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Infant Locomotion, the Language Environment, and Language Development: A Home Observation Study

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Abstract

Developmental transitions, such as the onset of walking, are associated with changes in a broad range of domains, including language development and social interactions. This study used a full-day home observation recording to compare the language environment of age-matched crawling and walking infants. Central to the study was exploring how the language environment related to vocabulary development of each locomotor group. Adult words, infant vocalizations, and parent-child conversational turn-taking were positively associated with infant vocabulary development, but only for walking infants. These findings provide further evidence for the integrated nature of infant locomotion, language development, and the social and linguistic environment.

Keywords: language development; motor development; social development; word learning; infant-adult interaction

Introduction

Research by Walle and Campos (2014) uncovered a previously undocumented finding: infant language development significantly increases following the acquisition of walking. This link has been replicated both cross-sectionally in the United States and cross-linguistically with infants exposed to Mandarin-Chinese in China (He, Walle, & Campos, in press). While these findings lend support to a link between walking and language, further study is required to help explain this relation. Specifically, it is unlikely that walking per se results in infants learning more words. Rather, walking likely impacts other factors associated with language development, which in turn facilitate infant language learning. The present study sought to examine one likely contributor: the infant language environment.

The acquisition of upright locomotion (i.e., walking) provides a number of distinct advantages to the infant over crawling in terms of motoric efficiency (Sparrow & Irizarry-Lopez, 1987), perspective (Clearfield, Osborne, & Mullen, 2008; Franchak, Kretch, Soska, & Adolph, 2011; Frank, Simmons, Yurovsky, & Pusiol, 2013), and exploration (Clearfield, 2011). In addition, the onset of infant walking has profound effects on the infant's social world. Observational work indicates that parents direct similar numbers of vocalizations to walking and crawling infants, but walking infants engage in more frequent prohibitive activities (Green, Gustafson, & West, 1980) and display greater "testing of wills" in social interactions (Biringen, Emde, Campos, & Appelbaum, 1995). Walking infants have

also been found to exhibit more vocalizations, gestures, and interactions with objects than crawling infants (Clearfield, 2011; Karasik, Adolph, Tamis-LeMonda, & Zuckerman, 2011), as well as to engage with distal objects and bid for adult attention, particularly while moving, more frequently and in different manners (Karasik, Tamis-LeMonda, & Adolph, 2011, 2014).

Although the above studies did not explore how such changes in the infant's social environment were associated with infant language development, the relation of adult-infant social interaction and language learning has been widely studied (e.g., Goldfield, 1987; Hart & Risley, 1995; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Tamis-LeMonda, Bornstein, & Baumwell, 2001; Zimmerman et al., 2009; Greenwood, Thiemann-Bourque, Walker, Buzhardt, & Gilkerson, 2010; Weisleder & Fernald, 2013). Quantities of adult-child turn-taking, child-directed speech, and child vocalizations are all positively correlated with more advanced child language skills.

Walle and Campos (2014) used naturalistic observations in a laboratory setting to examine the relation of crawling and walking infants' social environments and language development. They found that language input, parent and infant movement, and infant location differentially predicted language development for each group. Specifically, the variables were significantly related to walking, but not crawling, infants' language development. While informative, this study was limited in key ways. First, the observation was only 10-minutes in duration, making it unclear whether the data collected is representative of infants' real-world environments. Second, the observation took place in a laboratory setting and parents were purposefully distracted with a questionnaire. These constraints may have affected both infant and parent social behaviors. Observational data in the infants' natural environment and over a more extended period of time is required to lend validity to these previous findings. Information about the role of infant vocal behavior and infant-adult turn-taking in relation to locomotor development and language acquisition is also needed.

The present investigation used day-long home audio recordings to explore how same-aged crawling and walking infants' language input, vocal productions, and turn-taking were related to their receptive and expressive vocabulary development. We hypothesized that walking and crawling infants would hear similar amounts of adult speech, but

walking infants would produce more vocalizations and engage in more turn-taking bouts than crawling infants. Additionally, we predicted that these differences would be associated with differences in vocabulary size.

Methods

Participants

Thirteen 12- to 13.5-month-old infants were included in the study. Crawling infants ($n = 6$; $M_{age} = 12.68$, $SD = 0.45$) had an average of 4.90 months of crawling experience. Walking infants ($n = 7$; $M_{age} = 12.89$, $SD = 0.40$) had an average of 2.78 months ($SD = 1.67$) of walking experience. Walking infants all had at least 2 weeks of walking experience to (1) ensure proficiency of walking, and (2) because longitudinal findings from Walle and Campos (2014) indicate language gains following 2 weeks of walking experience. Average family income was approximately \$50,000. Most caregivers had a high school diploma or college degree. Six additional infants were excluded for reasons described below.

