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Parental Speech Varies by Infant Motor Skills and History of Prenatal Stroke

By

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In recent years, researchers have increasingly investigated relations between motor development in infancy and other areas of development, particularly social cognition and language acquisition (Libertus & Hauf, 2017). The development of gross motor skills – infants' ability to sit, crawl, stand, and walk - is not only closely associated with children's exploration of physical world (Libertus & Hauf, 2017; Adolph & Joh, 2007), providing new opportunities for learning about their environments (Van Hofsten, 2009), but is also shown to be related to the kinds of social interactions they experience and the language they hear and produce. For example, when infants transition from crawling to standing (or supine to unsupported sitting), they are able to use their now-free hands to show and share objects with caregivers – eliciting novel and infant-led bouts of shared attention (Karasik et al., 2012); additionally, postural changes provide infants with new visual vantage points that affect infants' social experiences (Kretch et al., 2012). Concurrently, development in motoric abilities relate to changes in infants' linguistic environments – upright postures, for example, seem to support the emergence of babbling with consonants, a more difficult form of babbling that parents respond to differently than to vowel-only babbles (Iverson, 2010). Indeed, how parents *respond* to their developing child may be even more important to early language development than infants' independent linguistic skills, motoric abilities, or chronological age: parents' perception of their child's maturity, which is heavily influenced by infants' motoric skills, is a powerful predictor of how parents interact with and speak to that child (Suttora & Salerni, 2011).

Motor Development and Language Development

Researchers have consistently found positive relations between motor development and language development. A classic work by Lenneberg (1967) demonstrated that infants tend to reach their major language milestones in a fixed order that is closely tied to chronological age - in addition, Lenneberg noted a “remarkable synchronization” between language milestones and motor skill milestones. For example, at 6 months, infants start to sit independently and also produce babbling that resembles single-syllable utterances; at 12 months, most infants can walk with support and also begin to produce simple words (e.g., *mamma or dadda*).

The onsets of walking and crawling have been studied in exploring this motor-language relation. In one longitudinal study by Libertus and Violi (2016), 3- to 5-month-old infants completed eight weekly sitting and grasping assessments. At 10 and 14 months of age, parents completed questionnaires about their infants’ language and vocabulary development. Results suggested that 3-5-month-old infants with faster rate of learning to sit independently (reported as sitting slope) had significantly larger receptive vocabularies at both 10 and 14 months. Oudgeoeg-Paz et al. (2015) also found that the mastery of sitting and walking (assessed by parent report) were both predictive of children’s spatial language at 36 months. Another longitudinal study (Walle & Campos, 2013) asked parents to complete a questionnaire on their infants’ locomotor and language development every two weeks from 10 to 13.5 months. Results suggested that the acquisition of walking was associated with both productive and receptive language - this study was also replicated by He et al. (2015) with Chinese infants exposed to Mandarin.

The studies described above focused on typically-developing populations. Research with children experiencing motor delays provide further support to the motor-language link. A study by LeBarton and Landa (2019) explored motor skills among both infants with high familial risk of autism spectrum disorder (as indexed by having an older sibling already diagnosed with ASD) and those with low risk of ASD at 6 months. Results showed that infants’ motor skills at 6 months among those in the high-risk group predicted both the likelihood of an ASD diagnosis at 24 – 36 months as well as productive language at 30 and 36 months. Another study, using meta-analysis which included data from 1953 infants with ASD, found that motor ability differed significantly between typically-developing children and children with ASD, and when examining data from autistic children alone, the relation between motor development and language development was significant (West, 2018). These findings suggest that motor delay, as an early emerging component of the ASD phenotype, plays an important role in later language development. Altogether, current research suggests that motor development is a critical predictor of later language development across typically-developing and certain clinical populations. Further, the fact that motor development, above the impact of age, relates to later language outcomes suggests that it is those experiences of moving on one's own that cascades into linguistic shifts, rather than a third factor that might relate to both (such as neural maturation).

Not Merely the Result of Neuromotor Maturation

The consistent results relating motor development with language development drive further inquiries: what is the explanation for this correlation? A classical view of "general maturation" would suggest that different domains of development are affected by the general maturation process equally (Gesell & Thompson, 1934). The view regards development highly dependent on chronological age, and consistent across context and populations. However, many researchers do not find this explanation compelling (Bates et al., 1979; Libertus & Violi, 2016; Iverson, 2010). Libertus and Violi (2016) explain that general maturation view assumes a bidirectionality between language and motor development due to the underlying maturation being shared, but this has not observed in later research. In other words, studies such as Wang et al. (2014) only report that motor skills predict later language skills, but not the other way around.

Iverson (2010) also explicitly claims that language development is not merely the consequence of neuromotor maturation. Instead, she argues that motor development, especially the achievement of major milestones, provides unique opportunities for children to practice skills needed for language – in particular, by altering interactions with people and objects.

