechanistic influences on language.

Thus, IDs studies are a crucial component of the developmentalist's toolbox, and despite the significant history of IDs research in the field of first language acquisition, we are still some way from understanding how and why children vary in language across development and how this affects later development in and beyond language. There are many reasons for this slow progress. IDs studies require large numbers of participants and are thus expensive. Also, greater use of the experimental method across the last three to four decades has consigned interindividual variability to error variance rather than treating it as something to be explained. There is a long history of division in the psychological sciences between so-called experimental and correlational approaches to the study of human behavior, going back to Wundt's [(1904 (1874)] distinction between experimental and cultural psychology. But there is a danger in attempting to infer cognitive processes from group-level comparisons alone: As Estes (1956, pp. 134–35) pointed out, "no inductive inference from the mean curve to the individual curve is possible…we can no longer expect averaged data to yield an answer to the question: 'What is the form of the individual function?'" Thus, group growth trajectories in language can reflect an infinite number of individual growth trajectories and thereby provide a false impression of the developmental phenomenon to be explained. Therefore, we gain clearer insights into the process of acquisition if we can combine experimental and IDs approaches.[2] We now review past IDs studies of acquisition.

3. VARIABILITY IN THE LINGUISTIC ENVIRONMENT

The linguistic environments of children vary widely within and across cultures. While children in the typically studied, child-focused European cultures receive a substantial amount of CDS, studies of non-WEIRD [Western, Economic, Industrial, Rich, Democratic (Henrich et al. 2010)] cultures have shown that children living in more traditional cultures receive less direct input (Cristia et al. 2017, Lieven 1994, Shneidman & Goldin-Meadow 2012), with the difference reflecting variation in language socialization and cultural notions of knowledge and competency (Schieffelin & Ochs 1986). Acquisition is no doubt resilient to these differences, and CDS may not be necessary for the acquisition process to begin, even though the specific properties of CDS (e.g., variation in pitch, variation in vowel quality, slower speech rate, simplified sentence structure) can capture a child's attention (Cooper & Aslin 1990) and are related to later language development (Liu et al. 2003; see also Golinkoff et al. 2015).

[1]This need not imply common endogenous mechanisms; one explanation of the association appeals to properties of the input in explaining growth (Hoff et al. 2018) and thus suggests a common exogenous influence.
[2]Many researchers in the psychological and cognitive sciences have aimed to unite experimental and correlational research (e.g., Cronbach 1957, Underwood 1975), and there are good reasons to doubt that full integration is possible (Borsboom et al. 2009). We do not argue for full integration; instead, we argue that a stronger focus on IDs will enable a more comprehensive understanding of first language acquisition.

As with most work on child language acquisition, much of what we know about variation in linguistic environments within cultures comes from studies of children from WEIRD cultures, and so the remainder of this section (and, indeed, this review) comes with the disclaimer that this knowledge represents a skewed view because variation is determined by cultural practices (e.g., child-rearing ideologies) and institutions (e.g., education) that are directly and peripherally related to child development. With this in mind, the evidence suggests substantial variability in the quantity and quality of the language that children hear, and this variability is related to several demographic variables.

Initially, studies of variation in children's linguistic environments investigated the link between IDs in input quantity and acquisition. In this vein, Huttenlocher et al. (1991) reported that higher quantities of input predicted higher rates of vocabulary growth in children between 14 and 26 months. Hart & Risley (1995) reported a similar finding in a socioeconomically diverse sample of North American children. From their data they estimated that, on average, children in a high–socioeconomic status (SES) group heard approximately three and a half times more words than children from a low-SES group; by the time the children reached the age of 4 years, the difference would translate to one of more than 30 million words (subsequently dubbed the 30 million word gap).

The finding that North American children from lower-SES groups receive less input is well established (e.g., Bergelson et al. 2019; Hoff 2003; Huttenlocher et al. 2007, 2010; Rowe 2012; though see Sperry et al. 2019), but its causes are likely complex and multifaceted. One potential source is education and access to information and services. For instance, Rowe (2008) found that caregivers in high-SES groups possessed greater knowledge of child development, and this greater knowledge significantly predicted higher rates of vocabulary growth among their children. However, the social stressors associated with economic hardship are also likely to have an effect: Justice et al. (2019) reported a developmental pathway whereby financial hardship increased parental distress, which adversely affected parent–child interaction and ultimately resulted in lower language skills.

