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Review Article

Early Motor and Communicative Development in Infants With an Older Sibling With Autism Spectrum Disorder

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Purpose: A recent approach to identifying early markers of risk for autism spectrum disorder (ASD) has been to study infants who have an older sibling with ASD. These infants are at heightened risk (HR) for ASD and for other developmental difficulties, and even those who do not receive an eventual ASD diagnosis manifest a high degree of variability in trajectories of development. The primary goal of this review is to summarize findings from research on early motor and communicative development in these HR infants.
Method: This review focuses on 2 lines of inquiry. The first assesses whether delays and atypicalities in early motor abilities and in the development of early communication provide an index of eventual ASD diagnosis. The second asks whether such delays also influence infants' interactions with objects and people in ways that exert far-reaching, cascading effects on development.
Results: HR infants who do and who do not receive a diagnosis of ASD vary widely in motor and communicative development. In addition, variation in infant motor and communicative development appears to have cascading effects on development, both on the emergence of behavior in other domains and on the broader learning environment.
Conclusions: Advances in communicative and language development are supported by advances in motor skill. When these advances are slowed and/or when new skills are not consolidated and remain challenging for the infant, the enhanced potential for exploration afforded by new abilities and the concomitant increase in opportunities for learning are reduced. Improving our understanding of communicative delays of the sort observed in ASD and developing effective intervention methods requires going beyond the individual to consider the constant, complex interplay between developing communicators and their environments.
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Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder that is characterized diagnostically by profiles of difficulty in social communication and interaction (American Psychiatric Association, 2013). Other areas of difficulty and atypicality include sensory processing and motor functioning, with motor disruptions in particular apparent across wide ranges of age and IQ (Fournier, Naik, Hass, Lodha, & Cauraugh, 2010). Difficulties in these and other domains are often accompanied by profiles of strength in other areas (e.g., enhanced perceptual abilities in the visual and auditory domains; Järvinen-Pasley, Wallace, Ramus, Happé, & Heaton, 2008; Mottron, Dawson, Soulières, Hubert, & Burack, 2006).

As a group, children on the autism spectrum are highly heterogeneous in their cognitive, language, and social abilities (e.g., Georgiades et al., 2013; Kim, Macari, Koller, & Chawarska, 2016; Wiggins, Robins, Adamson, Bakeman, & Henrich, 2011). Valid measures of IQ cannot be obtained for some, whereas others test within the normal range (e.g., Munson et al., 2008). Some children are nonspeaking, and for them acquiring functional spoken words presents a significant challenge. Others have highly fluent speech but use it in ways that do not advance communication in social settings (e.g., Tager-Flusberg, Edelson, & Luyster, 2011). Some children prefer solitary activities and rarely seek to interact with social partners, whereas others are highly eager to engage socially but have substantial difficulty in navigating the complexities of shared play and conversation.

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This heterogeneity, together with the fact that the diagnostic criteria for ASD are grounded in behaviors that do not typically emerge until at least 2–3 years of age (e.g., peer relationships, pretend play), has contributed to a conundrum in the diagnostic process. On the one hand, the desire to provide a rigorous, accurate diagnosis requires that clinicians wait until children are at least 2–3 years old before considering the possibility of an ASD diagnosis. On the other hand, many parents of children who eventually receive an ASD diagnosis report concerns about the child's development even before the child's first birthday (Coonrod & Stone, 2004; Zuckerman, Lindly, & Sinche, 2015). The existence of this lengthy gap between parents' initial concerns and the child's diagnosis, taken together with evidence indicating that children who receive intensive early intervention have better school-age outcomes (e.g., McEachin, Smith, & Lovaas, 1993; Sheinkopf & Siegel, 1998), has led to a surge of interest in identifying behavioral markers in infancy that can reliably predict a later ASD diagnosis.

Ideally such an effort would require following a sample of children prospectively and longitudinally from infancy until an age at which a reliable ASD diagnosis is possible. Unfortunately, any attempt to attain this ideal is complicated by the fact that ASD is a relatively low base rate disorder in the general population (one in 68 children; Christensen et al., 2016). At this rate, a general population study designed to identify early markers of ASD risk by following children from infancy to diagnosis would require a sample of about 1,400 children in order to obtain a subgroup of 20 children diagnosed with ASD at its conclusion. In the absence of significant funding and personnel, such an approach lacks feasibility.

To circumvent this obstacle, groups of researchers have begun to take a different approach—one that involves studying the later-born "infant siblings" of children who have already been diagnosed with ASD. Because the recurrence risk for ASD in families who have a child with ASD is approximately 18.7% (Messinger et al., 2015; Ozonoff et al., 2011), enrollment demands are greatly reduced: On average, a sample of only about 100 infants will yield a subgroup of 20 who are later diagnosed with ASD. In addition to being at heightened risk[1] (HR) for ASD, infant siblings are also at risk for delays and disorders in other developmental domains (e.g., language; Parladé & Iverson, 2015; motor; Garrido, Petrova, Watson, Garcia-Retamero, & Carballo, 2017). Studying infant siblings in the quest to identify early markers of ASD risk has been widely utilized by a number of research groups around the world (e.g., see E. J. Jones, Gliga, Bedford, Charman, & Johnson, 2014, for a review).