As these authors argue, there are more complex mechanisms underlying the motor-language relation than simple general maturation. Oudgenoeg-Paz et al. (2015) found that infants' exploratory behavior using self-locomotion mediates the relation between the onset of independent walking and later production of spatial language. Other studies show that infants who can stand independently spend significantly more time interacting with their caregivers as well as available toys than do non-standing infants. These interactions are also more complex than children's earlier social bids - standers are more likely to produce directed gestures, initiating joint attention by directing a caregiver's attention to certain objects (Clearfield, 2011) and object sharing (Karasik et al., 2011). This difference could be attributed to the fact that walking is a more efficient way of getting around than crawling – walkers cover more ground in less time than crawlers (Adolph & Tamis-LeMonda, 2014). Thus, children have more opportunity to initiate the interaction, and are able to free their hands to make communicative gestures – a critical component of developing language (e.g. Iverson & Goldin-Meadow, 2005). Infants' motor skills dramatically impact their social environments.

Caregiver Speech as Another Possible Mediator

Caregiver speech is another possible mediating factor linking the relation between language and motor development. Evidence reviewed above suggests that infants' developing motor skills allow them to experience and initiate new and more frequent bouts of social interaction, consequently eliciting speech from caregivers. Further, previous studies suggest strong positive relations between caregiver speech and children's language development in different aspects of language including lexical (Barret et al., 1988, 2009; Renari et al., 2020), syntax (Hoff-Ginsberg, 1986, 1990), length of utterance in morphemes (Dollaghan, 1999). Another influential study by Huff (2003) suggests that the positive relation between family SES and children's language development is mediated by caregiver language. However, the degree to which parent speech is influenced by children's changing motor skills is underexplored. If caregiver speech mediates the motor-language relation, this will provide useful insight to the long-term development of those children with developmental disabilities and severe motor delays.

There are a handful of studies that shed some light on the possible link between children's motor development and caregiver speech. A study by Wen et al. (2012) examined parent-child interactions during unstructured play sessions, both with typically-developing children and children at high risk for a diagnosis of ASD. When adjusted for age and developmental level, at-risk infants were less "lively" motorically, and had lower parent-reported motor activity. Simultaneously, parents' speech to their high risk children during the play session contained more directiveness and less sensitive responding compared to speech heard by low-risk infants. Another study examined the caregiver speech directed at severely preterm infants (Suttora & Salerni, 2011). Specifically, a semi-structured play session of infant-parent dyad was recorded at 6, 12, 18 and 24 months of corrected age. Experimenters assessed different factors such as caregiver speech, prelinguistic and verbal behavior, and psychomotor development (assessed using Bayley Scales of Infant Development). Here, earlier achievement of motor skills at 12 months predicted the verbal lexical variability in caregiver speech at 18 months. That is, motor achievement related to later caregiver speech, above and beyond general shifts in caregiver language expected as infants age. This effect may be driven by parents' perception of their children's maturity. Indeed, mothers report that they view their infants as being noticeably more independent when they start walking (Biringen et al., 1995). Another piece of anecdotal evidence comes from a study (Walle & Campos, 2013) where parents reported that their children "suddenly became a little person" and began to have personality when they started walking. The perception of maturation could be an important signal for parents to alter communicating patterns. While not the primary question of this study, later motor development may also relate to less mature child language, which caregivers match in complexity.

Current Study

The current study aims to explore the relation between motor development and language development in both typically-developing and motor-impaired children – specifically, children who suffered a perinatal stroke and have varying degrees of motor impairment, from minimal to significant. The data were collected through coding videos of naturalistic parent-child interactions in families' home. These videos are a part of larger project in University of Chicago – Language Development Project (LDP). Because we are interested in early motor skills, we will focus on recordings collected when children were 14, 18, and 22 months of age.

Many previous studies have measured motor skill using parent-reported milestone ages (e.g., Walle & Campos, 2013) or systematic motor development scales, often in laboratory settings (e.g., Veldman et al., 2019). However, motor skills were not formally assessed at this age in the LDP. Thus, we have created a motor development coding scheme based on several existing schemes designed for use with naturalistic data. First, the Ecological Momentary Assessment (EMA) method was applied. This method was first developed by Franchak (2019) to assess infants' naturalistic, everyday motor experiences. In that study, parents reported their infants' current body posture by responding immediately to prompts sent over text (at varying times, six times a day) over seven days. The method avoids reliance on caregiver's memory, and captures body postures across daily routine (rather than postures seen in-lab, which may not be representative). In the present study, we adapted the EMA and collect 14 "snapshots" of infants' posture - one every six minutes over a 90-minute video. The criteria for 6 body postures is based on Franchak (2019) (prone, supine, held, reclined, upright, sit). We additionally include the category "kneel" as this is occasionally produced by children in our dataset.

In addition to the EMA coding, three five-minute windows (15 minutes in total) were selected in each 90-minute video for more detailed analysis. Changes in posture, time spent in each posture, as well as time spent locomoting were coded. Taken together, this intensive coding captures infants' ability to maintain postures on their own, to switch postures independently (an important aspect of postural control), and their ability and propensity to move around their environments, potentially initiating bouts of social interaction. For the language data, type-token ratio are included. Exploratorily, we also examined these additional aspects of parent speech : sum of questions parents asked and mean length of sentence.