Even within socioeconomic strata, there is large variability in the quantity of children's input. In a sample of 29 low-SES Spanish-speaking families in the United States, Weisleder & Fernald (2013) estimated that daily word estimates in CDS can differ by as much as 18-fold (see also Shimpi et al. 2012). These differences significantly affected vocabulary development; greater input at 18 months was associated with greater processing efficiency (i.e., more rapid word recognition), which predicted greater vocabulary size at 24 months (see also Hurtado et al. 2008). Thus, variation in input is likely a stable property of individual caregivers that is influenced but not completely determined by SES (see Gilkerson et al. 2017).[3]

There is also variability in grammar in CDS. Early studies revealed grammatical differences in CDS among caregiver–infant dyads that were related to children's subsequent language development (e.g., Furrow et al. 1979); however, with some exceptions (e.g., Naigles & Hoff-Ginsberg 1998), the sample sizes were typically small. In a series of larger studies, Huttenlocher and colleagues (2002, 2007, 2010) quantified IDs in grammar in CDS and linked them longitudinally to children's language development. Huttenlocher et al. (2007) showed that the syntactic complexity of CDS increased across time (in infants followed from 14 to 30 months), and caregiver education level predicted variation in complexity. The influence of caregiver education was evident from the

[3]When we say that IDs are stable, we mean that variability is not random across individuals, who are likely to retain their rank relative to others across developmental time. For example, if Parent A typically directs 10,000 words to their infant in a day and Parent B directs 5,000 words, stability implies that this difference holds across time (taking into account general fluctuations in daily word counts). The same logic holds for children's language development.

earliest time point they studied and remained stable across the course of the study; this result suggests that IDs in syntactic complexity in CDS reflect stable properties of individual caregivers that are sustained across time. Huttenlocher et al. (2010) followed 47 infant–caregiver dyads from age 14 to 46 months and found that variability in both quantity (i.e., frequency) and diversity in CDS predicted vocabulary and grammatical development. Diversity, which is a measure of input quality, was indexed by lexical, phrasal, and clause type frequency. While there was a direct correspondence relationship between input and acquisition in the lexical and phrasal categories, syntactic development at the clausal level was predicted by lexical, phrasal, and clausal diversity in CDS. The influence of CDS on children's syntactic development was unidirectional from input to uptake, and this unidirectionality suggested a prominent role of input in syntactic development. Behavioral genetic studies suggest that this relationship is at least partially genetic (Dale et al. 2015), although the underlying biological mechanism is unclear. School studies show that children's syntactic development is significantly influenced by input from teachers, to whom they are not genetically related; such findings identify a clear role for environmental factors (e.g., Huttenlocher et al. 2002).

More recent research has revealed that input quality is in many cases a stronger predictor of language development than input quantity. However, input quality has been operationalized differently across studies; this variation suggests that multiple components of CDS and the context of caregiver–child interaction are important. Rowe (2012) reported that input quantity predicted acquisition in the third year, but indexes of quality, such as decontextualized language use, were more predictive a year later. Cartmill et al. (2013) showed that the proportion of time in which 14- to 18-month-old infants heard words in transparent referential contexts predicted their vocabulary at 3 years. Hirsh-Pasek et al. (2015) showed that the quality of infant–caregiver communication (joint communication, shared routines, and connectedness of exchange) at 2 years predicted language a year later, over and above quantity of input (see also Tamis-LeMonda et al. 2014). This finding is consistent with the suggestion that joint attention plays an important role in early language (Carpenter et al. 1998).

These latter results underscore the importance of competent others as linguistic models (Bruner 1983) but suggest that the scaffolding of communicative interaction varies. Romeo et al. (2018) presented data confirming this point. They showed that the number of conversational turns measured from daylong recordings significantly predicted 4- to 6-year-old children's language proficiency over and above measures of input quantity. They also reported that children who experienced a higher number of conversational turns showed greater activation in the Left Inferior Frontal Gyrus (LIFG) in Broca's Area during a separate language processing task conducted in a magnetic resonance imaging scanner. The number of conversational turns and the level of activation in the LIFG jointly mediated the relationship between SES and language outcomes. These data suggest that social processes underlying language use [the "conversational duet" (Hirsh-Pasek et al. 2015)] vary among individuals and have a profound effect on the behavioral and neurological foundations of language.