Measures

Home Language Environment Infant language environments were audio recorded using the LENA™ system. Small audio recorders were placed in pockets on the front of specially made vests. Each recorder captured up to 16 hours of audio data. Parents were instructed to turn on the recorder when the infant awoke in the morning and leave it on all day. The audio recording was analyzed by the LENA software, which consists of an automatic speech recognition algorithm trained on human-transcribed LENA recordings to apply mutually exclusive sound source labels to the entire recording (Xu, Yapanel, & Gray, 2009; Xu et al., 2008). The sound source categories include child wearing the recording, adult female, adult male, other child, overlap, electronic sounds (e.g., TV), noise, and silence. Each sound source except for silence is also labeled as either being loud and clear or as being soft and muffled; only the former were used in this study. Within adult vocalizations, the number of words is estimated. Within child vocalizations, whether the vocalization contains speech-related material (e.g. speaking, babbling, singing, cooing) or only contains non-speech-related material (e.g. crying, laughing, burping) is also automatically determined. The software also identifies what it calls conversational turns, episodes where a child speech-related vocalization and an adult vocalization are separated by no more than 5s. In the present study we focused on adult words, child speech-related vocalizations, and conversational turn counts.

Only infants with at least 10 recorded hours within a single day were included in the final sample. Two additional infants were excluded because the recording was less than 10 hours. Adult word, child vocalization, and turn counts were normalized by dividing by the number of hours of the recording ($M_{duration} = 15.23$ hours, $SD = 1.66$).

Receptive and Expressive Vocabulary Parents completed the MacArthur-Bates Communicative Development Inventory: Level 1 (MCDI) (Fenson et al., 1994). The MCDI contains a 396-item vocabulary checklist. Parents were instructed to mark words that their infant “understands” (i.e., receptive vocabulary) or “understands and says” (i.e. productive vocabulary). Extensive analyses of the internal validity and test-retest reliability for the English MCDI are reported by Fenson et al. (1994). Four additional infants were excluded because their MCDI score deviated substantially from the norming data provided by Fenson et al. (1994) (too low, receptive < 30: $n = 2$; too high, receptive > 288 or productive > 65: $n = 1$).

Locomotor Development Infant locomotor development was assessed using a motor development questionnaire (see Walle & Campos, 2014). The questionnaire asked if and when the infant had achieved specific motor transitions. Parents were instructed to refer to baby books or other records to assist in recalling the specific dates. *Crawling* was operationalized as the child self-locomoting a distance of at least twice his/her body length. *Walking* was operationalized as the child locomoting bipedally without support for at least 3 steps at a time.

Procedures

Parents were contacted from a database of families in Merced, CA and the neighboring Central Valley region who had expressed interest in participating in research. Families agreeing to take part were mailed a package containing consent documents, a demographic questionnaire, the MCDI questionnaire, the motor development questionnaire, the audio recorder, and two vests. Parents were contacted 4 days after the package was mailed to ensure receipt of the package, go over all procedures, and answer questions. Parents were instructed to complete the recording on a typical day for the child (e.g., no birthday parties, doctor appointments). The parent dressed the infant in the provided LENA-appropriate clothing and turned on the audio recorder at the start of the day. The infant wore the recorder throughout the day. Parents were permitted to pause the recording at any time during the observation, but asked to keep such pauses as minimal as possible. The parent was also instructed to complete MCDI and locomotor questionnaires on the same day as the audio recording. The parent returned all materials by mail. Participating families were offered the opportunity to review the recording from the DLP and erase specific portions that they did not wish to be included in the study, though no parent elected to do so.

Results

No significant age differences were found between the locomotor groups, $t(13) = 0.88$, $p = .40$. Walking infants had greater self-produced locomotor experience ($M = 6.83$ months, $SD = .77$) than crawling infants ($M = 4.90$, $SD = 1.15$), $t(13) = 3.61$, $p = .004$. However, total self-locomotor

experience was not related to either receptive ($r = .22, p = .48$) or productive ($r = .16, p = .59$) MCDI score.