We had two main hypotheses. First, there will be a positive association between motor skills and lexical variability in caregiver input overall, replicating the findings from Suttora & Salerni, 2011). Second, children from our clinical population will have worse motor skills on average compared to typically-developing children. Specifically, between 14-22 months, we predicted that primary aspects of motor development, such as the ability to sit, stand, and walk independently, will vary little for the TD children, while the children in the clinical group will show more variability and more development across these months. This predicted difference will make these children particularly more vulnerable to low-quality caregiver language input at a time that is critical for language development.

Method

Participants

Thirty children (15 typically-developing children and 15 children with an acquired brain injury due to perinatal stroke) were randomly selected from the database, and were coded at three different ages: 14 months, 18 months and 24 months. Each timepoint contains a 90-minute naturalistic recording of families in their homes.

Measures

Motor Development

Ecological Momentary Assessment (EMA). Within each 90-minute video, infants' body postures were recorded every six minutes. Thus, body posture was coded 14 times during each visit, for a total of 42 "posture snapshots" per participant. There were 7 categories of posture that we coded: held, sit, reclined, prone, supine, upright, and kneel. The criteria for identifying each were the same as the study by Franchak (2019) for the first six postures. Additionally, we coded "kneel", since several infants produced this posture. Supine was recorded when the infant is lying on the back. Held was recorded when if infant is held by their caregiver; sitting on caregiver's lap was also coded as held. Sit was recorded when the infant was in a seated position with back perpendicular to the ground. Reclined position refers to posture when infant is lying tilted back at a 45-degree angle (between sit and supine). Prone refers to any position with the infant's belly facing towards the ground. Upright is recorded when the infant is standing or walking. Finally, kneeling was recorded when the infant was using their knees to support the majority of their weight.

We additionally identified, for sitting and upright postures, whether the infant was primarily maintaining the postures themselves (e.g. standing independently) or was primarily being supported (e.g. sitting in a high chair).

Posture Switch. Every self-initiated posture switch was recorded within three randomly-selected five-minute time windows for each video. Specifically, whenever infants change from one category of posture to another without help from parents, that change as well as the time stamp was recorded.

Locomoting. In the same three 5-minute time windows, the amount of time the infant spent independently locomoting – walking, crawling, or scooting - was also recorded. Locomotion was only coded if the infant makes at least 5 consecutive "steps". Bouts of locomotion were separated by at least 3 seconds of stillness. The 3-s stop will mark as the end of one locomotion bout.

The detailed coding schemes with multiple examples is attached at the end of the paper.

Caregiver Speech

Previous research suggests that caregivers' quantity of and lexical diversity in speech shift with developmental time in response to aging (and, as we argue, motoric ability) (Elias, Hayes, & Broerse, 1988; Fraser & Roberts, 1975). Therefore, type-token ratio (dividing the total number of different words in the total utterance) number of parents' questions (total number of questions toward children), mean length of utterance (the average words in a sentence) at 34 and 38 months were used to examine differences in linguistic input across timepoints and populations. The reason why maternal speech data at a later timepoint were used is because that the previous work by Suttora and Salerni (2011) also indicated a predictive relationship

Results

Motoric Ability

Several differences emerged in motor skills between the typically-developing children and those who had suffered perinatal strokes. TD children spent significantly more time staying unsupported upright (*M* (TD) = .428, *SD* (TD) = .188; *M* (BI) =,248, *SD* (BI) = .272; p = <.001), while BI children spent significantly more time sitting (*M* (TD) = .148, *SD* (TD) = .153; *M* (BI) =.334, *SD* (BI) = .286; p < .001). TD children also switched postures significantly more often than BI children (*M* (TD) = 20.44, *SD* (TD) = 9.47; *M* (TD) = 20.44, *SD* (TD) = 9.47, *p* < .001), and produced significantly more postures than BI children in total (*M* (TD) = 38.09, *SD* (TD) = 13.46; *M* (BI) = 25.49, *SD* (TD) = 13.46).TD children spent more time walking independently than BI children (*M* (TD) = .099, *SD* (TD) = .065; *M* (BI) =.062, *SD* (BI) = .079; *p* = .017). Both BI Children and TD walked the most at 22 months (*M* (TD) = .117, *SD* (TD) = .072; *M* (BI) = .097, *SD* (BI) = .074).

Motor measure	Group	Visit 1	Visit 2	Visit 3
Proportion of time spent unsupported	TD	.677 (.13)	.686 (.22)	.662 (.16)
	BI	.563 (.20)	.697 (.20)	.732 (.20)
Number of postural switches	TD	20.13 (8.07)	21.00 (11.69)	20.20 (8.93)
	BI	13.60 (11.89)	10.47 (6.36)	14.73 (11.82)
Proportion of time spent locomoting	TD	.098 (.06)	.099 (.07)	.130 (.078)
	BI	.032 (.06)	.073 (.08)	.110 (.07)
Proportion of time spent walking	TD	.093 (.06)	.088 (.06)	.117 (.07)
	BI	.022 (.06)	.066 (.08)	.097 (.074)

Number of walkers	TD	14 (93%)	14 (93%)	15 (100%)
	BI	3 (20%)	9 (60%)	13/15 (87%)