Other variables related to children's home environments have been linked to language development. Home literacy environment (HLE), quantified through indices such as frequency of shared book reading and number of books in the home, is associated with spoken language development (e.g., Payne et al. 1994), but recent results suggest that its effect may be due to maternal language skills and not early exposure to literacy (Puglisi et al. 2017). Birth order also appears to affect children's language learning environments. First-born children have been reported to receive more input than later-born children. Hoff-Ginsberg (1998) reported that mothers used longer sentences with first-born children and that the same children had more advanced lexical and syntactic knowledge than later-born children. These results are consistent with observations that first-born children typically acquire language faster than later-born children (e.g., Fenson et al. 1994), although the effects are only present early in development and quickly disappear. Interestingly, Hoff-Ginsberg (1998) found that later-born children were better able to manage conversation through the use of social routines; this finding suggests that the experience of being one of several children has an impact on their development.[4]

Overall, the emerging picture is one of significant variability in children's linguistic environments that has meaningful implications for language development. Children's input varies in both quantity and quality, but this variation might affect acquisition at different developmental time points. The work on input quality has identified several important influences on children's language, from input diversity to variables linked to social scaffolding, but studies combining all of these variables have not been conducted. Input is significantly influenced by demographic variables and home environment, such as SES (especially parental education), HLE, and birth order. Variation in the input has been linked to variation in the acquisition of vocabulary and grammar, although much remains unknown. For instance, despite abundant evidence that children acquire frequent words earlier, it is unclear how much input is enough for grammatical acquisition; recent accounts have suggested that less may be needed than is typically thought (Yang 2016). Thus, there is a need to postulate explicit learning mechanisms that respond to the input (and that may or may not vary across individuals).

4. EARLY SPEECH DEVELOPMENT

Long before infants begin speaking, they are busy laying down language-specific knowledge and processing machinery (Jusczyk 1997). In the first 6 months of life, the knowledge is perceptual, but once children start babbling in the second half of the first year, their productions begin to resemble their native target (de Boysson-Bardies & Vihman 1991). A growing body of research suggests that auditory and speech processing in the first year is subject to significant individual variation and predicts later language development.

The sources of early individual variability appear to be measurable at birth and reveal correlates of the basic building blocks of language. For instance, Brito et al. (2016) reported that variation in resting-state electroencephalography (EEG) power in the gamma band range (24–48 Hz) in neonates correlated with language comprehension at 15 months. The gamma band has been implicated in phonemic perception (among other functions; see Meyer 2018), and so Brito and colleagues' result suggests that infants come differentially equipped with processing skills linked to the temporal sampling of auditory information (which may vary across different frequencies; see Goswami 2018). Notably, Benasich et al. (2008) reported significant correlations between resting gamma band power and language proficiency in a group of children followed from age 16 to 36 months.

This variation is reflected in neonates' performance on experimental tasks. Using EEG, Molfese & Molfese (1985) showed that children who had comparatively good language skills at 3 years exhibited greater sensitivity to different stop consonants at birth compared with a group who had comparatively poorer language at the same age. Molfese & Molfese (1997) reported comparable data in a separate sample but showed that auditory evoked potentials at birth discriminated high from low language skills at 5 years. Task performance need not be explicitly

[4]Studies comparing first-born with later-born children typically do not compare input to children within a family (i.e., siblings), and thus caregiver is not held constant. This may matter because properties of the input tend to reflect stable properties of caregivers (Huttenlocher et al. 2007). Other notable effects of birth order, such as its influence on IQ (e.g., Bellmont & Marola 1973), also disappear when siblings are compared against each other (Wichman et al. 2006). Similarly, Bornstein et al. (2004) found few differences between first- and second-born siblings in early vocabulary knowledge.

linguistic; Chonchaiya et al. (2013) found that developmental changes in Auditory Brainstem Response (evoked potentials elicited through clicks) between 6 weeks and 9 months predicted language proficiency in Chinese-acquiring infants at 9 months. The results were interpreted to reflect neurological development in the auditory system that supports acquisition. Specifically, the authors argued that slow neurological development can lead to imprecise processing of rapid temporal signals, which subsequently affects the perception of phonemic category boundaries (see also Tallal 2004). Similarly, Benasich & Tallal (2002) reported that rapid auditory discrimination at 7.5 months longitudinally predicted language proficiency at 16, 24, and 36 months (see also Choudhury & Benasich 2011). The literature on infant auditory processing suggests that one key indicator of future language learning success lies in the infant's ability to process and discriminate rapid auditory signals.

This skill no doubt enables children to break into their native language. The sooner they do so, the sooner they can begin building a lexicon. Tsao et al. (2004) showed that vowel discrimination as measured by the Headturn Preference Paradigm (HPP) in 6-month-old infants was significantly associated with language outcomes (vocabulary and early grammar, measured via parent report) at 13, 16, and 24 months. Similar work using both behavioral and electrophysiological measures has shown that better native phonetic discrimination in the second half of the first year is associated with better subsequent language development, whereas better non-native discrimination is associated with slower language growth (e.g., Conboy et al. 2008). Kuhl et al. (2008) argued that, taken together, these predictive relations suggest variability in the developmental timing with which individual infants make neural commitments to their native language.

