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Through Thick and Thin: Gesture and Speech Remain as an Integrated System in Atypical Development

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Abstract

Gesture and speech are tightly linked and form a single system in typical development. In this review, we ask whether and how the role of gesture and relations between speech and gesture vary in atypical development by focusing on two groups of children: those with peri- or prenatal unilateral brain injury (children with BI) and preterm born (PT) children. We describe the gestures of children with BI and PT children and the relations between gesture and speech, as well as highlight various cognitive and motor antecedents of the speech-gesture link observed in these populations. We then examine possible factors contributing to the variability in gesture production of these atypically developing children. Last, we discuss the potential role of seeing others' gestures, particularly those of parents, in mediating the predictive relationships between early gestures and upcoming changes in speech. We end the review by charting new areas for future research that will help us better understand the robust roles of gestures for typical and atypically-developing child populations.

Keywords: Gesture; Children with brain injury; Preterm children; Parental input

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1. Introduction

As Susan Goldin-Meadow famously quotes, "People move their hands as they talk – they gesture" (Goldin-Meadow, 1999, p. 419). This deceptively simple observation sparked major theoretical shifts in diverse fields, including developmental science, cognitive science, and neurolinguistics. The rich literature on gesture includes, but is not limited to, studies on gesture's role in language production and comprehension (e.g., Kita, Alibali, & Chu, 2017; Özyürek, 2014), gesture's role in teaching and learning (e.g., Alibali et al., 2013; Cook & Goldin-Meadow, 2006; Goldin-Meadow & Alibali, 2013; Roth, 2001), neural and cognitive correlates of gesture processing (e.g., Kelly, Manning, & Rodak, 2008; Özer & Göksun, 2020a; Wu & Coulson, 2014), how gestures vary across cultures and speakers of different language (e.g., Akhavan, Nozari, & Göksun, 2017; Gullberg, 2009; Kita & Özyürek, 2003; Lewandowski & Özçalışkan, 2018; Özyürek et al., 2008), and how gestures' roles change for individuals who do not have a conventional language system (e.g., Flaherty, Hunsicker, & Goldin-Meadow, 2021; Goldin-Meadow, 2005); many of which are reviewed in the current special issue.

Gesture and speech form a single system, and the two are tightly linked in typical development (McNeill, 1992). Gestures that typically developing (TD) children produce in different language environments provide a unique window into their communicative development. In the early years, children communicate information in gesture that they are not yet able to do so in speech (e.g., Acredolo & Goodwyn, 1988; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Iverson & Goldin-Meadow, 2005). Gestures not only supplement the information children communicate, but it also predict later changes in spoken language development (e.g., Rowe & Goldin-Meadow, 2009b). Recent research suggests that gesture might even play a causal role in bringing in later changes in speech (e.g., LeBarton, Goldin-Meadow, & Raudenbush, 2015). This review seeks to examine the role of gestures in language development of atypically-developing populations, with a specific focus on two groups: children with peri- or prenatal unilateral brain injury (children with BI) and preterm born (PT) children. We ask whether and how gestures play a similar or a different role in language development for these populations, whose unique developmental trajectories present significant challenges. Specifically, we ask whether the role of gestures in language development remains intact and robust "through thick and thin", that is, during both typical and atypical development. We also leverage the literature on children with BI and PT children to address broader questions about the internal (child-level) and external (environmental-level) sources of variability in children's gestural production and gesture-speech integration.

Our first goal is to examine the relation between gesture and speech in children with atypical developmental trajectories—is the relation intact and robust as it is in TD children? One possibility is that the relations are robust and the same for TD and atypically developing children. However, it is also possible that gesture and speech relations are different for TD and atypically developing children. Due to different biological and environmental constraints atypical developing children face, the gesture and speech link could be disrupted or weaker, and the two might not form an integrated system in atypical development. Alternatively, gesture and speech may be more tightly linked in atypical development compared to

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typical development since these children might have difficulties but also heightened heterogeneity in their language production and comprehension. Gesture and speech might also be more strongly linked in atypical development since linking between different domains can be more noticeable for children who follow atypical developmental trajectories than TD children (Karmiloff-Smith, 2009). Besides these scenarios, one could expect individual variability in gesture production and the relationship between speech and gesture. Relations might vary as a function of specific characteristics and experiences of the children, ranging from their neonatal biological risk factors to their early visuomotor development. Taken together, our first goal is to describe and discuss gesture production and the relations between speech and gesture in children with BI and PT children.

