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Infant Language Development Is Related to the Acquisition of Walking

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The present investigation explored the question of whether walking onset is related to infant language development. Study 1 used a longitudinal design ($N = 44$) to assess infant locomotor and language development every 2 weeks from 10 to 13.5 months of age. The acquisition of walking was associated with a significant increase in both receptive and productive language, independent of age. Study 2 used an age-held-constant study with 12.5-month-old infants (38 crawling infants; 37 walking infants) to further explore these findings. Results from Study 2 replicated the differences in infant language development between locomotor groups. Additionally, a naturalistic observation of parent–infant interactions (20 crawling dyads; 24 walking dyads) revealed that language development was predicted by multiple factors in the social environment, but only for walking infants. Possible explanations of the findings (e.g., social, cognitive, neurological) are discussed, and topics for future research are highlighted.

Keywords: langauge development, motor development, epigenetic phenomena, social development

This article explores the relation between walking and language development at the time when both processes are showing their developmental onsets. The relation between these two processes was discovered serendipitously while investigating factors (including language) related to infant retention of affective expressions. Empirical data indicating the link between walking and language development were first presented by Walle and Campos (2011). The present report describes two studies that elaborate on this initial, unexpected finding. In Study 1, a longitudinal design was used to determine whether the onset of walking predicts instances of increased language development, allowing one to infer an antecedent–consequent relation between walking and language. We then sought to confirm this linkage in Study 2, as well as explore one set of factors that may be involved in the interrelation of walking and language around the first year of life.

Motoric Transitions as Epigenetic Phenomena

The onset of specific motoric transitions has been described as a setting event—a catalyst that impacts many areas of the developing infant's life (for a review, see Campos et al., 2000). Such are deemed epigenetic phenomena because they dramatically alter a number of aspects of psychological development by fundamentally changing the context within which the infant develops (see Gottlieb, 1983).

The associations between motoric and psychological development have been documented in the linguistic, cognitive, emotional, and social literatures (for reviews of this research, see Campos et al., 2000; Iverson, 2010). For example, the emergence of rhythmic arm shaking of a rattle is associated with infant reduplicated babbling (e.g., Iverson, Hall, Nickel, & Wozniak, 2007), and the acquisition of upright sitting is related to infant perceptual completion of partially occluded objects (Soska, Adolph, & Johnson, 2010). A number of studies have also demonstrated the relation of infant self-produced locomotor experience (through crawling or experience in an infant walker) with a broad array of psychological phenomena, including cognitive development (Bertenthal, Campos, & Barrett 1984; Bai & Bertenthal, 1992), development of spatial search (Kermoian & Campos, 1988), perceptual development (Higgins, Campos, & Kermoian, 1996), social development (Campos, Kermoian, & Zumbahlen, 1992), emotional development (Campos, Bertenthal, & Kermoian, 1992), and neurophysiological processes (Bell & Fox, 1996). Experimental studies have demonstrated that some of the above relations are caused by locomotor experience, specifically by randomly assigning prelocomotor infants to a condition in which infants control a powered-mobility device and others do not (Dahl et al., in press; Uchiyama et al., 2008). In each of these studies, the acquisition of a new motoric skill was associated with development in a broad range of psychological areas. Furthermore, the acquisition of motoric skills may generate contexts in which new psychological capacities develop.

Studies linking motoric and psychological development make it clear that investigations focusing on the time during which a developmental transition occurs can illuminate the broad range of effects that such transitions have on development, as well as

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increase our understanding of underlying mechanisms that facilitate the development of such psychological phenomena. Although much of the empirical literature has focused on the effects of sitting up, reaching, and crawling on psychological development, less research has examined a locomotor transition of equal significance: the acquisition of upright locomotion (i.e., walking). However, unlike the transition from no locomotion to locomotion, changes involving walking cannot readily be studied through experimental design. Thus, research must be constrained to the study of antecedent and consequent relations, such as can be provided by longitudinal studies.