Parental Speech

Parents of TD children had significantly higher type-to-token ratios in their speech than did parents of BI children at both 34 months (p = .018) and 38 months (p = .0478), and the difference was larger at 34 months. (*M* (TD34) = .179, *SD* (TD34) = .108; *M* (BI34) = .137, *SD* (BI34) = .095, p = .018); (*M* (TD38) = .163,   (TD 38) = .067; *M* (BI38) = .140, *SD* (BI38) = .028, p = .0478). BI Parents asked more questions than TD parents, but this difference was only significant at 34 months (M (*TD*34) = 238.50, *SD* (TD34) = .151.99; *M* (BI34) =326.24, *SD* (BI34) = 112.68, p = .003).

Motor Skills, Group Status, and Parental Speech

To address our hypothesis about a relation between group status, motor skills, and parental speech, we first ran linear regressions with group status, age, and motoric ability as fixed effects variables, subject as a random-effects variable, and different aspects of parental speech as outcome variables. When combining the TD and BI data together, group status predicted parental speech more than almost any aspect of motor skills. The only significant relation between motor skills and parental speech, after controlling for group status, was the proportion of time spent walking (*M* =.08 , *SD* =.075) and sum of parents' questions at both the 34 month (*M* = 280.90, *SD* = 140.75, p = .035) and 38 month timepoints (*M* = 308.60, *SD* = 168.42, p = .045), such that more time spent in walking got more questions from their parents at both 34 and 38 month. No other significant correlations were found.

When separating the TD and BI data, results showed that for TD children, there was a significant correlation between the number of postural switches (*M* = 20.44, *SD* = 9.74) and the sum of parents' questions at the 34 months (*M* = 94.53, *SD* = 36.74; R = .32, *p* = .034) and 38 months (*M* = 294.67, *SD* = 200.18; R = .31, *p* = .040). Number of switches is also significantly related to mean length of parent utterance at 34 months (*M* = 2.03, *SD* = .83; R = .40, *p* = .007) and marginally 38 months (*M* = 1.48, *SD* = .40; R = .28 p = 0.061), and the sum of parent's questions in 34 months (*M* = 294.66, *SD* = 200.18; R = .32, *p* = .034) and 38 months (*M* = 238.60, *SD* = 151.99, *p* = .040).

For BI children, proportion of time spent locomoting related to parents' type-to-token ratio (R = .38, *p* = .013) and number of questions at 34 months (R = -.33, *p* = .031). No other significant relations between motor measures and parental speech were found for children in this group.

Discussion

Children's healthy motor development is of significant importance, and one reason for this is its close relations with language development found in previous literatures. The present study aims to explore the mechanism of motor-language relation -- whether parental speech is a mediating factor. Studies have long demonstrated a relation between parental speech and children's language development. If the relation between parental speech and children's motor development could be established, it would support the parental speech as an important mediating factor and would be important evidence to inform parents, clinicians, and teachers of children with motor delays. The proposed mechanism was that children's motor development is related to parent's perception of their children's maturity. Parents tend to consider children with better motor skills more mature and speak in a more complex way to them. We proposed two hypotheses. First, that brain injured children would have worse motor skills compared to typically-developing children; second, that there would be a positive correlation between parental language input and children's motor skills, and the brain injured children are more vulnerable to low-quality parental speech.

In agreement of earlier findings (Kidokoro et al, 2014), the present study finds evidence of motoric delays using a new coding scheme with naturalistic interaction. using a new coding scheme with naturalistic interaction video.They actively switched body posture significantly more often, had significantly more total postures, and spent more time locomoting (including walking) than did brain-injured children. Although they spent similar amounts of time in unsupported postures, typically-developing children spent more time upright – a more difficult posture, while brain-injured kids spent more time sitting – a relatively easier posture which requires less effort and less balance. Most of the typically-developing children coded for this project were able to walk independently by the age of 14 months, while there was much larger variability among brain injured children. Several children in the clinical group still were not able to walk by the age of 22 month. Data showed another interesting pattern: when children in the clinical group were not yet able to walk independently, "scooting" was a common locomotion method for moving around. Some of brain-injured children are adept in using "scooting" where we to move to different places, but none of the typically-developing children use this method of locomoting. Scooting is sometimes considered to be a prelude to crawling, and provides chances for brain-injured children to explore their surrounding environment. However, compared to crawling, which requires coordination on both legs and both arms, scooting usually puts pressure on one side of body and is much slower on average than crawling.

Another major focus of the present study was the relation between motor and language development. Multiple aspects of motor skill were identified through video coding, and parental language data were obtained from existing data coded for other projects using this dataset. The motor skill data coding schemes used here were developed and used for the first time, and correlational analyses showed that different variables, including proportion of time spent upright, proportion of time walking, total number of posture switches, total number of posture are all positively correlated to each other, showing a good construct validity in general. The only measure that was not related to other measures is the "proportion of time spent unsupported". If we were coding earlier home visits, perhaps between 6 – 12 months, we would see the measure showing differences across groups and time relating more strongly to the other motor skills variables.