Our second goal is to leverage the focus on atypical children to address broader cross-cutting issues about gesture and gesture−speech relations. A rich body of prior literature characterizes gesture and its relations to speech in both TD children and children with atypical trajectories (e.g., Iverson et al., 2018), as well as the consequences of early variability in gesture production (e.g., Rowe & Goldin-Meadow, 2009b). Less is known about the sources or *contributors* of the variability in children's gestures or relations between speech and gesture (e.g., Özer & Göksun, 2020b). Here, atypically developing children with varying neural and environmental profiles present a special opportunity to examine such relations. Studies in TD children suffer from restricted range issues because the individual variability across these children in terms of their child-level (e.g., visuomotor skill) or environment-level factors (e.g., parental input) that might predict gesture profiles is more limited than it is in atypically developing children. Prior reviews on children with atypical-developmental trajectories primarily focused on Autism Spectrumm Disorder (ASD) or children with Down syndrome, who primarily have significant difficulties and delays in their communicative development (Dimitrova, Özçalışkan, & Adamson, 2016; Özçalışkan, Adamson, Dimitrova, & Baumann, 2017; Watson, Crais, Baranek, Dykstra, & Wilson, 2013). Children with BI and PT children are unique groups to examine the role of gesture in language development as some perform at or above the level of their TD peers, whereas others fall behind in their communicative development (e.g., Bates et al., 1997; Stiles, Reilly, Levine, Trauner, & Nass, 2012). The wide variability observed in children with BI and PT children can be helpful to tackle the interactive and cascading effects of child- and environment-level factors in early language development. In this review, we focus on three primary groups of factors that contribute to variability in children's gesture profiles. First, we highlight early child-level predictors that emerge within the first year of life and might have a cascade of effects on children's later gestures as well as the relation between speech and gesture (see Iverson, 2021, for a review on early developmental cascades). Second, we focus on the role of gestures children see in others—particularly in their caregivers. Third, we also acknowledge the possible interactive relations between child-internal and external factors—for example, how the ways in which environmental factor predicts gesture profiles might vary as a function of child-internal factors.

With these two broad goals, we focus on children before school entrance, 0−5 years of age, since these are fundamental years for language development. Given the paucity of literature on gesture comprehension even in TD children, we mainly focus on gesture production in the current review. We highlight the importance of focusing on gesture comprehension in the

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future directions section, with the exception of examining gesture exposure, since comprehension is beyond the scope of the current review. We also limit our discussion to the gesture production and the relations between speech and gesture with an emphasis on studies that explored the use of gestures during the prelinguistic and the one-word period and examine the relation to vocabulary development. This is not because gesture ceases its crucial role in later years. On the contrary, gestures continue to take an even more diverse set of roles as children's communicative repertoire widens—for example, gestures are used as a foray into children's first sentences or narratives (e.g., Demir, Levine, & Goldin-Meadow, 2015). However, the literature on children with BI and PT children's gestures beyond this period remains limited. Further, one of our primary goals is to review the earlier emerging factors that predict variability in the first stages of gesture production and gesture-speech combinations.

2. Gesture and speech production during the prelinguistic and one-word period in TD children

In TD children, gesture precedes and predicts upcoming changes in speech (for a review, see Goldin-Meadow & Alibali, 2013). Children start communicating via gestures before producing their first words (Acredolo & Goodwyn, 1988; Bates et al., 1979). These gestures include deictic (pointing) gestures that are used to single out objects, people, or locations in the environment (e.g., pointing at a cup to indicate a "cup"), conventional gestures (e.g., waving hands), and iconic (representational) gestures that reference objects, actions, or relations by representing an aspect of their referent's shape or movement (e.g., flapping hands to indicate "wings"). At the earliest prelinguistic stages (6−10 months of age), infants' gestures are typically produced without speech but with nonspeech vocalizations. After a while, as children start producing single words, they start synchronizing their gestures with words. After the initial stages of vocabulary development, children continue to use gestures as they extend their language abilities. Gestures become more intertwined with speech by development (e.g., Capirci &Volterra, 2008; Capirci, Contaldo, Caselli, & Volterra, 2005). Specifically, children frequently combine their gestures with words. In such combinations, a gesture often, especially initially, conveys information that reinforces or is redundant with the information in speech (e.g., pointing at a cup while saying "cup"). Over time, gestures can also convey information that is different from the information conveyed in speech. For example, gestures might disambiguate the information conveyed in speech, primarily when it is produced with demonstrative or pronominal forms (e.g., pointing at a cup while saying "it"). Finally, at later ages, children start producing gesture-speech combinations where gestures supplement or add to the information in speech (e.g., pointing at a cup while saying "mommy" to indicate "mommy's cup"). These latter combinations convey sentence-like meanings where one piece of the information is conveyed in gesture and the other one in speech (Özçalışkan & Goldin-Meadow, 2005). Variability in early gesture production is linked to later developments in language. For example, names for objects that young children indicate in gesture are more likely to quickly enter their spoken vocabularies than names for objects that they do not indicate in gesture do not enter their vocabularies several months