Another significant early developmental achievement that is subject to IDs is segmentation from running speech. Infants begin to show evidence of successful segmentation in the second half of their first year, but their ability to segment varies and is related to their subsequent vocabulary development. Newman et al. (2006) compared the linguistic skills of children who had previously participated in segmentation studies. Children in the top 15% for vocabulary skills at age 2 years were significantly more likely to have successfully segmented speech than infants in the bottom 15%. These differences were still evident when a subset of the children were tested at ages 4–6 years. Similar prospective longitudinal studies using the HPP have reported similar effects (Newman et al. 2016, Singh et al. 2012). For instance, Newman et al. (2016) measured children's input and showed that type–token ratio in the input and segmentation abilities at 7.5 months explained independent variance in infants' vocabulary at 2 years.

Several other studies have used EEG to study word segmentation and provide further insight into the presence and nature of IDs. These studies have consistently shown an event-related potential signature of successful segmentation that varies across children and across developmental time. Successful segmentation is marked by a negative-going evoked potential in response to a segmented (familiar) word compared with a baseline (unfamiliar) word (Kooijman et al. 2005), and this evoked potential appears to be developmentally preceded by a response of the opposite polarity (i.e., a positivity; Kooijman et al. 2013). The negativity likely reflects a mature segmentation response (i.e., the extraction of the full word form); this association is supported by a similar response to known words in older infants (Thierry et al. 2003). In contrast, the immature positivity may reflect low-level phonetic processing (Kooijman et al. 2013). The size of the negativity also is related to subsequent measures of vocabulary and grammatical development (see Junge & Cutler 2014). Kidd et al. (2018b) showed in a sample of 103 9.5-month-old English-acquiring children that the distribution of the segmentation response revealed a large range of developmental states within a single age group. In a field in which sample sizes are typically low and the dependence on age as a key independent variable is high (see Cristia et al. 2014), the heterogeneous range of performance is notable.

The source of IDs in early speech development is an important issue on which the data are scarce. The existing data suggest that both input and children's early productions matter. For phonetic perception, Garcia-Sierra et al. (2016) reported that receiving comparatively high amounts of input was associated with more advanced native language discrimination. For segmentation, DePaolis et al. (2011) found that infants' mastery of specific consonants predicted their ability to identify words containing those consonants in running speech. However, the amount of input a child receives also appears to matter: Hoareau et al. (2019) showed that input quantity at 4 months predicted 8-month-old children's ability to segment pseudowords from running speech via SL (Saffran et al. 1996), over and above the effect of the children's productive abilities.

Overall, studies of IDs in early speech development indicate that these differences exist and predict later language. A meta-analysis investigating the relationship between early speech processing and language reported an average effect size of $r = 0.31$ (Cristia et al. 2014), which suggests a robust effect. However, the data inevitably invite multiple explanations, and more work is needed. Since most studies report simple correlations or split their data on the basis of language outcomes, unmeasured variables that share variance with speech and language (e.g., attention, temperament) likely contribute to the effect. Also, in many of these studies, the tasks used to predict language outcomes are not designed to measure IDs; thus, some studies may not be adequately sensitive to the full range of IDs (see Section 7). More work is required to determine the developmental antecedents of early auditory and speech processing and their consequences.

5. VOCABULARY

On average, children produce their first word at around 12 months, but even at this early stage in development, there is measurable variation in their vocabulary size (for an early review, see Bates et al. 1995). In a large population study of children acquiring Australian English, Bavin et al. (2008) reported large variability in 12-month-olds' vocabulary as measured by the MacArthur-Bates Communicative Development Inventory [MB-CDI (Fenson et al. 2007)]. Comprehension vocabulary ranged from 0 to 397 words (median = 57), and production vocabulary ranged from 0 to 57 words (median = 3). IDs in vocabulary are stable across childhood (Bornstein et al. 2016) and are important predictors of future cognitive achievement and social outcomes (e.g., Morgan et al. 2015). Section 3, on linguistic variation in the environment, established that the input has a significant effect on children's vocabulary development and while the input is stable across time, it is influenced by several factors (e.g., SES). A host of other factors beyond the input have been implicated in variability in vocabulary.

Behavioral genetics studies suggest that 25–60% of variation in vocabulary is attributable to genetic factors (e.g., Dale et al. 2000, Samuelsson et al. 2005) and that genetic contributions increase as children get older (Hayiou-Thomas et al. 2012). Thus, vocabulary is most significantly influenced by environmental variables during the period in which children are building the foundations of the linguistic system (i.e., from birth to 4 years). Potential explanations for the increase in genetic influence over time include gene–environment correlation (i.e., individuals seeking out environments on the basis of genetic predispositions), language becoming yoked to general cognitive processes that also increase in heritability across development [e.g., IQ, as described by the Wilson effect (Bouchard 2013)], the emergence of new genes for language learning, and changes in the structure of the environment that minimize environmental influence (e.g., school attendance).