Infant Language Environment

Crawling infants heard significantly more adult words ($M = 1497.07/\text{hour}, SD = 748.80$) than did walking infants ($M = 711.90, SD = 440.60$), $t(13) = 2.35, p = .04, d = 1.28$. Infant vocalizations did not significantly differ for crawling ($M = 84.83/\text{hour}, SD = 33.57$) and walking ($M = 120.00, SD = 50.69$) infants, $t(13) = 1.45, p = .18, d = 0.82$. Frequency of parent-infant turn-taking episodes also did not differ significantly between crawling ($M = 27.33/\text{hour}, SD = 15.35$) and walking ($M = 26.36, SD = 19.46$) infants, $t(13) = 0.10, p = .92, d = 0.06$.

Infant Language Development

Crawling and walking infants' receptive and productive scores on the MCDI were compared. Walking infants had larger receptive vocabularies ($M = 124.00, SD = 63.80$) than crawling infants ($M = 105.33, SD = 47.16$), but this difference was not statistically significant, $t(13) = 0.88, p = .40, d = 0.33$. Similarly, walking infants also had larger productive vocabularies ($M = 17.14, SD = 18.72$) than crawling infants ($M = 6.33, SD = 6.59$), but again this difference did not reach significance, $t(13) = 1.34, p = .21, d = 0.77$.

Infant Language Environment and Language Development

Six hierarchical multiple regressions were conducted to examine the relation of each language environment variable (Adult Words, Child Vocalizations, and Conversational Turns) to language development (Receptive and Productive MCDI scores) as a function of Locomotor Status (Table 1). All predictors were mean centered before being entered. The language environment variable and Locomotor Status were entered separately in Step 1; Step 2 included both variables and the interaction term. Regression equations demonstrating significant or trending interactions were graphed to examine the nature of the interaction (Figure 1).

Adult Words. A significant main effect for Adult Words predicting Receptive Vocabulary was present in Step 1. This effect dropped out in Step 2, in which Locomotor Status and Adult Words x Locomotor Status were significant and trending, respectively (Fig. 1A). For Productive Vocabulary, neither main effect was significant in Step 1. In Step 2, both Locomotor Status and Adult Words x Locomotor Status were significant predictors of infant Productive Vocabulary. As shown in Fig. 1B, the interaction was such that for walkers but not crawlers, a high adult word count was associated with significantly larger infant Productive Vocabulary.

Child Vocalizations. Child Vocalizations was significantly related to Receptive Vocabulary in Step 1, but none of the variables or their interaction were significant predictors in

Step 2. For Productive vocabulary, Child Vocalizations was a significant predictor in Step 1. However, in Step 2 this effect disappeared and a significant Child Vocalizations x Locomotor Status interaction was present. Visual inspection of the interaction (Fig. 1C) indicated that vocalizing more was associated with larger productive vocabularies for walking but not crawling infants.

Conversational Turns. Conversational Turns was a significant predictor of Receptive Vocabulary in Step 1, but was no longer significant in Step 2. Conversational Turns was a significant predictor of Productive Vocabulary in Step 1. This effect dropped out in Step 2 and a significant effect of Locomotor Status was present, as well as a significant Conversational Turns x Locomotor Status interaction. Viewing the interaction (Fig. 1D) indicated that engaging in more conversational turn-taking was associated with larger productive vocabularies for walking but not crawling infants.

Table 1: Multiple regressions predicting infant MCDI

	Receptive MCDI		Productive MCDI	
	β	ΔR^2	β	ΔR^2
Adult Words				
Step 1		.40 [†]		.22
Adult Words	.74*		.34	
Locomotor Status	.60 [†]		.57	
Step 2		.17 [†]		.49**
Adult Vocalizations	.41		-.22	
Locomotor Status	.71*		.75**	
Adult Words x Locomotor Status	.58 [†]		.98**	
Child Vocalizations				
Step 1		.40 [†]		.56*
Child Vocalizations	.66*		.71**	
Locomotor Status	-.09		.09	
Step 2		.08		.30**
Child Vocalizations	.15		-.28	
Locomotor Status	-.01		.24	
Child Vocalizations x Locomotor Status	.56		1.08**	
Conversational Turns				
Step 1		.60**		.50*
Conversational Turns	.75**		.60*	
Locomotor Status	.20		.39	
Step 2		.09		.39***
Conversational Turns	.33		-.27	
Locomotor Status	.19		.38**	
Conversational Turns x Locomotor Status	.51		1.07***	

Notes. β = standardized regression coefficient.
[†] $p \leq .10$, * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