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later (Iverson & Goldin-Meadow, 2005). As another example, the size of children's gesture vocabulary, that is, the number of different meanings they convey in gestures at 14 months, is related to the size of their receptive vocabulary at 42 months, even after controlling for early differences in the number of spoken words children produce at 14 months (e.g., Rowe & Goldin-Meadow, 2009b).

3. Gesture production and gesture−speech relations in children with early brain injury (children with BI)

Children with BI and PT children both experience disruption in their pre/perinatal neurological development but also vary in their specific biological and environmental profiles. Children with BI develop language using different biological/neural substrates than those engaged when children acquire language with no brain injury (e.g., Raja Beharelle et al., 2010). Thus, examining gestures in children with BI might reveal whether the same gesture−speech relations remain intact even in the face of significant neurological risk. In terms of their vocabulary development, children with BI experience an initial delay in getting their language off the ground. After the initial delay, as a group, these children perform within the low-normal to normal range based on standardized test scores by the time they reach school (Bates et al., 1997; Feldman, Holland, Kemp, & Janosky, 1992). However, there is variability in outcomes, with the delay being more transient for some children than others. The early body of work by Bates and colleagues primarily relied on parental responses to the MacArthur Communicative Development Inventory (MCDI) to assess children's early gestures. Initial findings suggested that children with early right hemisphere damage were consistently behind in their gesture production between 10 and 17 months of age (Bates et al., 1997). More recent work with a larger sample, again using MCDI, similarly showed that children with right hemisphere damage were behind their peers with left hemisphere damage and TD peers at both 12 months of age—an age when differences in the speech were not observed yet (Trauner, Eshagh, Ballantyne, & Bates, 2013). Even though they were behind, for children with right hemisphere injury, early gestures correlated with vocabulary production at 24 months of age—a pattern that was mirrored by TD children.

More recent work relied on direct observations of child gestures during naturalistic communication, and confirmed the predictive role of gestures. For example, Sauer and colleagues (2010) examined gestures and words children with brain injury produced at 18, 22, and 24 months of age. While children with BI, as a group, did not differ in the total amount of gestures or types of gestures produced than TD peers, they exhibited great variability in their gesture profiles that led to different outcomes for later vocabulary knowledge, assessed by Peabody Picture Vocabulary Test (PPVT). Children with BI whose gesture was within the range of TD children had a productive vocabulary at 22 and 26 months and a receptive vocabulary at 30 months that were also within the TD range. However, children with BI whose gesture was below the TD range remained below their language outcomes at all time points. Children with BI whose gestures were within the range of TD children differed from their peers who were below in their lesion characteristics—children with small lesions and

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children with periventricular lesions were more likely to produce gestures within the TD range compared to those with larger lesions and children with cerebrovascular lesions. The two groups were not different in their initial speech, highlighting the diagnostic value of early gestures over speech. Together, these results suggest that gesture predicts later vocabulary production and comprehension (as measured by PPVT). The predictive role of gesture was also over and above early language, as measured by CDI.

Özçalışkan, Levine, and Goldin-Meadow (2013) examined gesture production in children with BI during naturalistic communication, leveraging the same dataset but with a larger sample and focusing on a longer time span. This study also broadly confirmed robust gesture−speech relations in children with BI. As a group, children with BI did not differ from TD children in the total number of gestures produced, but a role of lesion size was observed where children with small lesions produced more gesture tokens than their peers with larger lesions. Children with large lesions also produced a fewer number of gesture-speech combinations than their TD peers and their peers with small lesions. Children's gesture-speech combinations were further categorized according to the semantic elements conveyed: arguments without a predicate (e.g., pointing at mother while saying "crayon"), arguments with a predicate (e.g., pointing at a cup while saying "drink"), and multiple predicates with or without arguments (e.g., saying "I like it" while making an iconic gesture for "eat"). While children with BI were delayed in their production of each gesture-speech combination type compared to TD children, they were delayed in the emergence of these constructions in speech as well. Further, both in TD and children with BI, constructions expressed by gesture-speech combinations emerged in gesture first before they appeared in speech. These findings support the view that although language development is delayed in children with BI, the process by which gesture and speech both go hand in hand is similar. In addition to similarities, BI differed from TD children in that the role of gesture in predicting upcoming changes in the speech was disrupted for complex sentence types (i.e., constructions with multiple predicates). Children with BI produced these specific constructions in speech first, but the variability in the meanings they conveyed remained limited. The gesture-speech combinations representing such relations present particular motoric demands, which might have influenced the relations between speech and gesture, which we will discuss later.