In what follows, I provide an overview of work that my students and I have carried out over the past 14 years as part of this larger early identification effort. In addition to seeking to describe the early development of HR infants later diagnosed with ASD (HR-ASD) and compare it to that of unaffected infants, we have also been heavily engaged in understanding the high degree of variability in trajectories of development exhibited by HR infants who do not receive an ASD diagnosis. Specifically, we have asked whether and to what extent differences and delays in infant motor and communicative abilities might have downstream effects on the later development not only of those skills but also on the development of abilities in other domains. Thus, I begin by describing two illustrative findings of differences and delays in motor and communicative development in HR-ASD infants in relation to comparison infants. I then turn to the issue of the potential cascading developmental effects of these early differences and describe results from studies that have approached this issue in different ways. In a final section, I provide some preliminary conclusions from this body of work and suggest implications for clinical practice.

Motor and Communicative Development and the Early Identification of ASD

The findings described in this article are drawn from two completed longitudinal studies of HR infants. All HR infants had at least one older sibling with a confirmed ASD diagnosis. Both studies utilized similar procedures: Infants were enrolled at 5 months of age and were seen monthly until 14 months of age, with follow-up sessions at 18, 24, and 36 months. All data collection was completed in infants' homes, with visits generally lasting 45 min and involving a combination of unstructured naturalistic observation and caregiver–infant play. The Mullen Scales of Early Learning (MSEL; Mullen, 1995) were administered at 6, 12, 18, 24, and 36 months. At each visit beginning at 8 months, caregivers completed the MacArthur–Bates Communicative Development Inventories (CDI; Fenson et al., 1993). At 36 months, the Autism Diagnostic Observation Schedule–Generic (ADOS-G; Lord et al., 2000) was administered to HR children by an experienced clinician naïve to all prior study data.

Based on results from the ADOS-G, CDI, and MSEL, children were classified into one of three mutually exclusive outcome groups following their 36-month visit (see Iverson et al., 2018; Parladé & Iverson, 2015, for additional details). Children were included in the ASD group (HR-ASD) if they scored at or above algorithm cutoffs for ASD on the ADOS-G with confirmation by clinical best estimate using the Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition, Text Revision criteria (American Psychiatric Association, 2000). Children in the language delay group (HR-LD) did not receive a diagnosis of ASD at 36 months

[1]Literature focusing on the infant siblings of children with an ASD has typically referred to them as "high risk" or "autism risk," referring to a heightened biological probability of receiving an eventual ASD diagnosis. Unfortunately, the terms "risk" and "high risk for ASD" carry necessarily negative connotations and are deeply intertwined with the medical model view of ASD. Although we utilize this terminology for the sake of consistency with an existing body of literature and we recognize that, for many autistic people (see Sinclair, 2013), ASD reflects (sometimes severe) impairments in a host of different skills, it is important to note that, for many others, ASD represents a valued part of their identities, and for these people, the term "risk" is problematic and stigmatizing. For additional discussion of ASD-related terminology, see Kapp, Gillespie-Lynch, Sherman, & Hutman, 2013; Sinclair, 2013.

but had either (a) a history of delayed language, defined as standardized scores on the CDI at or below the 10th percentile at more than one time point between 18 and 36 months and/or (b) a clinically significant delay in language at 36 months (i.e., standardized scores on the CDI at or below the 10th percentile and standardized scores on the Receptive and/or Expressive subscales of the MSEL equal to or greater than 1.5 *SD*s below the mean at 36 months). Children who met neither of these criteria were classified as "no diagnosis" (HR-ND).

For purposes of comparison, we also included data from a group of infants with a typically developing older sibling and no family history of ASD. These low-risk (LR) infants were observed as part of a separate completed longitudinal study (e.g., Berger, Cunsolo, Ali, & Iverson, 2017; Iverson, Hall, Nickel, & Wozniak, 2007) that utilized a similar observation schedule and identical procedures. All HR and LR infants were born at term with no pre- or postnatal complications and came from English-speaking homes.

The Development of Sitting in HR and LR Infants

One major focus of our work in the area of motor and postural development has been the transition to independent sitting. This transition, which dramatically alters infants' experiences with objects, people, and their own bodies, is among the most important in the first year (see Iverson, 2010).

Leezenbaum (2015) utilized hierarchical linear modeling to examine growth trajectories of infant posture longitudinally in the first year. As part of this research, she coded posture in a 30-min segment of the home visits that occurred at infant ages 6, 8, 10, 12, and 14 months. These segments included both naturalistic observation and caregiver–child play, and infants were free to move (i.e., not held by a caregiver; not constrained in a highchair, infant seat, or in any other type of infant furniture). She identified the onset and offset of each posture and calculated the percentages of time spent in each one as the primary dependent variable.

Although a broad array of infant postures was coded for this study, I will focus here on lying and unsupported sitting. *Lying* was coded when infants were either prone or supine, and *unsupported sitting* was coded when infants were seated, without support from a person, object, or furniture and with the hands free to move (i.e., not touching the floor; see also Nickel, Thatcher, Keller, Wozniak, & Iverson, 2013).