Early work on the composition of children's vocabulary suggested that individuals differed in the degree to which their early words were referential (i.e., containing mostly concrete nouns) or expressive [i.e., reflecting social routines (Nelson 1973)]; such variation suggested that children make use of multiple learning strategies early in development. Although this classification has been challenged (Lieven et al. 1992), more recent work has shown that children's early productive vocabulary possesses a high degree of idiosyncrasy across individuals (Mayor & Plunkett 2014) and varies in the rate of development across children and across developmental time (e.g., Ganger & Brent 2004). The speed and relative acceleration of early vocabulary growth predict subsequent vocabulary development independent of SES, input, and child gesture use (Rowe et al. 2012).

Biological sex also influences early vocabulary development. Girls typically outpace boys in early development, although the differences are small and become negligible after 2 years (e.g., Fenson et al. 1994, Huttenlocher et al. 1991). The reason for this difference is unclear, but some studies suggest it may reflect sex differences in neural development. Friederici et al. (2008) assessed phoneme discrimination in 4-week-old infants and reported sex differences that were mediated by testosterone levels. Female infants and males low in testosterone showed successful discrimination, but males high in testosterone did not (testosterone has an influence on brain development; see Filová et al. 2013). Other measures of neural development linked to language, such as EEG coherence (Hanlon et al. 1999) and the Auditory Brainstem Response (Chonchaiya et al. 2013), show similar sex differences.

Early in communicative development, children make significant use of gesture to communicate, the frequent use of which positively predicts vocabulary acquisition (e.g., Bates et al. 1979, Iverson & Goldin-Meadow 2005). In a meta-analysis, Colonnesi et al. (2010) reported significant concurrent ($r = 0.52$) and longitudinal ($r = 0.35$) relationships between pointing gestures and vocabulary, a relationship that increased in strength across development. Notably, it was declarative and not imperative pointing that carried this result. This relationship has been interpreted to suggest that declarative pointing is the first form of naming (Bates et al. 1979), but the emergence of declarative pointing also likely reflects a key sociocognitive development important for language acquisition: shared intentionality (i.e., the ability to share psychological states with another) (Tomasello & Carpenter 2007).

Children's early symbolic gesture use (e.g., iconic gestures such as pretending to drink from a cup to denote DRINK) also predicts their vocabulary development (Acredolo & Goodwyn 1988). However, iconic gestures are typically infrequent compared with pointing, especially in the input (Iverson et al. 1999). A broader category of gesture—gesture type, which combines children's pointing, iconic gesture, and conventional gesture use (e.g., shaking head to denote NO)—is a stronger predictor of vocabulary development (Rowe et al. 2008).

Several factors likely contribute to variation in early gesture. The first concerns variation in parental gesture, which is directly related to children's gesture use (Rowe & Goldin-Meadow 2009; Rowe et al. 2008, 2012). Insofar as gesture use can be increased through intervention (Rowe & Leech 2018) and varies cross-culturally (Cattani et al. 2019), the data suggest significant environmental influence. However, because children's early gesture reflects an emerging capacity for symbolic representation (Bates et al. 1979), gesture use may also reflect variation in children's capacity to manipulate symbols and/or coordinate symbol use during communicative exchange. This latter suggestion is consistent with data showing that children's symbolic play is significantly associated with their gesture use and language development (including vocabulary) across infancy and early childhood [$r = 0.35$ in a recent meta-analysis investigating the relationship between symbolic play and spoken language (Quinn et al. 2018)].

Cognitive factors related to information processing also appear to have a significant influence on vocabulary development. Children's phonological WM, as measured by nonword repetition, has long been linked to vocabulary development (e.g., Gathercole et al. 1992). However, the interpretation of the effect is controversial. The traditional interpretation is that performance on nonword repetition tasks reflects phonological WM capacity, which varies across individuals and causally affects vocabulary development (Gathercole 2006). The alternative explanation is that the relationship reflects variation in long-term vocabulary knowledge that results in differences in real-time phonological encoding (see Stokes et al. 2013). Melby-Lervåg et al. (2012) reported longitudinal data consistent with the latter interpretation; these data also are consistent with computational modeling work (Jones et al. 2007) and with data that show that nonword repetition is predicted by several distributional properties of the input (Szewczyk et al. 2018). A lesser-studied, though potentially more robust, predictor of vocabulary development is variation in declarative memory, which shows consistent correlations with vocabulary skills in children aged 4 years and older (Hamrick et al. 2018).