The correlations we conducted showed that our second hypothesis was partially supported. Specifically, when we combined the data of children with brain injury and typically-developing children all together, the proportion of time spent in walking was significantly correlated to the total number of questions parents asked at both 34 months and 38 months. The possible explanation could be that walking is sign for parent to perceive their children as being more mature and are willing to ask them more questions. Also, when they are moving around further and faster, there might be more common to say things like "where are you going? Can you get that for me. It is possible that walkers can ask more of these questions than crawlers or scooters. When we only look at the typically developing children, the sum of parents' questions was correlated to number of postural switches at both time points - when children are more motivated and able to switch postures, parents may consider them to be more mature in general. When we only observe the brain-injured children, the proportion of time spent locomoting and the proportion of time spent in walking are related to type-token ratio as well as the sum of parents' questions. Of all of the significant correlations between parental speech and motor skills, parents' sum of questions measure seems to be most related to motor skill measures. We find that there are relations between children's early motor skills and parents' later speech. It is worth noting, however, that the type-token ratio, usually considered as important measure of language complexity and variability does not to correlate to motor measure

Although not the main focus of the present study, we also included children's language data for additional analyses. We found many correlations between motor skill and *children's* speech. For brain-injured children, their total posture and the proportion of time spent in locomoting is significantly related to children's type-token ratio and children's mean length of utterance. For typically developing children, their type-token ratio is related to number of switches, total posture, proportion of time in locomotion and walking. These correlations replicated the consistent finding of the relation between motor and language development, and also confirm the new coding scheme worked well with naturalistic data. Overall, number of posture changes and total postures produced related to *child* speech, and walking related to *parental* speech, for children with brain injuries. In contrast, number of posture changes and total postures produced related to *both* parent and child speech, while walking predicted later *child* speech. These findings hint that relations between child motor skills, child speech, and parental speech may unfold differentially based on group status – that is, how much and what kinds of motoric abilities children possess relate to their own speech and the speech directed at them differ between typically-developing children and children in clinical groups.

There are two major limitations of the present study. First, there was little variability in motor abilities within the TD children, and if we started earlier, it might allow us to have variability in both groups. Secondly, for each 90-minute video, only 15 minutes were coded. Children perform very differently across the sessions; 15 minutes (three 5-minute clips) might not be representative of children's motor skills. The complete analysis of the full naturalistic video might yield a more reliable measure. Third, the coding scheme for the present study has not been used previously. Although different measures of motor skill were correlated with each other, it is necessary to test its construct validity using other popular motor skill measurements.

In general, the present project successfully replicates the previous finding on the relation between children's motor skills and their language skill. It supports our first hypothesis that children with early brain injury have lower motor skill than typically developing children. It also partially supports out second hypothesis that there is also a correlation between children's motor skills and the quality of later language input from parents.

Reference

Clearfield, M. (2011). Learning to walk changes infants' social interactions. *Infant Behavior And Development*, *34*(1), 15-25. https://doi.org/10.1016/j.infbeh.2010.04.008

Elias, G., Hayes, A., & Broerse, J. (1988). Aspects of Structure and Content of Maternal Talk With Infants. *Journal of Child Psychology and Psychiatry*, *29*(4), 523–531. https://doi.org/10.1111/j.1469-7610.1988.tb00743.x

Fraser, C., & Roberts, N. (1975). Mothers' speech to children of four different ages. *Journal of Psycholinguistic Research*, *4*(1), 9–16. https://doi.org/10.1007/BF01066986

He, M., Walle, E., & Campos, J. (2015). A Cross-National Investigation of the Relationship Between Infant Walking and Language Development. *Infancy*, *20*(3), 283-305. https://doi.org/10.1111/infa.12071

Hoff-Ginsberg, E. (1986). Function and structure in maternal speech: Their relation to the child's development of syntax. *Developmental Psychology*, *22*(2), 155-163. https://doi.org/10.1037/0012-1649.22.2.155

Hofsten, C. (2009). Action, the foundation for cognitive development. *Scandinavian Journal Of Psychology*, *50*(6), 617-623. https://doi.org/10.1111/j.1467-9450.2009.00780.x

Iverson, J. (2010). Developing language in a developing body: the relationship between motor development and language development. *Journal Of Child Language*, *37*(2), 229-261. https://doi.org/10.1017/s0305000909990432

Karasik, L., Adolph, K., Tamis-LeMonda, C., & Zuckerman, A. (2012). Carry on: Spontaneous object carrying in 13-month-old crawling and walking infants. *Developmental Psychology*, *48*(2), 389-397. https://doi.org/10.1037/a0026040

Kretch, K., Franchak, J., & Adolph, K. (2013). Crawling and Walking Infants See the World Differently. *Child Development*, *85*(4), 1503-1518. https://doi.org/10.1111/cdev.12206

LeBarton, E., & Landa, R. (2019). Infant motor skill predicts later expressive language and autism spectrum disorder diagnosis. *Infant Behavior And Development*, *54*, 37-47. https://doi.org/10.1016/j.infbeh.2018.11.003