With regard to lying, initial levels (i.e., time spent in lying at 6 months) and growth parameters did not differ across all four groups of infants. The percentages of time spent in lying declined rapidly from 6 to 10 months, with trajectories for all groups generally low, flat, and stable from 10 to 14 months. Despite these similarities in trajectory shape, post hoc analyses (conducted by systematically varying the intercept) revealed statistically significant differences in the overall amounts of time spent in lying between the HR-ASD infants and other HR and LR infants at 10 and 12 months. Specifically, at 10 months, HR-ASD infants spent a significantly higher percentage of time in lying (M = 15% of the observation) than LR (M = 2%), HR-ND (M = 4%), and HR-LD infants (M = 2%). A similar difference was evident at 12 months between HR-ASD infants (M = 5%) and LR and HR-ND infants (*M*s = 2%). Thus, despite exhibiting a declining trajectory of time spent in lying just as did the other three groups of infants, HR-ASD infants spent more time in this posture overall at 10 and 12 months. This is striking because it is an age when virtually all infants are crawling and many are beginning to stand, cruise, and walk (e.g., Adolph & Berger, 2015). Infants who spend prolonged periods of time in lying, particularly at older ages, likely miss opportunities to explore and engage with their environments in meaningful ways. For example, object exploration is constrained by the increased biomechanical demands of moving the upper limbs against gravitational forces; the view of the world is generally restricted to the ceiling or floor, and unless an adult moves directly into the field of view, establishing eye contact (a salient social cue for adults) as an overture to social interaction is virtually impossible.

With regard to the development of unsupported sitting, substantial differences were apparent in growth trajectories for LR infants versus the three HR outcome groups, all of whom displayed similar trajectories. Thus, LR infants spent comparable percentages of time in unsupported sitting across the 6- to 14-month period, with 23% of the 6-month session spent in this posture and little change across the remaining sessions, with a slight deceleration over time as infants began to pull to a stand. In contrast, trajectories for the HR groups all took the form of a more pronounced inverted "U" shape. At 6 months, in comparison to LR infants (M = 23%), all three groups of HR infants spent significantly less time in unsupported sitting (HR-ND M = 13%, HR-LD M = 10%, HR-ASD M = 0%). Of note, only one HR-ASD infant was observed in unsupported sitting at 6 months. At this age, all three HR groups spent more time in supported sitting (HR-ND M = 35%, HR-LD M = 44%, HR-ASD M = 46%) relative to their LR counterparts (M = 26%), but the differences were significant only for the HR-LD and HR-ASD groups. From 6 months on, however, growth in time spent in unsupported sitting occurred significantly more rapidly for HR than LR infants so that, by 10 months, this pattern was reversed. HR infants were spending significantly more time (*M*s = 46.51%) than LR infants (M = 33%) in this posture, again at a time when infants are typically crawling and beginning to cruise, stand, and walk.

The Development of Infant-Initiated Communication in HR and LR Infants

In several studies, we have analyzed the development of communication and language in HR and LR infants and toddlers across the first 3 years of life. Findings generally indicate that HR-ASD infants exhibit slowed growth across a variety of communicative behaviors (e.g., gestures, gesture + vocalization coordinations; Iverson et al., 2018; Parladé & Iverson, 2015). These slowed rates of growth appearto be specific to ASD (i.e., differ from those exhibited by HR-LD infants, who also exhibit delayed language), and over time, they result in a progressive loss of ground in comparison to other HR and LR peers.

In addition to these findings, which tell us about differences in overall quantity of communicative production, we have also examined the frequency of spontaneously initiated infant communication (i.e., vocalizations and gestures not produced in response to communications by the caregiver; Winder, Wozniak, Parladé, & Iverson, 2013). Our decision to focus on this type of communication stemmed from the fact that reduced spontaneous communication is a diagnostic hallmark of ASD, and there is evidence of significantly reduced spontaneous initiation of communication from studies of older children with ASD (e.g., C. D. Jones & Schwartz, 2009; Stone & Caro-Martinez, 1990). Using data from home visits completed when infants were 13 and 18 months of age, we asked whether a similar pattern would be evident in HR infants, especially those later diagnosed with ASD.

All instances of infant-initiated communication (gestures, nonword vocalizations, and words) were coded from the 45-min segments of naturalistic observation and caregiver–infant play. We calculated the rate per 10 min of infant-initiated communication as a dependent measure. Comparison of these data between LR and HR infants who did not receive an ASD diagnosis indicated that, although rates for both groups increased significantly from 13 to 18 months, relative to LR infants, HR infants spontaneously initiated communication less frequently overall (LR M_{13} = 11.09, M_{18} = 17.02; HR M_{13} = 9.52, M_{18} = 12.33). As expected, the rates of infant-initiated communication for the subgroup of HR-ASD infants were substantially and significantly lower than those for their unaffected HR peers (M_{13} = 3.30; M_{18} = 3.42) and showed almost no change over time.

The results summarized above are consistent with those from other studies that have reported early emerging differences in motor and communicative development between HR-ASD infants, other HR infants, and LR infants (see E. J. Jones et al., 2014). In general, HR-ASD infants did not engage in unsupported sitting at 6 months, and they also did not show an increase in initiation of spontaneous communication between 13 and 18 months. Not only are there differences in early developmental trajectories of HR-ASD and comparison infants in both the motor and the communicative domains, but there are also differences between HR infants without ASD and LR infants. In the next section, we consider the nature of these differences and their implications for subsequent development in other behavioral domains and on infants' environments.

Cascading Effects of Early Motor and Communicative Delays

Since Zwaigenbaum et al.'s (2005) seminal publication on the early behavioral development of HR infants who later receive an ASD diagnosis, there has been a surge of empirical activity focused on the prospective study of HR infants, with the goal of identifying markers of ASD in infancy. Although these efforts have been valuable and have enhanced our understanding of the development of ASD in the first years of life, they have yielded somewhat mixed findings with regard to early markers of ASD (e.g., see E. J. Jones et al., 2014). Perhaps the most robust finding from this body of work has been that of extensive variability among HR infants who do not receive an ASD diagnosis (e.g., Rogers, 2009), many of whom also exhibit early delays in the achievements of foundational infant and toddler behaviors (i.e., gross and fine motor skills, communicative behaviors, language). For some HR infants, these delays resolve over time, with age-appropriate skill levels apparent by 36 months. For others, however, they persist. Indeed, recent studies conducted on large samples of HR infants without ASD diagnoses have reported rates of mild to moderate developmental delay among 3-year-old HR toddlers approximately three times greater than among their LR peers (10.59% vs. 3.38%; Charman et al., 2017; see also Messinger et al., 2013).