Another variable associated with vocabulary development is lexical processing efficiency—that is, the speed and/or accuracy with which infants process words in real time (Fernald et al. 2006). For example, lexical processing speed is associated with individual variability in vocabulary development (e.g., Hurtado et al. 2008, Lany et al. 2018a), predicts infants' ability to acquire the meaning of new words (Lany 2018), and predicts later language and cognitive outcomes (Marchman & Fernald 2008). Processing efficiency mediates the relationship between CDS and early vocabulary size (Weisleder & Fernald 2013), suggesting that children in richer linguistic environments develop more efficient processing skills, which facilitates subsequent vocabulary growth. Lany et al. (2018b) showed that lexical processing efficiency is also related to SL, independent of vocabulary size, most likely because greater processing efficiency enables better sequential learning.

The data on IDs in vocabulary development suggest that a wide array of environmental, cognitive, and social factors contribute to variability even before children begin producing their first words. A priority for future research is to determine the individual contributions of each variable across development alongside their interactions. For instance, while developments in early speech predict later vocabulary development, we do not know how this association interacts with other prominent but later-emerging predictors, such as early communicative gesture. What is more certain is that variability in vocabulary development has significant knock-on effects for development in other linguistic domains, such as grammar, to which we now turn.

6. GRAMMAR

Section 3 established that there is significant and meaningful variation in the grammatical features of children's input and that this input varies with SES (Huttenlocher et al. 2002, 2007) and has a significant effect on children's grammatical development (Huttenlocher et al. 2010, Lieven 2009). These differences may have a greater impact on the acquisition of complex (i.e., multiclause) sentences (Vasilyeva et al. 2008); the acquisition of simple grammatical conventions may be less prone to input effects, or alternatively, input frequency may predict grammar only at early stages of acquisition. Similarly, SES impacts on children's performance on experimental tests of grammar (Dollaghan et al. 1999, Huttenlocher et al. 2002) and on their online grammatical processing as measured via eye tracking (Huang et al. 2017).

The most statistically powerful and robust behavioral genetic studies of early grammatical development (2–3 years) suggested moderate genetic contributions (27–43% of variance explained) and larger contributions from shared environment (47–56% of variance explained) (Dale et al. 2000, Dionne et al. 2003). These studies also showed substantial phenotypic and genetic overlap between vocabulary and grammatical skills; this finding is consistent with the observation that vocabulary and grammar are closely coupled in development (Bates et al. 1995). Both studies (Dale et al. 2000, Dionne et al. 2003) used the MB-CDI to estimate vocabulary and grammar; Stromswold (2001) criticized this approach because of the MB-CDI's reliance on parental report. However, subsequent research by Hayiou-Thomas et al. (2006) tested the same sample at age 4.5 years on several behavioral measures of vocabulary and grammar (among other tests) and confirmed the previous results. Note that while the general assumption is that vocabulary bootstraps early syntactic development (Bates & Goodman 1997), syntactic knowledge can also bootstrap vocabulary (Gleitman 1990). The behavioral genetic data therefore suggest that learning in each domain relies on similar mechanisms, which share common underlying genetic and environmental influences.

The behavioral genetic data are supported by a host of behavioral data in several different languages and populations (see Bates & Goodman 1997, Frank et al. 2019) and by computational modeling (e.g., Plunkett & Marchman 1993). However, the precise nature of the effect is still unclear. While the association between the two domains is robust, statistical evidence for direct and directional developmental dependency is lacking (Dixon & Marchman 2007, Hoff et al. 2018), and when children are older than 4 years, the evidence suggests a direct effect of syntax on vocabulary (Brichmann et al. 2018). The studies that find no evidence for direct dependencies suggest that properties of the input influence growth in both domains; this suggestion is consistent with Dale and colleagues' (2000) finding that shared environment contributed most strongly to their observed vocabulary–grammar correlation. Future research would benefit from measuring vocabulary and grammar at more fine-grained levels because the relationship may be specific to particular vocabulary and grammatical features (e.g., verbs and verbal morphology) rather than between total vocabulary size and total number of grammatical forms known. The bidirectional nature of the relationship across development also needs further attention because the mutual influence of each domain may change across development.

A significant amount of research on grammatical development has investigated the relationship between cognitive skills and grammar acquisition and processing. Most of this research has concentrated on three skills: memory (especially WM), SL, and EF. We review research that considers each of these concepts in turn.