Lenneberg, E. (1967). The Biological Foundations of Language. *Hospital Practice*, *2*(12), 59-67. https://doi.org/10.1080/21548331.1967.11707799

Libertus, K., & Hauf, P. (2017). Editorial: Motor Skills and Their Foundational Role for Perceptual, Social, and Cognitive Development. *Frontiers In Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00301

Libertus, K., & Violi, D. (2016). Sit to Talk: Relation between Motor Skills and Language Development in Infancy. *Frontiers In Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00475

Oudgenoeg-Paz, O., Leseman, P., & Volman, M. (2015). Exploration as a mediator of the relation between the attainment of motor milestones and the development of spatial cognition and spatial language. *Developmental Psychology*, *51*(9), 1241-1253. https://doi.org/10.1037/a0039572

Veldman, S., Santos, R., Jones, R., Sousa-Sá, E., & Okely, A. (2019). Associations between gross motor skills and cognitive development in toddlers. *Early Human Development*, *132*, 39-44. https://doi.org/10.1016/j.earlhumdev.2019.04.005

Wang, M., Lekhal, R., Aaro, L., Holte, A., & Schjolberg, S. (2014). The developmental relationship between language and motor performance from 3 to 5 years of age: a prospective longitudinal population study. *BMC Psychology*, *2*(1). https://doi.org/10.1186/s40359-014-0034-3

West, K. (2018). Infant Motor Development in Autism Spectrum Disorder: A Synthesis and Meta-analysis. *Child Development*, *90*(6), 2053-2070. https://doi.org/10.1111/cdev.13086

Dollaghan, C., Campbell, T., Paradise, J., Feldman, H., Janosky, J., Pitcairn, D., & Kurs-Lasky, M. (1999). Maternal Education and Measures of Early Speech and Language. *Journal Of Speech, Language, And Hearing Research*, *42*(6), 1432-1443. https://doi.org/10.1044/jslhr.4206.1432

Erratum: Affective Reorganization in the Infant, the Mother, and the Dyad: The Role of Upright Locomotion and Its Timing. (1995), *66*(4). https://doi.org/10.2307/1131788

Franchak, J. (2018). Changing Opportunities for Learning in Everyday Life: Infant Body Position Over the First Year. *Infancy*, *24*(2), 187-209. https://doi.org/10.1111/infa.12272

Hoff-Ginsberg, E. (1986). Function and structure in maternal speech: Their relation to the child's development of syntax. *Developmental Psychology*, *22*(2), 155-163. https://doi.org/10.1037/0012-1649.22.2.155

Hoff-Ginsberg, E. (1990). Maternal speech and the child's development of syntax: a further look. *Journal Of Child Language*, *17*(1), 85-99. https://doi.org/10.1017/s0305000900013118

Raneri, D., Von Holzen, K., Newman, R., & Bernstein Ratner, N. (2020). Change in maternal speech rate to preverbal infants over the first two years of life. *Journal Of Child Language*, *47*(6), 1263-1275. https://doi.org/10.1017/s030500091900093x

Suttora, C., & Salerni, N. (2011). Maternal speech to preterm infants during the first 2 years of life: stability and change. *International Journal Of Language & Communication Disorders*, *46*(4), 464-472. https://doi.org/10.1111/j.1460-6984.2011.00007.x

Wan, M., Green, J., Elsabbagh, M., Johnson, M., Charman, T., & Plummer, F. (2012). Parent–infant interaction in infant siblings at risk of autism. *Research In Developmental Disabilities*, *33*(3), 924-932. https://doi.org/10.1016/j.ridd.2011.12.011