What do these findings demonstrate about gesture production and gesture-speech integration in children with BI? Findings suggest that even though children with BI might fall behind TD children in their gesture production, TD children's gesture−speech relations overall remain intact and robust. The specific characteristics of the children also contribute to patterns observed—for example, lesion size or laterality seems to be a predictor of gesture production (e.g., Trauner et al., 2013). Finally, it is possible that the motor functioning of children has implications for the relationship between speech-gesture, which highlight the importance of examining antecedents of early gestures—a topic we will discuss later.

4. Gesture production and gesture−speech relations in preterm-born children

Preterm (PT) birth is defined as being born before 37 weeks of gestation. An estimated 15 million babies are born preterm (Ohuma et al., 2023). Based on birth weight, PT births are

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categorized as low birth weight (<2.500 g), very low birth weight (<1.500 g), and extremely low birth weight (<1000 g) (Hille et al., 2001). Another categorization involves gestational age (GA): extremely preterm (<28 weeks), very preterm (28 to <32 weeks), and moderate to late preterm (32 to <37 weeks) (Goldenberg, Culhane, Iams, & Romero, 2008; Wolke, Johnson, & Mendonça, 2019). Children born preterm (born before 37 weeks of gestation) present a different profile than children with BI. Most PT children vary in neonatal risk factors, such as their gestational age and birth weight, and the environmental factors they are exposed to, such as their neonatal intensive care unit environment. Rapid brain development in PT children continues outside the womb due to interrupted pregnancy for PT children (Adams-Chapman, 2006). Thus, early birth presents neurological risks as well—suppression of cerebral neurogenesis, early disruption to white and gray matter development, and delayed myelination of white matter that connects different neural networks, leading to problems in neurocognitive development (DeMaster et al., 2019).

Neurocognitive problems are heightened for children born with lower birth weights and at earlier gestational weeks (e.g., Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Bolk et al., 2018). Long-term impacts of these neurodevelopmental disruptions on cognitive skills can be observed in even lower-risk PT children (GA between 30 and 34 weeks; birth weight < 2500 g) (Soria-Pastor et al., 2009), and problems seem to increase in later childhood (Constable et al., 2008, but see Guarini et al., 2009). As in other domains of cognitive development, PT children, particularly very PT children, demonstrate significant language delays compared to full-term (FT) children (e.g., Barre, Morgan, Doyle, & Anderson, 2011; Cusson, 2003; Foster-Cohen, Edgin, Champion, & Woodward, 2007; Ionio et al., 2016; Sansavini et al., 2014; Zimmerman, 2018). A longitudinal study testing a large sample of very PT, moderate to late PT, and FT children at five time points (5 and 20 months, 4, 6, and 8 years) showed that PT children in both groups performed worse than FT group (Putnick, Bornstein, Eryigit-Madzwamuse, & Wolke, 2017). The stability of language performance across time points was found for all age groups. However, other studies did not demonstrate this delay in comparing moderate to late PT children to FT children between 10 and 30 months on their lexical (Pérez-Pereira & Cruz, 2018) and grammatical development (Pérez-Pereira, Fernández, Gómez-Taibo, & Resches, 2014).

Regarding early gesture production, most studies used the parental reports from the subsection of MacArthur-Bates CDI and indicated that PT children produce significantly fewer gestures than FT ones between 12 and 24 months (Cattani, Bonifacio, Ferz, Iverson, Zoccoli, & Caselli, 2010; Ortiz-Mantilla, Choudhury, Leevers, & Benasich, 2008; but see Sansavini et al., 2011 for 12 months). Using Finnish CDI, Stolt et al. (2014) also showed a lower number of early (i.e., first communicative gestures) and late (i.e., actions with objects, imitation adults, pretend actions) gestures in very PT children than FT children between 9 and 15 months (at three time points), and a greater difference was observed for late gestures. However, no significant differences in gesture use were observed between low-risk PT children (mean gestational age of 32.6 weeks) and FT children (Pérez-Pereira et al., 2014). Analyses from parent-child play sessions corroborated parental reports, suggesting a delay at the onset of gesture use at 12 months (Benassi et al., 2016). In contrast, Suttora and Salerni (2012) found that very PT children produced a similar amount and types of gestures as FT children.