The robust nature of this variability, together with the increased likelihood of suboptimal developmental outcomes among non-ASD HR children, has led us to pursue questions about the potential cascading developmental effects of these early appearing differences. Although delayed development is often conceptualized as a characteristic of the child, a developmental cascades framework allows us to consider the spreading effects of early emerging differences and delays in development, not only within a given domain but also across domains and in relation to broader social and environmental issues. Although the nature of these effects could be direct or indirect, operating through various pathways, their consequences have a similar impact, namely to shape (or even alter) the course of development (for additional discussion, see Massand & Karmiloff-Smith, 2015; Masten & Cicchetti, 2010). The work I describe in the next sections is centered on two questions motivated by a developmental cascades framework. One has to do with the unexpected impact of early differences in other domains across developmental time, and the other deals with their effects on the learning environment.

Do Early Developmental Differences Impact the Emergence of Abilities in Seemingly Unrelated Domains?

In the first 2 years of life, infants achieve a series of gross motor milestones, each of which involves gaining control over body segments (e.g., head, torso), managing an influx of novel perceptual information afforded by new postures (e.g., the 180° panoramic view of the surrounding environment afforded by sitting upright), and progressing from less to more mature forms of behavior (e.g., the Charlie Chaplin–like gait of new walkers to the smoother, more efficient gait of the experienced walker). Although these new skills are impressive in their own right because they mark significant advances in motor skill, they also give rise to a whole series of new experiences and opportunities for infants.

For example, when infants begin to sit, they gain an entirely new vantage point on their surroundings. Their new, upright position affords better visual access not only to the physical environment but also to people who may be nearby. Sitting provides a biomechanically supportive context for reaching (Carvalho, Tudella, Caljou, & Savelsbergh, 2008; Carvalho, Tudella, & Savelsbergh, 2007; Hopkins & Rönnqvist, 2002), and hands that are free to move can explore spaces more extensively (Rochat & Goubet, 1995) and objects in more sophisticated ways that involve combining looking with other manual and oral exploratory behaviors (e.g., infants can look at an object while transferring it from hand to hand; Soska, Adolph, & Johnson, 2010).

All of these new possibilities for interaction with objects and people enhance infants' access to rich perceptual and social information that is useful for the development of communication and language (Libertus & Violi, 2016). Effective exploration of objects, supported by the development of independent sitting, allows infants to extract information about object properties that are relevant for the construction of categories foundational for word learning and language (e.g., Siegel, 1989). A sitting infant surrounded by objects and with an attentive caregiver nearby can easily shift gaze from toys to caregiver, engaging in the triadic behavior that constitutes joint attention, a foundational skill for language growth (e.g., Tomasello & Farrar, 1986).

These examples illustrate a key feature of the developmental cascades framework, which is that it allows us to consider (and potentially explain) relations between developing behaviors in seemingly unrelated domains. Perhaps even more powerful is the fact that it allows us to think concretely about the potential effects of early delays or disruptions in a given domain on development in other areas. Thus, for example, from a developmental cascades perspective, delayed emergence and/or consolidation of new motor skills may have unanticipated yet powerful downstream effects on the development of behaviors in other domains that are known to benefit from new opportunities and experiences provided by motor advances.

In our work on HR infants, we have examined this possibility in studies focused on two key motor achievements: sitting and walking. In this work, we have attempted to demonstrate that not only are delays in early motor development important as potential identifiers of risk for poor developmental outcomes in HR infants but also that these delays have developmental consequences that are cascading and far-reaching, emerging in unexpected places and potentially placing infants who are already at risk for developmental difficulties at an even greater disadvantage.

Example 1: Sitting and reduplicated babble onset. Recall the significant differences in percentages of time spent in unsupported sitting at 6 months reported by Leezenbaum (2015) and described above. Relative to LR infants, all three HR outcome groups spent half as much time (or less) in unsupported sitting, and all but one HR-ASD infant spent no time in this posture at all.

In addition to conferring increased opportunities for engaging with objects and social partners, the development of sitting has significant implications for the development of vocalization (Iverson, 2010). Infants' vocal capacities are fundamentally altered when they transition from lying positions to upright sitting. In the sitting posture, greater expansion of the chest cavity is possible, permitting deeper respiration and resulting in increased capacity for extended phonation. The speech articulators fall into a new, forward position, and mandibular movement now works with gravitational forces (Yingling, 1981). Together, these alterations in systems underlying speech production create new possibilities for infants to explore and discover properties of their own vocal tracts. In particular, because sitting provides a biomechanically supportive context for mandibular activity and because young children achieve their early syllabic vocalizations (including reduplicated babble) by opening/closing of the mandible (Davis & MacNeilage, 1995; Green, Moore, & Reilly, 2002), we might expect to find relations between infants' sitting status and their production of reduplicated babble (i.e., vocalizations characterized by consonant-vowel (CV) repetitions, e.g., [bababa]).