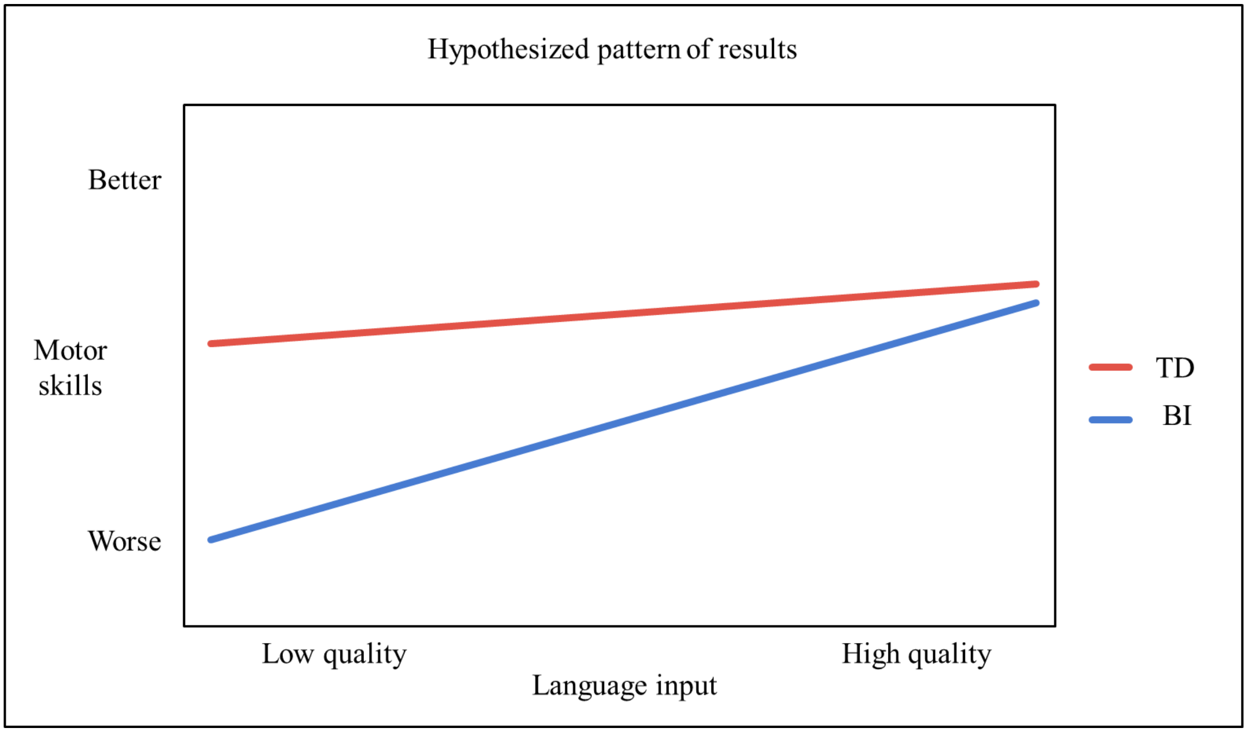
Walle, E. A., & Campos, J. J. (2013). Infant Language Development Is Related to the Acquisition of Walking. *Developmental Psychology*. Advance online publication. doi:10.1037/a0033238

Adolph, K., & Joh, A. S. (2007). Motor development: How infants get into the act. In A. Slater, & M. Lewis (Eds.), *Introduction to infant development* (2 ed., pp. 63-80). Oxford University Press.

Gesell, A. (1934). *An atlas of infant behavior: A systematic delineation of the forms and early growth of human behavior patterns. Normative series. (With H. Thompson and C. S. Amatruda.) Naturalistic series. (With A. V. Keliher, F. L. Ilg, and J. J. Carlson.).* Yale Univ. Press.

Figure 1

Hypothetical Results



Note. The figure illustrates the hypothetical relationship between motor skills and language input. TD represents typically-developed children. BI represents children with an acquired brain injury. In both groups, better motor skills will relate to higher-quality language input; however, typically-developing children will have better motor skills on average and less variability in motoric ability than BI children.

Appendix A

There are three kinds of information included in the naming of a video (e.g., P23.01.T1). The first number represents the participant's number (P23); the second number represents the time of visits ("01" represents the first visit, which is at infant's 14 month of age. Every visit is done for every 4 months); the last number indicates which part of video of the same visit: the whole visit was around 90 minutes. T1 include first 60 minuets and T2 include the rest of 30 minutes. For each participant, we are coding the video during the 1st, 2nd and 3rd visit (correspondent to their 14-month, 18 month and 22 month of age). We are coding the videos using two different methods.

Ecological Momentary Assessment (EMA)

The EMA coding method is modified from the work done by Franchak et al., (2019). We are going to capture 14 snapshots, one for every 6 minutes (at 6 mins, 12 mins, 18 mins, 24 mins, 30 mins, 36 mins, 42 mins, 48 mins, 54 mins, 60 mins at T1 and 6 mins, 12 mins, 18 mins, 24 mins at T2). The screenshot of a blank coding sheet for participant 22 is attached.

Time (mins)			Time(mins)			Time (mins)	
P22 (14 month)			P22 (18 month)			P22 (22 month)	
T1	**Posture**		**T1**	**Posture**		**T1**	**Posture**
6			6			6	
12			12			12	
18			18			18	
24			24			24	
30			30			30	
36			36			36	
42			42			42	
48			48			48	
54			54			54	
60			60			60	
T2			**T2**			**T2**	
6			6			6	
12			12			12	
18			18			18	
24			24			24	

For each of these moments, we are going to record the posture (body position) of the participant. There are 8 types of postures we are going to choose from: upright, sit, prone, supine, held, reclined, kneel, squat. The criteria for the first six posture were taken from work by Franchak et al., (2019) directly. I added the "kneel" and "squat" because they are common posture children use among the videos. And there are many literatures mentioned it as a milestone.