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Nevertheless, PT children used fewer gesture-word combinations at 18 and 24 months than FT infants. At 24 months, extremely PT children produced fewer spoken-gestural combinations in a standardized task of predicate production than FT children (Sansavini et al., 2015). Fewer representational gestures that referred to actions and objects were produced in the PT group than FT group. In a more recent study, Sansavini et al. (2019) showed that the frequency of pointing gestures at 18 months was fewer in very PT children who displayed language delays compared to very PT children who did not have language delays and FT children.

Only a few studies examined the predictive role of gesture production on language development and mainly presented a close link between gesture and speech (e.g., Pérez-Pereira et al., 2014; Stolt et al., 2014, 2016; Suttora & Salerni, 2012). PT infants' pointing gestures from parent-child play sessions at 12 months positively correlated with their vocabulary size at 18 months (assessed by CDI) and lexical complexity scores obtained from play sessions at 24 months (Suttora & Salerni, 2012). PT children's early gesture use at 15 months (based on CDI), together with their early receptive and expressive lexicon at 12 and 15 months, predicted their later receptive and expressive vocabulary sizes at 24 months of age (Stolt et al., 2014). For the FT group at the same ages, earlier gestures predicted later expressive vocabulary. In a follow-up study, Stolt et al. (2016) showed that early gestures at 9 and 15 months were also related to PT children's receptive and expressive language skills at 5 years of age. Nevertheless, Pérez-Pereira et al. (2014) indicated that gestures at 12 months did not associate with low-risk PT children's word production at 30 months.

What do these findings demonstrate about gesture production and gesture-speech integration in the PT group? Similar to children with BI, although PT children mostly produced fewer gestures than FT children, studies thus far mainly present a close link between early gestures and later vocabulary development as in TD children. Some mixed findings do exist. For example, Pérez-Pereira et al. (2014) argued that the effect of gestures on later language development might be reduced. However, Stolt et al. (2016) highlighted the power of early gesture production on PT children's language skills as late as 5 years of age. The sample characteristics were across studies (i.e., low-risk vs. extremely PT), which could explain some of the mixed findings. Most of the studies that did not reveal associations assessed gesture use through the parental report at younger ages and reported association to later child language outcomes (but see Suttora & Salerni, 2012). Detailed analyses of infants' spontaneous gesture use during parent−child interactions are rarer, but they also demonstrated that children characterized by developmental delays continued to heavily use communicative gestures, possibly due to linguistic delays at later ages (Suttora & Salerni, 2012). Overall, the gestational week, variability in measures, and sample characteristics seem to be connected to the predictive value of gestures on later language development and could explain mixed findings.

To summarize the literature on both children with BI and PT children, both groups exhibit delays in their gesture production, but also considerable heterogeneity exists. Variability in children's gesture production does predict later changes in speech again for both groups. The fact that variability in gesture precedes and predicts later variability in speech raises questions regarding the roots of the variability in children's gestures in the first place (Iverson & Goldin-Meadow, 2005).

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5. How and why do gesture and speech go hand in hand?

The findings reviewed above support the hypothesis that gesture precedes and predicts upcoming changes in speech both for TD children and children with atypical developmental trajectories—specifically children with BI and PT children. But why and how does gesture predict later changes in speech? One possibility is that the relationship between speech and gesture is coincidental. For example, according to Trauner et al. (2013), children with right hemisphere injury might exhibit a delay in both their gesture production and their speech, but the reason might not be due to a specific underlying link between the two systems. Instead, the relation might be purely due to children with BI's difficulties with integration, which might be reflected in their difficulty integrating gestures with speech but also integrating oral language into meaningful stimuli. Gestures might be related to speech because gesture use is a general indicator of children's communicative skills. In other words, children who are communicatively more advanced might use a wider range of gestural meanings early on and then proceed to overall better language skills. However, empirical evidence does not support these two types of arguments. As discussed above, specific gestures selectively predict specific aspects of language development (Rowe & Goldin-Meadow, 2009a).