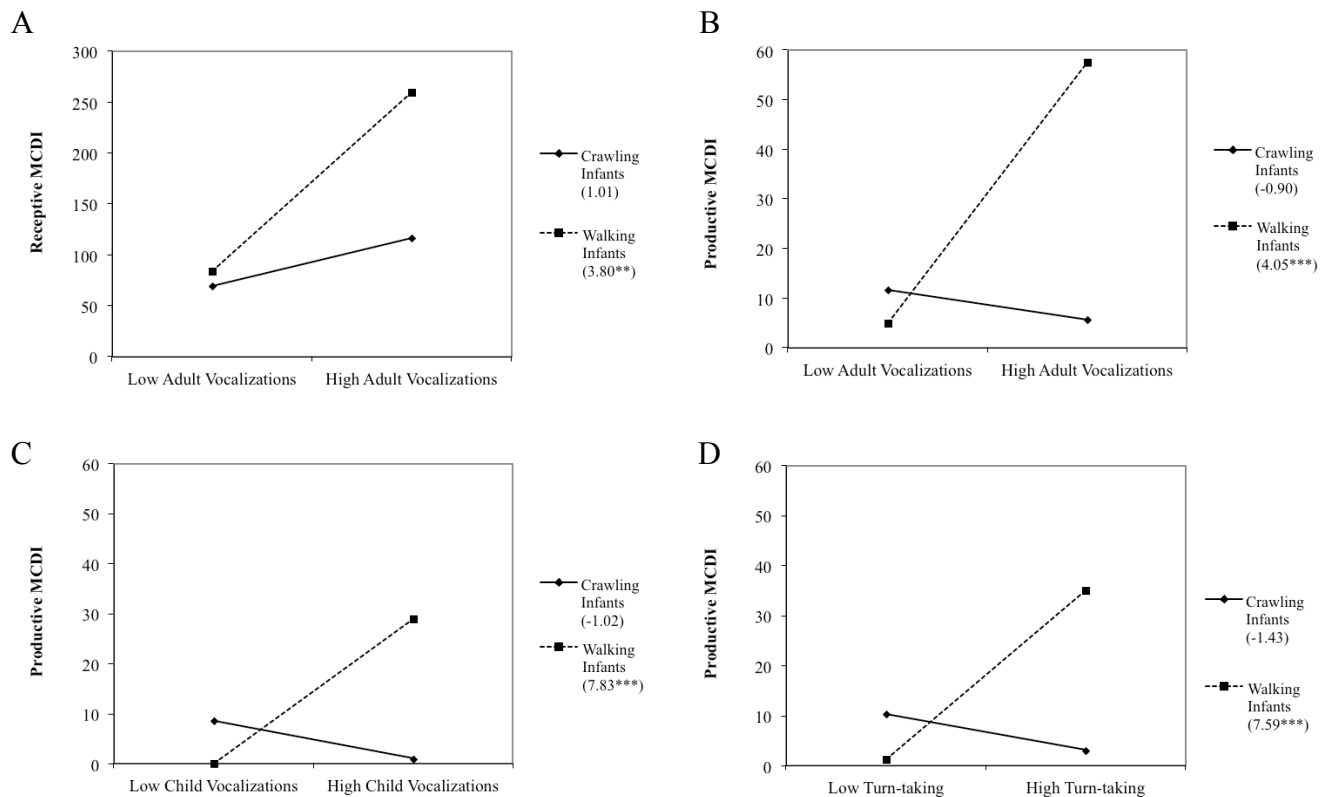


Figure 1: The graphs display infant MCDI score (indicated on the y-axis) and home language environment variables (indicated on the x-axis) at low (1 *SD* below the mean) or high (1 *SD* above the mean) levels for each variable as a function of infant locomotor status (i.e., crawling or walking). Numbers in parentheses are unstandardized simple slopes. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

Discussion

The present study sheds further light on the relation of infant walking and language development. Surprisingly, crawling infants were exposed to more adult vocalizations than were walking infants. This may be in part because walking infants produced approximately 40% more vocalizations than did crawling infants (though this difference was not statistically significant). Also contrary to our predictions, conversational turn counts were similar across locomotor groups.

A number of distinct relations were present linking the language environment with infant language development as a function of locomotor development. Greater number of adult words corresponded with increased receptive and expressive vocabulary size for the walking infants, but not for the crawling infants. Similarly, frequency of infant vocalizations and number of infant-adult conversational turns were related to infant expressive vocabulary size, but again only for the walking infants.

This study replicates and extends previous research. The overall pattern of findings is similar to many of results reported by Walle and Campos (2014). However, the use of an extensive home observation provides increased confidence in possible qualitative differences in how the language environment corresponds with language

development for crawling and walking infants. It also indicates that a number of different variables related to infants' social and language experiences, namely adult word count, child vocalization count, and quantity of child-adult vocal turn taking show this pattern of relating to vocabulary scores for walking infants but not for crawling infants, suggesting the interaction among many and various linguistic, social, and motor factors in infant development.