Leezenbaum (2015) tested this prediction in an analysis of vocalization data from the 6-month time point. She coded all vocalizations produced during our 45-min observations and further identified those that included at least one CV or CV-like unit (i.e., syllabic vocalizations). She then compared rates of syllabic vocalization production in infants who had versus had not achieved the independent sitting milestone at 6 months. For purposes of analysis, the LR and HR-ND groups, which contained similar numbers of sitters versus nonsitters (LR *n*s = 14 vs. 11; HR *n*s = 13 vs. 11) were combined. The HR-LD and HR-ASD groups were excluded because very few infants could sit independently at 6 months (three HR-LD, zero HR-ASD).

There were no differences in overall rates of vocalizations between sitters ($M = 11.65$, $SD = 1.29$) and nonsitters ($M = 9.77$, $SD = 4.45$). However, there were differences in rates of syllabic vocalization production that were consistent with the prediction, findings that held at both the group and individual levels. At the group level, rate of syllabic vocalization was significantly higher among sitters ($M = 1.29$, $SD = 3.12$) than nonsitters ($M = .32$, $SD = 1.43$, $p = .017$), and 41% of sitters (but only 9% of nonsitters) produced any syllabic vocalizations (p = 013).

The age held constant design used in this analysis allows us to rule out the possibility that the observed association between attainment of independent sitting and production of syllabic vocalizations is simply due to the influence of maturation. The results are consistent with the view that sitting has cascading effects on the development of vocalization, providing a unique new context in which infants can actively explore their own vocal tracts and discover novel sound-making possibilities.

We also have evidence that delays in the development of sitting may be associated with later onset of reduplicated babble (i.e., vocalizations containing at least two CV units). Data on infant age at reduplicated babble onset (defined as the age when parent report of reduplicated CV vocalization was confirmed by an experimenter) in HR and LR infants suggest that, on average, HR infants begin to produce reduplicated babble at around 8 months (range 5–18 months), compared to 7 months (range 5–9 months) for LR infants. Although 8 months is well within the normative age range for babble onset (e.g., Oller & Eilers, 1988) and this difference is not statistically significant, several of the HR infants did not babble until 10 months or even later, a delay that has been identified as a red flag for later language concerns (Fasolo, Majorano, & D'Odorico, 2008; Lohmander, Holm, Eriksson, & Lieberman, 2017; Oller, Eilers, Neal, & Schwartz, 1999). Many of these same infants also exhibited delayed sitting, and indeed, there are significant associations between infant age at reduplicated babble onset and both age of onset of unsupported sitting ($r = .463$, $p = .035$) and quality of sitting at 7 months assessed via the Alberta Infant Motor Subscales ($r = -.375$, $p = .05$; higher score indicates better control in the sitting posture; LeBarton & Iverson, 2016; Piper & Darrah, 1994). These associations suggest the possibility that, for some HR infants, slower mastery of the sitting posture restricts opportunities to explore the new possibilities for vocalization afforded by sitting, and this, in turn, impacts the emergence of consonant sounds and reduplicated babble.

Example 2: Walking experience and vocabulary development. The emergence and development of walking radically alters infants' experience with and ability to explore the environment. Whereas the world view of crawling infants is dominated by the floor, walking infants have enhanced visual access to distally located and elevated objects and more frequently have objects and caregivers' faces in their visual fields (Kretch, Franchak, & Adolph, 2014). Walkers can explore environments more efficiently, spending more time in motion and traveling nearly three times as far as do crawlers on an hourly basis (Adolph et al., 2012), and they carry objects while locomoting more frequently and cover greater distances while doing so (Karasik, Adolph, Tamis-LeMonda, & Zuckerman, 2012).

Along with increased exploration and access to objects, the transition to walking is accompanied by major quantitative and qualitative shifts in infant communication. Specifically, when infants begin to walk, they become more active in initiating and spend more time in social interaction (Clearfield, Osborne, & Mullen, 2008), produce more adult-directed vocalizations and gestures (Clearfield, 2011), and engage in more moving bids with objects (i.e., bringing, then showing or offering a toy to an adult; Karasik, Tamis-LeMonda, & Adolph, 2011). Combining communicative behaviors with locomotion, as in moving bids, enhances the communicative potential of these behaviors, especially with regard to initiating moments of shared attention to objects that are especially valuable for language learning (e.g., Tomasello & Farrar, 1986). It is not surprising, therefore, that there is growing evidence of increased language growth (assessed via the CDI) following walk onset, independent of infant age (He, Walle, & Campos, 2015; Oudgenoeg-Paz, Volman, & Leseman, 2012; Walle, 2016; Walle & Campos, 2014).

In a recent study, we sought to extend this line of work by examining the relation between the onset of walking and vocabulary development in HR and LR infants. This interest was sparked by our observation of a high degree of variability in the age at which HR infants begin to walk. Relative to LR infants, who walked on average at 11.76 months (range 9–15 months), age at walk onset (defined as taking three unsupported, consecutive steps during a home observation) was 12.59 months (range 8–17 months) for HR-ND infants, 13.15 months for HR-LD infants (range 10–17 months, $p = .033$), and 13.14 months for HR-ASD infants (range 11–16 months). In light of this variability, we were interested in determining whether onset of walking is also a point of inflection for language development in HR infants, a substantial proportion of whom experience both motor and language delays (e.g., Bhat, Galloway, & Landa, 2012).