Recent findings suggest that gesture might play an active role in children's language development and gesture and speech might be causally related. Specifically, gestures might provide children with an opportunity to practice different constructions before they can do so in speech. This practice might play an active role in children's language learning. Supporting this view, LeBarton et al. (2015) conducted an 8-week at-home intervention study with 18 months old children. Children who were told to point to different objects that were named by the experimenter increased the number of meanings they conveyed via gestures when interacting with the experimenter and their caregivers compared to those who were simply exposed to the object names. Moreover, children who were told to gesture also had a larger spoken vocabulary at a follow-up visit. These findings are consistent with the literature on older children. Children perform better on various math tasks when they are asked to gesture compared to when they are told not to gesture (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; for a review of the causal role of gesture in cognition, please see Goldin-Meadow & Wagner, 2005).

The picture of the link between early gestures and spoken language is incomplete without taking parental input into account—caregivers might be a critical component of the active role of the gesture. The interaction between parental input and children's own gesture use could create cascades on later language learning, or parental input may moderate the link between children's gestures and later language development. Parents not only respond to their children's gestures but also translate them—right after children produce a gesture, mothers typically produce a word that could be considered a translation of the gesture (Marcos, 1991; Olson & Masur, 2013, 2015). Upon seeing children producing a gesture + speech combination, parents produce a two-word utterance in speech, translating the combination. Such combinations are more likely to enter children's speech later on compared with those that are not translated (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Thus, parents might

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play a crucial role in mediating the relationship between gestures and upcoming changes in speech (Özçalışkan, Limia, & Dimitrova, 2017). Little is known about the role parents play in scaffolding the relationship between speech and gesture in children with BI or PT children, although patterns similar to what is observed in typically-developing children have been observed in other atypically developing children, such as children with ASD (Dimitrova et al., 2016).

Finally, it is also possible that gesture and speech remain together due to different reasons in different populations. While motor difficulties might limit children with BI's or PT children's ability to produce complex gestures and their later production of complex utterances, parents might play a more important role for these children than typically developing children. We next discuss potential sources of variability in children's gesture profiles.

6. Sources of variability in gesture profiles: Antecedents of early gesture

While the prior literature heavily emphasized characterizing the gestures, relations among speech, gestures, and their consequences, less is known about the *antecedents* of these relations. One possible antecedent is children's general cognitive skills. Overall, the cognitive capacity of children might relate to gesture use (Özer & Göksun, 2020b). Variability in gestural communication might also be tied to children's interest and engagement with others, that is, social engagement. Indeed, in typical development, the earliest gestures infants produce (e.g., giving, showing, or requesting gestures) around 8−10 months of age are primarily produced to direct the communicative partner's attention (Bates, Camaioni, & Volterra, 1975). Infants' joint attention abilities significantly correlate with their gesture use as early as 10 months of age (Salo et al., 2018).

Motor difficulties are another factor that might relate to the use of gestures in children with atypical trajectories. Children with BI present varying degrees of hemiparesis in the contralateral hand, with some studies also reporting difficulties in the ipsilateral hand. Such motor difficulties might relate to difficulties in producing certain kinds of gestures—for example, complex, iconic gestures that are seen in gesture-speech combinations expressing complex sentences (Özçalışkan et al., 2013). Supporting this view, PT infants' motor skills are related to their delays in language learning (Benassi et al., 2016; Sansavini, Guarini, & Caselli, 2011). PT infants who produced pointing gestures at 12 months had higher scores on motor scores on the Physical Development Index (Suttora & Salerni, 2012). Benassi et al. (2016) also found that fine motor skills at 12 months were related to gesture production in extremely PT infants.

Finally, rather than attempting to isolate the aforementioned factors as individually predicting gesture production, it is important to acknowledge that cascading effects emerge among early abilities (Iverson, 2021) and predict later developments in gesture and speech. For example, in a recent study, we found that visual processing of 12- to 16-month-old infants mediates the link between infants' motor skills and early communicative behavior, including gestures. This relationship among motor skills, visual processing, and language development was particularly stronger for PT infants than TD infants, suggesting a potential developmental cascade (Kobaş et al., 2022). Further, hand-motor difficulties might limit the social engagement

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children have with their surroundings as well as their ability to produce complex gestures, all of which might combine to have downstream interactive effects on later developments in speech.