Future Considerations

This data set is plentiful in opportunities for future study. In-depth analysis of the child-directed adult speech would help determine if there are qualitative differences in the language used toward crawling and walking infants that may account for the differential relations with infant language development. Analysis of the content of infant vocalizations could also help to confirm differences in infant productive language skill, as well as explore possible differences in phonetic and other features of infant babbling across this developmental transition. Additionally, the turn-taking episodes represent a rich source for examining the underlying communicative nature of the infant language environment. Coding of who initiated the vocal interactions is amenable to automated analysis (Jaffe et al., 2001; Warlaumont, Richards, Gilkerson, & Oller, 2014) and would provide more specific information about how changes in infant-caregiver interaction dynamics may

underlie the observed relationships between locomotor achievement and language development.

While the data set is high in ecological validity, the number of infants observed limited our analyses. Many of the effect sizes were substantial, but not all reached significance, possibly signaling that the study was underpowered. For example, although walking infants vocalized nearly 25% more than did crawling infants, this finding did not reach significance. A similar explanation likely accounts for the non-significant differences in infant receptive and expressive vocabulary scores. Research on this relation has typically included 20-40 infants per group to account for the large variability of infant vocabulary scores (e.g., Walle & Campos, 2014; He et al., in press). A larger sample would also enable more sophisticated statistical models to explore how elements of the language environment may be interrelated with one another in predicting infant language.

Second, measures of infant language and motor development relied on parental report. Although the MCDI is a commonly used measure of infant vocabulary development, an in-lab assessment of infant receptive and productive language to corroborate parental report would strengthen the findings. For the acquisition of walking, we encouraged parents to refer to a baby book or other records, as this milestone tends to be well remembered, and also used a relatively conservative estimate of proficiency (2+ weeks of walking experience) for inclusion in the walking group. However, confirmatory observational data of infant motoric development would be preferable.

Third, and more broadly, additional research is needed to identify *mechanisms* responsible for the link between infant walking and language development. The findings suggest that the language environment plays some role in this association, but explanations accounting for the differential impact of the environment on language development remain to be studied. There are a plethora of psychological processes that may be affected by the onset of infant walking which may facilitate language development independently of, or in concert with, the language environment. For example, the onset of upright locomotion provides a clearer perspective and allows for more versatile interactions with the world (see Frank, et al., 2013; Karasik, et al., 2011; Kretch, Franchak, & Adolph, 2014). This perceptual advantage may result in changes in attentional allocation to and perceptual affordances of objects in the environment to facilitate word learning (e.g., Yu & Smith, 2012). Onset of upright locomotion has also been shown to affect the ways in which infants bid to parents with objects, which in turn affects the types of verbal responses given by the parents (Karasik et al., 2014). Freeing of the hands may also correspond with increased use and appreciation of gestural communication to facilitate word learning (see Iverson & Goldin-Meadow, 2005; Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Together, changes in perspective and gestural engagement may aid the development of joint attention skills critical for word

learning (e.g., Brooks & Meltzoff, 2008). Postural changes may also affect physiological systems underlying infant vocalization to affect child speech production (Boliak, Hixon, Watson, & Morgan, 1996). Finally, it remains possible that the walkers are overall more developmentally advanced than the crawlers. Although previous research using a longitudinal design found an effect of walking independent of age (Walle & Campos, 2014) and a growing number of studies demonstrating differences between crawling and walking infants suggest a more complex picture, this research does not completely rule out a broad maturational explanation. Thus, developmental differences should continue to be addressed in future research. We predict that no one element of change in the system is accountable for the increase in language; rather, we think it likely that the interaction of multiple changing components in concert facilitates ongoing, dynamic change to the developmental system (see Thelen, 1995; Thelen & Smith, 1994). Therefore, what is most called for is a longitudinal investigation incorporating convergent research operations across a broad range of related, yet distinct, developmental processes to identify the unique and interactive effects of potential mechanisms.

In conjunction with previous research, the present study indicates: (1) a link between infant language development and the acquisition of walking, (2) infants' social and linguistic environment differ as a function of locomotor quality, and (3) crawling and walking infants' social/linguistic environments are differentially associated with their language development. Further research is needed to more closely examine the relationships identified in the present investigation, as well as explore mechanisms that may be related with the acquisition of walking and language development. Most importantly, such investigations are likely to prove most fruitful when these processes are conceptualized and studied in an integrated rather than isolated fashion.

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