We used data from the CDI to examine growth in word comprehension and production in relation to walking experience in the sample of 91 HR and 25 LR infants described above (West, Leezenbaum, Northrup, & Iverson, in press). We aligned time relative to the onset of walking so that each monthly session following the final crawl-only visit represented 1 month of walking experience, and using piecewise hierarchical linear modeling analyses, we were able to test whether infants exhibited additional growth in vocabulary following walk onset, above and beyond growth evident across the entire 7-month observation period, controlling for age at walk onset.

For Words Understood, across all observations, LR and HR-ND infants averaged increases of 11.35 and 10.91 words per month and did not differ from one another. The HR-LD group had a marginally lower growth rate relative to the LR group, with a 6.2-word increase per month on average. HR-ASD infants had a significantly reduced rate, with a mean increase of only 1.85 words per month. From the last crawl-only session to the final session (evaluated to assess additional growth as infants gained walking experience), the LR and HR-ND groups increased beyond baseline on average by 18.78 and 19.62 additional words understood per month, respectively, and did not differ significantly from one another. However, both the HR-LD and HR-ASD groups (7.65 and 5.3 additional words understood per month beyond baseline) showed significantly reduced growth relative to LR infants. Thus, despite the fact that HR-LD and HR-ASD infants were older than LR infants at walk onset, they did not appear to reap the benefits of walking in the same way. The pattern of results for Words Produced was statistically identical, with both HR-LD and HR-ASD infants showing significantly attenuated growth following walk onset relative to LR infants.

Although future work using richer methods (e.g., spontaneous language production) to examine the relation between walk onset and growth in communication and language is needed, these two examples illustrate potential pathways by which motor advances (and motor delays) can exert cascading effects on development in the domain of language. Early motor abilities create opportunities for exploration and interaction that are important for the development of vocalization and language. Delays in the emergence and consolidation of these abilities and differences in resulting infant experiences may therefore be related to delays in vocal and language development. For infants with known vulnerabilities in language (e.g., HR infants), delayed or less effective use of walking may reduce opportunities for exploration and interaction, which may further disadvantage language learning.

Before proceeding, it is important to offer a caveat regarding the nature of this argument. All other things being equal, motor development normally participates in the processes by which communicative and language skills are acquired. Normal participation, however, is not the same as logical or causal necessity. Processes of communication and language are exceptionally complex and multidetermined. There are undoubtedly a variety of factors that contribute to growth and delays in children's skill in these areas. There are also undoubtedly alternative ways of accessing contexts for the acquisition of language and communication that, in typical development, are provided by gains in motor skill. Indeed, providing such alternatives could lead to effective intervention. The notion is simply that advances in motor skill, which trigger expanded access to objects, people, and language input, normally serve as an agent of change for communicative growth; delays in skill onset and in trajectories of skill acquisition, differences in how infants make use of new motor abilities to explore the environment, and differences in the environment's response to the infant (an issue to which we now turn) will be reflected in later communicative and language delays, particularly in infants with known vulnerabilities in language.

Do Early Developmental Differences Impact the Language Learning Environment?

We have seen examples of ways in which early emerging delays and differences in foundational motor skills can have cascading developmental effects on advances in a seemingly unrelated domain—communication and language. As noted above, however, developmental cascades can also manifest in a variety of other ways. Here I discuss two examples that illustrate how delays and differences in gesture production and fine motor abilities, respectively, can exert cascading effects on the language learning environment and the nature of the communicative input that children receive.

Example 1: Communicative delays and caregiver input. As noted above, spontaneously initiated communication differs between HR infants without an ASD diagnosis and LR infants at both 13 and 18 months of age. In addition, even by 18 months, differences exist in the frequencies with which HR and LR infants produce different types of gestures. Specifically, HR infants produced more of the earlier-developing giving and requesting gestures (Mdn = 4.5) but fewer of the later-developing showing and pointing gestures (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Mdn = 1.5) than LR infants (Mdns = 2 and 8.5, respectively), though only the latter difference was statistically significant. This group variation in the relative production of giving/requesting and showing/pointing gestures led us to consider the question of whether there may be variation in caregivers' responses to HR versus LR infants' gestures.

Leezenbaum, Campbell, Butler, and Iverson (2014) coded the responses that mothers of 18-month-old HR and LR infants provided to their infants' giving/requesting and showing/pointing gestures and classified them according to whether or not they contained a verbal translation of the gesture's referent. For instance, if a mother said "Oh wow! Let's get the car!" immediately following her infant's point to a toy car, the response would be identified as containing a translation (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007).

Mothers of HR and LR infants were similarly and highly responsive to their infants' gestures. On average, 82% and 94% of HR and LR infants' gestures, respectively, received a maternal response. In addition, although there were no group differences in the mean proportions of maternal verbal responses containing a translation, there was an effect of gesture type on maternal translations, with mothers in both groups more likely to translate the referents of point/show (M_{LR} = 0.75, M_{HR} = 0.67) than give/request gestures (M_{LR} = 0, M_{HR} = 0).

The finding that point/show gestures received proportionately more maternal translations than give/request gestures must be interpreted in relation to the differing profiles of production of these two types of gestures displayed by HR and LR infants. Recall that, relative to their LR peers, HR infants produced many fewer point/show gestures—precisely the gestures that are most likely to elicit translations. Thus, although mothers of HR infants were no different than mothers of LR infants in their provision of translation responses, their infants gave them fewer opportunities to provide translations because they produced comparatively fewer point/show gestures. HR infants, therefore, received fewer translations overall. Because moments in which infants are actively attending to an object while a label is provided are considered to be "magic moments" for word learning (e.g., Tomasello & Farrar, 1986), this finding suggests that differences in infant communication have significant implications for the nature of the input they receive. Reduced production of showing and pointing gestures by HR infants may result in fewer opportunities to hear object labels while attending to the relevant objects, and this may help explain the widely observed delays in early vocabulary that have been reported for HR infants (e.g., Iverson et al., 2018; Mitchell et al., 2006).