7. Sources of variability in gesture profiles: Seeing others' gestures

Gestures that children see play an important role in their early communicative development, but less is known about how children process gestures others produce in these early years. Existing evidence suggests that even one-word speakers (ages 1−2.5) can understand others' gestures both when a gesture is redundant with speech and also when gesture substitutes speech (e.g., Morford & Goldin-Meadow, 1992). Behaviorally, children start to understand iconic gestures that represent entities at around 3 years of age (Stanfield, Williamson, & Özçalişkan, 2014) and iconic gestures that represent actions and events at around 4 years of age (Glasser, Williamson, & Özçalışkan, 2018). The ability to integrate information across speech and gesture continues to develop with age (Sekine & Kita, 2015; Thompson & Massaro, 1994).

Children's primary communication partner in the early years is their parents. Research on TD children suggests that starting from the first year of life, infants respond to parental gestures with gestures (Kuchirko, Tafuro, & Tamis LeMonda, 2018). Overall, parents who gesture more have children who gesture more (Liszkowski, Brown, Callaghan, Takada, & De Vos, 2012; Rowe, Özçalışkan, & Goldin-Meadow, 2008). In fact, parent gesture use predicts children's gesture use at 14 months, which in turn explains socioeconomic status related discrepancies in children's vocabulary development at school entrance (Rowe & Goldin-Meadow, 2009b).

Almost nothing is known about the role of parental gestures in children with BI and PT children in children's communicative development. Similar to their role in production, gestures of others might play a similar role for atypically developing children than children with typical developmental trajectories. However, it is also possible that infants who start atypical trajectories might benefit more from high-quality environmental experiences, such as parental gesture input, than children following typical developmental trajectories (DeMaster et al., 2019; Gueron-Sela et al., 2015). According to the differential susceptibility hypothesis, PT infants are more vulnerable to negative environmental experiences; however, positive environmental experiences may benefit these children more than FT children (Gueron-Sela et al., 2015). As argued by the differential susceptibility model, enriched experiences such as positive parent−child relations can be a supportive neuroprotective factor for PT infants (DeMaster et al., 2019). Parents of PT children may modify interactions with their PT children as a result of these children's higher need for arousal regulation or information processing (Eckerman et al., 1994). Supporting this view, Gueron-Sela et al. (2015) reported that, on a measure of social competence, PT exposed to high maternal stress performed worse than PT exposed to low maternal stress, and the difference was larger for PT than TD children. These findings might extend to other domains and PT children might also benefit from caregivers' gestures to a greater extent as well. Alternatively, for children with developmental

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challenges, it might be difficult to integrate speech and gesture, so they might benefit less from the gestures of others.

Thus far, to our knowledge, only one study examined the role of parental gestures in PT children's language development. At 14 and 20 months, parents of PT infants produced fewer gestures than parents of FT children, with no difference in their verbal input at 20 months. Preliminary analyses also suggest that children's gesture use at 14 months (based on the parental report) may mediate the relation between parents' gestures at 14 months and children's expressive vocabulary at 20 months only for the PT group. Hence, parents' gestures seem to be more beneficial for the PT group, which is consistent with the differential susceptibility hypothesis (Doğan et al., 2021).

While there is no existing data on the differential role of parental gestures in children with BI versus TD children, an experimental study manipulated gestures that children see (Demir, Fisher, Goldin-Meadow, & Levine, 2014). When presented with stories in different conditions—one where the storyteller produced co-speech gestures and one where there were no gestures, children with larger lesions showed more improvement when stories were presented with a co-speech gesture than children with smaller lesions and TD children. Whether the greater contribution of gestures can be attributed to children's neurological differences, as per differential susceptibility, or simply lower language performance remains unclear. For example, work on other children with particular difficulties in language, such as children with specific language impairment, shows that these children make better use of information provided in gesture than TD children in various language tasks (Botting, Riches, Gaynor, & Morgan, 2010; Kirk et al., 2011). Younger, TD children who have lower language skills also benefit from gestures to a greater extent than older children (McNeil et al., 2000). There might also be bidirectional relations between children with atypical developmental trajectories and their parents. Children's language competence is known to relate to caregivers' gestures to a greater extent when the child's language skills are more limited (e.g., Iverson et al., 2006; Talbott et al., 2015). Overall, while seeing others' gestures, particularly their caregivers' gestures, might benefit children with BI and PT children to a greater degree than TD children, the exact mechanism underlying this relationship remains unclear.