Verbal WM is a complex construct describing the concurrent maintenance and processing of linguistic information. As one of the best-studied constructs in cognitive psychology, it often features in explanations of grammatical acquisition and processing (e.g., O'Grady 2005). IDs studies have linked variability in verbal WM to grammatical acquisition and online processing; most of this research has focused on children aged 4 years and older. For instance, Engel de Abreu & Gathercole (2012) reported that verbal WM longitudinally predicted L1 and L2 grammatical acquisition in a sample of trilingual children living in Luxembourg. Consistent with work in adult psycholinguistics, several studies have reported associations between verbal WM and complex sentence comprehension (e.g., Boyle et al. 2013); in particular, these studies suggested that infrequent sentences that follow noncanonical patterns (e.g., object relative clauses) place particular burden on computational resources. However, the nature of the association is hotly debated. While early studies assumed that the relationship reflected core differences in verbal WM capacity that supported grammatical processing, an alternative explanation is that performance on verbal WM tasks reflects differences in long-term linguistic knowledge (MacDonald & Christiansen 2002). That is, children with higher verbal WM perform better on tests of grammatical knowledge because they have more advanced grammatical knowledge (see Kidd 2013).

A concept that is functionally related to processes underlying WM is EF, a set of domain-general control functions for regulating thought and action. Performance on EF tasks systematically varies among individuals and is highly heritable (Friedman et al. 2008). The role of EF in language acquisition remains unclear. Several studies have reported significant associations between EF and language proficiency (e.g., Carson et al. 2005, Gooch et al. 2016), and others have reported that early language skills predict later EF skills (Kuhn et al. 2014). However, Gooch and colleagues' (2016) cross-lagged longitudinal analyses revealed no reciprocal relationship between EF and language proficiency. Attentional control is clearly a prerequisite for language, and any effect of EF on language acquisition may change throughout development. For instance, EF skills manage competition between representations and responses; in keeping with this role, these skills have been implicated in children's processing of lexical and syntactic ambiguity (Khanna & Boland 2010, Woodard et al. 2016). Thus, high cognitive flexibility associated with comparatively good EF skills is likely important in managing competing linguistic representations online—grammatical or otherwise.

One final cognitive process that has been linked to grammatical acquisition is SL. SL was previously not considered to vary among individuals (e.g., Reber 1993). However, growing evidence has shown significant individual variation in SL and has linked this variation to other cognitive skills including language (e.g., Kaufman et al. 2010). Lany (2014) reported that 22-month-old children with comparatively good grammatical knowledge performed better on an SL task than did children with comparatively lower grammatical skills. Studies also have shown positive associations between performance on tasks measuring SL and grammatical proficiency (e.g., Kidd & Arciuli 2016). The most straightforward assumption regarding these results is that an individual capacity for SL supports the identification of distributional regularities in the input and this capacity may be recruited by the processing system for sequencing linguistic information during comprehension and production. Despite recent progress on this topic (see Arciuli & Conway 2018), some important details remain unknown. For instance, the field lacks reliable measures of SL at young ages, and the SL–language relationship is therefore difficult to estimate.

Overall, the literature on grammatical development reveals multiple sources of variability. Children's input varies at both the lexical and grammatical levels, and both appear to affect grammatical development (Huttenlocher et al. 2010). This exogenous source of variance is accompanied by endogenous variability in language learning ability, which behavioral genetic research suggests may be general to multiple domains of language and has been linked to cognitive mechanisms that are in principle separate from language but may support its acquisition. There is more work to be done. First, one pressing question concerns whether variation in grammatical knowledge, at least as it is measured in experimental paradigms, reflects variation in knowledge or in the processes that implement that knowledge (see Huang et al. 2017). Second, the identification of general cognitive predictors of grammatical processing has a long history in many subfields of psycholinguistics, including language acquisition. However, capturing meaningful IDs using cognitive tasks presents a significant challenge, especially in young children. This creates difficulties in measurement, a topic to which we now turn.

7. MEASUREMENT

The study of IDs poses methodological and statistical challenges beyond those encountered in typical experimental research. It has been observed for decades that experimental and correlational traditions within psychology have operated independently, answering different questions and using different methodologies (Borsboom et al. 2009, Cronbach 1957). Historically, research on language acquisition has drawn insights from both traditions, often combining the two. However, a good experimental task is not necessarily a good task for measuring IDs. As Hedge et al. (2018) pointed out, reliability in an experimental context means that an experimental effect is repeatedly detected, which requires reducing the influence of extraneous interindividual variation. However, a reliable task for IDs preserves the rank order of participants over several administrations, which requires amplifying interindividual variation. As such, tasks that are well suited for experimental purposes may be poorly suited for the study of IDs. To illustrate this point, Hedge et al. calculated the test/retest reliability of several common tasks in cognitive psychology and found that, in many cases, reliability fell short of conventional guidelines. Thus, a pressing concern for the study of IDs in language development is the development of tasks designed to measure IDs. This conclusion applies to predictors of IDs as well. Controlling for unreliably measured variables in statistical models can lead to unacceptable Type I error rates for variables of substantive interest, with the error rates increasing as the sample size increases (Westfall & Yarkoni 2016).