Held	Held will be scored when caregivers are holding infants in their arms, on their lap, or in an infant carrier. If infants are sitting or standing on a caregivers' lap and it seems that infants are mostly self-supported, the position will NOT be scored as held. Instead, it will be score as "sitting with support" or "stand with support".
Supine	Supine will be scored when infants are lying flat on the back.
Reclined	Reclined will be scored when children are lying tilted back at the 30-45 degree, such as in a car seat or swing, or when children's back are inclined to sofa.
Prone	Prone will be scored when children have their belly towards the ground, including lying face done, stationary while propped up on hands and knees/ feet. When children are in crawling position, it will be scored as "prone (crawling)".
Sit	Sit will be scored when children's back is vertical to the ground. The "independent sitting" and "supported sitting" will be differentiated. When children are mostly self-supported, it will be annotated as "independent". If the child is sitting in adults' lap, or when the posture is largely rely on other people or items, it will be annotated as "supported".
Upright	Upright is scored when infants were standing, walking or running. When children are slightly holding onto a caregiver or furniture for support, and are

	mainly self-supported, it will be scored as independent upright. If the upright position is mostly support by other people, such as when a children is sitting on mom's lap, or largely rely the sofa for support, it will be annotated as "supported".
Kneeling	Kneeling will be scored when infants have their kneels on the ground and became main source of supports. In this project, kneeling was also scored if the children have their kneel on the ground but were sitting on their heels. If the child are kneeling with only one knee, it will be annotated as "single knee".
Squat	Squat will be scored when

Notes:

1. For upright and sitting, coders will determine whether it is supported or independent. In general, coders make a judgment whether the sitting/upright position is mainly supported by the child him/herself.
2. If at certain targeted time point, the kid's posture is not clear or the child is out of camera frame, we will continue to watch the video, until the next frame where the posture is obvious and easy to identify. (e.g., If at 12 mins, the child's body position could not be identified clearly, we will continue to play the video. If at 12 mins 14 secs where the posture could be easily identified, we record the data at this time instead.
3. There are certain visits where the T1 portion does not have full 60 mins (e.g., 58 mins or 59 mins). In this case we will just code the last frame of T1.
4. At any point when the child's position is not clear or not typical, coders will make a notes on that and it will be discussed together.

15-min detailed coding

Besides the EMA coding, we will also do a 15-min detailed coding for each visit. We have decided that it would not be realistic to do the full 90-mins detailed coding for every single kid because of the time constraint. We will randomly select three 5-mins time frame to do detailed coding: active position switch, time spending in locomotion.

1. The default time frame selected are: 10-15min in T1, 34-39min in T1, 7 -12 mins in T2. However, if for certain session, the child is spending lots of time on high chair, lots of time staying outside of camera frame, or was during the structured experimenter playing session, a different time period would be selected.
2. For the 15 mins, coders will record the name of every posture and the time stamp of each posture. The criterion for each posture will be the same as EMA methods.
3. Whenever the child starts a new posture and when it was an active position switch, the new posture will be highlighted.
4. If the child first switches a position from one to another, and quick switch to the third position, we will only record the beginning and the ending position, neglecting the "intermediate posture". (e.g., if the kid first changes from supine to sit, and then quickly change from sit to upright, we will only record the "supine" and "upright").
5. If a child is out of the camera frame for more than 3 secs, it will be recorded.

Participant	Duration	Timestamp	Posture	
	0:50	12:00	upright	
	0:02	12:50	squat	
	0:14	12:52	upright	
	0:02	13:06	squat	
	0:06	13:08	upright	
	0:15	13:14	held	
	0:49	13:29	supine	
	0:05	14:18	prone	
	0:09	14:23	upright	
	0:02	14:32	squat	
	0:15	14:34	upright	
	0:04	14:49	upright	support
	0:07	14:53	upright	
	0:01	15:00	squat	
	0:30	15:01	upright	
	0:04	15:31	squat	
	0:10	15:35	upright	
	0:06	15:45	squat	
	0:27	15:51	upright	
	0:13	16:18	squat	
	0:14	16:31	upright	
	0:01	16:45	squat	
	0:14	16:46	upright	
		17:00		
	0:29	34:00:00	upright	
	0:03	34:29:00	reclined	
	0:22	34:32:00	upright	
	0:37	34:54:00	sit in lap	support
	0:27	35:31:00	upright	
	0:04	35:58:00	squat	
	0:04	36:02:00	upright	support
	0:19	36:06:00	sit	support
	0:03	36:25:00	upright	
	0:12	36:28:00	squat	
	0:06	36:40:00	upright	
	0:15	36:46:00	squat	
	1:59	37:01:00	sit	support
		39:00:00		

Besides the posture switching, we will also record the time each kid spent on locomotion within these 15 mins. Locomotion mainly includes crawling, walking, running, scooting.

1. For each locomotion, the start time and the ending time will be recorded.

2. The locomotion will only be recorded if there are at least 3 consecutive moves. (e.g., if the child only walks for 2 steps, it would not be counted as locomotion) and make noticeable displacement
3. When a kid is not moving for more than consecutive 3 seconds, it means the previous locomotion stopped. (For example, if a child walks for 10 secs, and stop for 2 sec, walk again for 6 sec, and stop for 5 sec, we count the locomotion time as 10 + 2 +6 = 18 sec.

Locomotion	Start	End	Druation
walk	12:01	12:03	0:02
walk	12:15	12:21	0:06
walk	12:41	12:49	0:08
walk	12:59	13:03	0:04
walk	13:08	13:10	0:02
walk	14:45	14:47	0:02
walk	14:53	14:56	0:03
walk	14:22	14:23	0:01
walk	14:37	14:38	0:01
walk	35:52:00	35:54:00	0:02
walk	0:19	0:22	0:03
walk	1:29	1:32	0:03
walk	2:07	2:09	0:02