8. Lessons to be learned from children with BI and PT children

What are the theoretical contributions of focusing on gesture-speech relations in children with atypical developmental trajectories? Examining children with atypical developmental trajectories enables us to examine relations between speech and gesture in populations that present wider variability that is not otherwise observed in TD children—variability in their environmental experiences, child-level profiles (e.g., motor skill), and in neurological profiles. Because research with children with atypical trajectories reveals that these children do not form homogeneous groups, this in turn highlights the need to acknowledge the great variability in all children's gesture profiles. The variability might be due to both external (e.g., environmental experience, parental input) and internal factors (e.g., different cognitive profiles, general communicative ability, motor skills, attention processes, early visual-spatial

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abilities). The extent of variability might be greater within the atypical group is higher compared to TD children, which in turn might lead to increased variability in gesture use and increased predictive role of gesture use for later development for atypical children compared to TD. By examining this variability in gesture use, we can specifically address the interactive effects of gesture use with other sociocognitive processes and can inform delays and possible problems in atypical groups' language development. A focus on the atypical population is advantageous because many developmental studies with TD children suffer from possible limitations as the individual variability across these children is limited. Stated differently, reduced variability in TD children is associated with restricted range issues, which in turn limits our analytical ability to explore associations between various factors. Overall, while group-level studies are informative, individual-based analyses should also be considered for future research as children with BI and PT exhibit different social and cognitive profiles that may lead to different gestural profiles. Individual variations in using cognitive resources play a key role even in how TD children benefit and learn from gestures (e.g., Kartalkanat & Göksun, 2020; for a review, see Özer & Göksun, 2020b). Thus, research on atypically developing populations might raise broader cross-cutting questions regarding all children's gesture development.

In terms of its practical implications, examining gestures alongside speech might provide a complete view of atypically developing children's communicative skills. Due to various reasons, even when there might be delays in speech, gestures might provide parents or clinicians with a better understanding of the nature of the children's delay. Gestures could also be used for early diagnosis. Individual differences in children's gesture profiles are present even when differences in speech are not. These differences in gesture use predict later developments in speech (Rowe & Goldin-Meadow, 2009b). This raises the possibility of considering children's gestures as a diagnostic tool. Finally, if gesture indeed plays a causal role in children's language development, then it could also be leveraged as an intervention tool more broadly (Sauer et al., 2010).

9. Future directions and conclusion

Many questions remain unanswered regarding gestures in children with atypical developmental trajectories. How can the rich research on gesture established by Goldin-Meadow's work shed further light on our understanding of atypically developing children? First, most of the previous research has focused on children's production of gestures. Research on gesture comprehension examines how seeing others' gestures might relate to language processing, particularly the gestures of primary caregivers (Kuchirko et al., 2018; Liszkowski et al., 2012; Rowe et al., 2008). Future studies on atypically developing children would benefit from examining gesture comprehension—especially in the context of parent−child interactions. Second, focusing on later years, particularly school years, could be particularly informative since both children with BI and PT children are shown to exhibit significant difficulties in academic performance. Research on TD children shows that gesture continues to play a central role in academic settings (e.g., Cook & Goldin-Meadow, 2006). Thus, a fruitful area for future

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research would be on gesture comprehension in children with atypically developing children and particularly in content-rich domains, such as mathematics, that children struggle with. Third, research on children with BI and PT children focused primarily on specific subpopulations. For the former, the emphasis has been on children with peri- or prenatal brain injuries. Less is known about how gesture-speech integration might vary in children with different ages of lesion onset profiles. Widening the range in terms of age of lesion onset is important since such studies might reveal further information about the plasticity of the relation between gesture-speech. For the latter group, the emphasis has been on early preterm birth. Much less is known about gesture−speech relations in children with late preterm birth (34−36 weeks), despite late preterm-born children constituting the majority (75%) and the fastest-growing group of all PTs. Finally, the majority of the literature focused on standardized tasks to assess gestures, such as parental reports. Future studies would benefit from examining gestures in the context of both experimental and naturalistic settings.

In conclusion, following the footsteps of Susan Goldin-Meadow, this review discussed the role of gestures in the early language development of two atypically developing groups—children with BI and PT children. The studies presented suggested that the close link between gesture production and early language development remains intact even in atypical populations where children progress through development with unique challenges—through thick and thin. Notably, we highlighted a wide heterogeneity in these populations due to higher variability of child internal (e.g., neurological profiles, different cognitive profiles, motor skills, attention processes) and external (e.g., parental input) factors than TD children. These heightened sources of variation in children with BI and PT children can allow researchers to examine the unique and interactive functions of gestures with speech in early atypical developmental trajectories. Taken together, these findings on children with BI and PT children not only inform us about gesture production and gesture-speech integration in atypically developing children, but also have the potential to contribute to our broader understanding of the role of gesture in children's communicative development.

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