A focus on IDs also presents many statistical challenges and opportunities. Precisely measuring IDs requires the construction of psychometric models linking constructs to observed variables. As Borsboom (2006) pointed out, this process often forces researchers to become more explicit about the nature of their constructs. For example, we could imagine reaction times on each trial of a lexical processing speed task like that used by Fernald et al. (2006) to represent separate measurements of a latent processing speed; this construct would represent a reflective measurement model, such as factor analysis. Alternatively, we could imagine lexical processing speed to be an emergent consequence of a collection of word-specific processing speeds; this construct would represent a formative measurement model, such as principal components analysis (for an example comparing models of these sorts in developmental psychology, see Willoughby & Blair 2016). Moreover, in the study of grammatical development, IDs in comprehension of a particular structure could be conceived of as discrete or graded, corresponding to latent class models or latent variable models (for an example comparing models of this sort in the study of category learning, see Bartlema et al. 2014). Even more ambitious models are possible, such as those linking cognitive process models with psychometric models (Voorspoels et al. 2018). Constructing and testing psychometric models of this nature will undoubtedly increase the sophistication and precision of theories of language acquisition; however, doing so will require familiarity with statistical methods outside the mainstream, such as hierarchical modeling, structural equation modeling, and Bayesian methods.

8. CONCLUSIONS

Over 30 years ago, Chomsky (1986, p. 18) wrote that variation "is marginal and can be safely ignored across a broad range of linguistic investigation." The research reviewed here points to the opposite conclusion: Language acquisition is a process characterized by stable and meaningful IDs. There is complex, systematic variability in children's linguistic and broader sociocommunicative environment, and this variability is significantly related to their subsequent development in every linguistic domain we have considered. IDs are not only caused by variation in input: Even at birth, there are differences among children that reflect endogenous processes. IDs within domains are typically related to differences in later developmental achievements. Thus, early proficiency in processing speech is related to vocabulary development, which is related to grammatical development. Therefore, there is significant permeability in the system; in other words, the linguistic system is tightly woven (Bates et al. 1988, Frank et al. 2019), and this interconnectedness is revealed by a focus on IDs.

The IDs data in development are consistent with a growing body of literature showing IDs in adults' ultimate attainment in domains in which IDs were not typically expected (e.g., grammar; see Dąbrowska 2012). These differences reflect the outcomes of development, and thus they are almost certainly influenced by the kinds of variables reviewed here in addition to other variables that influence later language development (e.g., reading). IDs in attainment are related to but are not the same as IDs in online processing, which are also pervasive throughout the system but not well understood (see Kidd et al. 2018a). Building a science of IDs across the range of psycholinguistics is thus an important research priority.

To conclude, we return to theory. The broad observation of system-wide IDs and permeability throughout the entire linguistic system is most consistent with the emergentist approach, but we emphasize that the hypothesis space is still large, and much work remains to be done. Framing the study of acquisition through a focus on IDs forces an explicit delineation of both endogenous and exogenous constraints on development. Thus, the major theoretical issue concerns whether endogenous constraints are representational and language-specific, as is often claimed, or whether they are learning mechanisms (language-specific or otherwise). The IDs data constrain the hypothesis space and provide a means with which to theory-test. Moreover, the study of IDs enables us to track the developmental dynamics of the acquisition process; by revealing patterns of association and dissociation across development, we better understand the complexities of the linguistic system. In this vein, future IDs work must concentrate on predicting and accounting for variability as well as understanding the consequences of variability for developmental processes and outcomes.

FUTURE ISSUES

1. What are the limits of variability across each linguistic domain? For instance, while there is likely wide variability in knowledge of vocabulary, how much does knowledge of formal systems like phonology and grammar differ across individuals? Is this variability a property of acquisition rates, or are differences inherent in the mental representations for those systems?
2. How does variability in knowledge states affect the online processing of language within and across domains? We know that lexical processing is related to vocabulary knowledge (Fernald et al. 2006), but comparable data from other domains like grammar are less common, as are explorations of cross-domain interactions.
3. Which cognitive systems and processes predict variability in language acquisition? Although processes like memory, executive function, and statistical learning have been linked to variation in language, the specific connections between these processes and language are unclear.
4. What are the neural bases of variation? There are tantalizing suggestions that early variation in neural structure and encoding predicts variation in language, but we do not know the full extent and limits of this relationship.
5. How can we build better measures of individual differences in language and related cognitive processes? While we have good standardized measures across several languages, these measures are often fairly coarse and do not typically tap dynamic in-the-moment language skills. A focus on variability in language processing as revealed through methods such as eye tracking and electroencephalography may reveal more about the dynamic processes underlying acquisition.

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