Example 2: Fine motor abilities and caregiver labeling. The previous example illustrates one way in which reduced production of communicative behaviors has cascading effects on the nature of caregivers' communication to infants. We have recently begun to explore a similar type of pathway between infant fine motor abilities and caregiver input.

This work is grounded in previous observations of a strong, positive association between fine motor skills in the second year and expressive language at age 3 years in HR infants without an ASD diagnosis (LeBarton & Iverson, 2013). Although this relationship likely reflects the operation of multiple underlying mechanisms, we focused our attention on the possibility that infant fine motor skills—specifically infant object manipulation during interactions with caregivers—shape the nature of the input that infants receive. Support for this potential connection comes from work by Yu and Smith (2012), who examined infant word learning in a laboratory task in which caregivers and their 18-month-old toddlers played with a set of novel objects that caregivers named with novel labels. Following the play session, infants' learning of the novel words was tested. The authors reported that infants were more likely to learn words for objects they were holding during instances of caregiver labeling than for objects they were not holding.

Yu and Smith (2012) noted that when toddlers hold objects, those objects occupy a greater portion of the visual field because of the relatively short length of toddlers' arms. This effectively isolates the object from others in the surrounding environment. When a caregiver then labels the object, the link between the held object and the auditory label is clearer and more salient to the child. In other words, coordination between toddlers' manual actions on objects (in this case, simply holding the object) and caregiver labeling of the object may assist very young children in the process of word learning (see also Pereira, Smith, & Yu, 2014; Yu & Smith, 2017).

Although these findings are intriguing, they come from a stripped-down laboratory task in which only four objects were presented, and the surrounding environment was relatively free of competing stimuli (i.e., white walls and surfaces). But children's everyday environments are filled with objects, people, and many other competing sights and sounds. In order for this strategy to be effective in real-world settings, caregivers must coordinate production of labels with moments of infant object manipulation. To address this question, we (West & Iverson, 2017) conducted an analysis of longitudinal data from a group of 13 LR infants observed at home with a primary caregiver (mothers in all cases) during play with a standard set of toys at ages 10, 12, and 14 months. We examined infant object manipulation, maternal speech (particularly labeling), and the coordination of maternal labeling with infant object manipulation across the 10- to 14-month period, a time typically characterized by development by rapid growth in infants' word vocabularies.

Frequency of maternal utterances remained unchanged across the period of observation, as did the proportions of maternal utterances containing labels. As expected, however, infants spent progressively higher proportions of time manipulating objects with age, and they also spent greater proportions of time engaged in more complex object manipulations (e.g., functional actions, such as using a spoon to stir in a bowl). Importantly, maternal input varied in relation to infant object manipulation. Relative to instances in which infants were not manipulating objects (i.e., were not in manual contact with any object), instances of infant object manipulation elicited fewer maternal utterances (perhaps because mothers wished to avoid overloading their young listeners with information), but those utterances contained proportionately more labels.

In addition, mothers were most likely to provide labels when infants were both holding and looking at an object (vs. only looking at or only holding the object). However, maternal labeling also varied as a function of how infants manipulated objects. Across time, mothers were substantially more likely to label objects that infants incorporated into functional (e.g., bringing a toy cup to the lips) or sensorimotor (e.g., banging the spoon on the floor) actions than objects that infants were passively holding.

Overall, these findings suggest that, in everyday interactions, infant object manipulation serves as a powerful elicitor of maternal labeling. When infants hold and look at an object and especially when they actively move the object, caregivers may interpret these behaviors as indexing infant interest in and engagement with an object and respond by providing the object's label. There is evidence of differences in both frequency and quality of object manipulation in HR infants with and without an eventual ASD diagnosis (Kaur, Srinivasan, & Bhat, 2015; Libertus, Sheperd, Ross, & Landa, 2014, Experiment 2) and of reduced production of functional actions in HR-ASD infants (Sparaci, Northrup, Capirci, & Iverson, in press). These results lead naturally to the question of whether and how these differences may impact caregiver input to HR infants, a question that we hope to address in future work.

Taken together, the two examples presented above illustrate ways in which infant behavior plays a role in shaping language input. Infant gestures, particularly point/show gestures, reliably elicit object labeling, as do complex forms of object manipulation. When the emergence and production of these behaviors is slowed or reduced, caregivers' opportunities to respond with timely labeling of the object of interest—input critical for the child's development of language—are reduced.

Conclusions and Clinical Implications

Although we are just beginning to understand the course of early motor and communicative development in HR infants and the ways in which aspects of development in these domains may be related to and predictive of later developmental outcomes, there are two main conclusions that can be drawn from the research reviewed above.

First, HR infants who do and who do not receive a diagnosis of ASD vary widely in motor and communicative development. Some HR infants are indistinguishable from LR peers, and some exhibit early but transient delays in development; but the most significant delays are apparent in HR-ASD infants. Indeed, as noted above, unsupported sitting was virtually absent among HR-ASD infants at 6 months, and they also did not show the expected growth in infant-initiated communication from 13 to 18 months. This conclusion is supported by numerous other studies of motor (e.g., Estes et al., 2015; Leonard, Elsabbagh, Hill, & BASIS Team, 2014; Libertus et al., 2014) and communicative and language development (Iverson et al., 2018; Landa & Garrett-Meyer, 2006) in HR and LR infants.

Although this motor and communicative variation among HR infants is now well established, one outstanding issue that has yet to be adequately addressed in this body of work is that of specificity. It remains unclear whether differences in the timing and course of early motor and communicative development observed among HR-ASD infants are indices of general developmental delays or are specific to ASD. A very small number of studies to date have begun to address this issue by including a contrast group of infants who are identified with other, non-ASD developmental concerns (e.g., language delay, atypical development; Iverson et al., 2018; Landa & Garrett-Meyer, 2006; Leonard et al., 2014; West et al., in press). Findings thus far have been somewhat mixed with regard to whether differences in motor and communicative development observed early in life are specific to ASD, but additional longitudinal research utilizing this type of design is clearly required.

Second, variation in infant motor and communicative development appears to have cascading effects on development. We have provided examples of such effects on the emergence of behavior in other domains (e.g., sitting and reduplicated babble, walking and vocabulary development) and on the broader learning environment (e.g., infant gesture production and caregiver input, infant object manipulation and caregiver labeling). The notion that even very small, early-appearing disruptions in development can have cascading and far-reaching downstream effects underscores the importance of attending to early signs of delay (see also Thelen, 2004), particularly in populations of infants with known developmental vulnerabilities.

Clinically, there are two implications suggested by these conclusions. The first is that although developmental delays and disorders are frequently conceptualized as characteristics of the child (e.g., the presumption that a child with delays in the ability to initiate joint attention will become a child with delayed language), the reality is that they are best understood in terms of the dynamic interaction between the child and the child's environment. Delays and limitations in children's abilities to interact with their physical and social environments fundamentally alter how those environments respond to the child. For example, when a child initiates communication less frequently or attempts to do so with behaviors that are less salient or interpretable to social partners, much of the responsibility for maintaining the interaction falls to the partner. This may, in turn, lead to a reduction in shared topics for communication (because topics must largely be generated by the partner), which, in turn, will impact the nature and frequency of linguistic input directed to the child. In addition, delays exhibited by the child influences caregivers' sense of the child's developmental level, such that caregivers provide input that may not be optimal for learning (see Iverson & Wozniak, 2016, for additional discussion and examples).

This view suggests an approach to early intervention that not only identifies profiles of strengths and weaknesses of the child and develops appropriate strategies to address them but also attends to the potential impact of differences in child behavior on caregiver behavior and on the learning environment. For instance, several studies have reported that caregivers are more likely to respond to infant vocalizations that contain consonants than to those that contain only vowel sounds (e.g., Gros-Louis, West, Goldstein, & King, 2006). For a young child who is delayed in production of consonant sounds, caregivers could be trained to provide enriched verbal responses to vowel-only vocalizations. A strategy of this sort might reduce missed opportunities for timely linguistic input and their potential impact on subsequent learning.

The second clinical implication of this work is that advances in communicative and language development are supported by advances in motor skill. In other words, motor development (and motor delay) really matters. One of the central developmental tasks of infancy is exploration. The acquisition and deployment of new, progressively more sophisticated gross and fine motor skills allow infants to access more of the world around them (e.g., when they progress from crawling to walking) and more and richer information about the social and physical worlds (e.g., the relation between sitting and advances in object exploration). When these advances are slowed and/or when new skills are not consolidated and remain challenging for the infant (e.g., an infant who has difficulty grasping objects), this enhanced potential for exploration and concomitant increase in opportunities for learning are reduced. Viewing development as the product of systems interacting in time and delayed development as reflecting disruptions not only within individual systems but in systems interactions with one another (Thelen, 2004; Thelen & Smith, 1996) underscores the need to ascertain whether there are delays in infant motor behavior that accompany concerns about delayed communication/language.

Although delays or disruptions in motor development cannot solely explain delayed language development, they may provide valuable diagnostic information and unique opportunities to create intervention strategies that simultaneously address motor and communication skills. With regard to early identification and diagnosis, early motor skills are strongly predictive of later language (Wang, Lekhal, Aarø, & Schjølberg, 2014). Identifying infants with delayed motor development, particularly those from populations with known vulnerabilities in language (e.g., infants with a family history of dyslexia; Viholainen, Ahonen, Cantell, Lyytinen, & Lyytinen, 2002), may provide an early window of opportunity for enhanced developmental surveillance and introduction of enrichment strategies if concerns are noted.

With regard to intervention, a systems approach to development requires collaboration between speech-language pathologists, physical therapists, and occupational therapists to devise intervention methods that simultaneously target skills in multiple domains. For example, for an infant or toddler who has poor trunk control and is not yet sitting well, time spent working on exploration and acquiring control of the sitting posture could also be used to target developing communication skills. Toys could be placed on the floor near the upright infant, and caregivers could be encouraged to hold toys up in the infant's line of sight, respond with rich verbal input when the infant is looking or vocalizing at a toy (Goldstein, Schwade, Briesch, & Syal, 2010), and comment on what the infant is doing. Activities such as these may support the creation of moments of shared attention and provide infants with precisely the types of opportunities for object play and social and communicative interaction that typically occur when infants begin to sit. Capitalizing on moments when infants are working on more advanced motor skills and introducing the types of opportunities for enhanced exploration and learning that fall naturally from the targeted motor skill may help reduce the potentially negative cascading effects of early motor disruptions on the development of infants with or at risk for developmental delays or disorders.

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