The acquisition of walking offers a number of advantages for infants' interactions with the world. Walking is a more rapid mode of locomotion and requires less energy than crawling (Sparrow & Irizarry-Lopez, 1987), affords a more flexible viewpoint while locomoting (Clearfield, 2004), and frees the hands to manipulate and direct attention to objects of interest (Clearfield, Osborne, & Mullen, 2008). Walking infants also demonstrate increased "testing of wills" in social interactions with their parents in comparison with crawling infants (Biringen, Emde, Campos, & Appelbaum, 1995). Although such changes are as apparent as an iceberg floating in the sea, the more impactful psychological consequences lie beneath the surface. More concretely, it is not the emergence of walking per se that is of great importance, but rather the *functional consequences* of its acquisition on development, such as increased ability to shift attention, increased intentionality and goal-directed behavior, improved concept formation, changes in parental expectations, and richer social interactions (Bertenthal et al., 1984; Campos, Kermoian, Witherington, & Chen, 1997).

Language Development in the Window of Walking Onset

Although the acquisition of walking and language development may appear as separate domains of behavior, we believe linkages exist that set the stage for exploring the interweaving of their development. A handful of researchers have speculated on a connection between language and locomotor development (see Iverson, 2010). Oudgenoeg-Paz, Volman, and Leseman (2012) recently reported that infant age of sitting and walking forecasted productive language development in late infancy. However, this study did not collect data during the transition to walking, used very large intervals (4 months) between infant language assessments, and did not report on receptive language.

Empirical research that is temporally proximal to the acquisition of upright locomotion is crucial to understanding the relation of walking with language development. Examination of developmental transitions when they occur helps to reveal control parameters that aid in determining the relation of two phenomena. The significance of investigating developmental transitions has been revealing for both the locomotor (e.g., Campos et al., 2000) and language (e.g., Parladé & Iverson, 2011) development literatures. However, no study to date has directly investigated the connection between walking acquisition and language development during the transition from crawling to walking.

One hint of a link between walking and language development comes from examination of the *observed* trajectories of language development reported by Fenson et al. (1994). There is an apparent marked point of inflection for both receptive and productive vocabulary scores between 11 and 15 months of age. Whether one views this as the start of *the* "spurt" (e.g., Goldfield & Reznick, 1990), one spurt of many (Dandurand & Shultz, 2011), or the start of logarithmic acceleration (Ganger & Brent, 2004) in language, this apparent shift corresponds with the developmental window within which infants typically begin to walk (Bayley, 1969). The acquisition of walking is likely interconnected with and bidirectionally influenced by a number of underlying mechanisms related to language development. One such mechanism of particular interest for the present investigation is the social environment.

Language is an inherently social enterprise that undergoes significant development during the second year of life (see Baldwin & Meyer, 2007). Many developmental researchers have noted the complex interplay between parent–infant social interactions and language learning (e.g., Brooks & Meltzoff, 2008; Goldfield, 1987). Extrapolating from this work, changes in infant exploratory behaviors and interactions with objects following the onset of walking may encourage increased joint-attention episodes, discourse, and labeling of objects and events, thereby facilitating infant language learning. Parent reports and home observations indicate that caregivers direct more verbalizations to walking infants than crawling infants (Biringen et al., 1995; Green, Gustafson, & West, 1980). Increased parent vocalizations to infants following the acquisition of walking may facilitate the linguistic development of walking infants.

Clearfield (2011) compared the social behaviors of crawling infants, crawling infants in a walker device, and walking infants. Walking infants demonstrated more exploration of the room, more engagement with items in the room, more vocalizations, and more gestures than crawling infants or crawling infants in walkers. A longitudinal follow-up demonstrated increases in each of the above behaviors following the onset of walking. This suggests that there is something unique to walking, beyond the physical change in posture, which alters social interactions following the onset of walking. Other studies have found that walking infants engage more frequently with distal objects and demonstrate more bids for attention than crawling infants (Clearfield et al., 2008; Karasik, Tamis-LeMonda, & Adolph, 2011). Increased infant exploration of the environment, particularly exploration distal from the caregiver, likely necessitates that parents and infants use more distal communication, such as vocalizations and gestures.

The changes in infants' social engagement following the acquisition of walking overlap with the apparent increase in language development between 11 and 15 months of age (Fenson et al., 1994). This coincidental reporting in the literature coupled with the broad impact of epigenetic phenomena, such as has been reported for the acquisition of crawling and walking, on psychological development lays the foundation for the present study.

The Present Investigation

In the present empirical investigation, we explored the relation between walking acquisition and infant language development. As noted above, an experimental study involving random assignment of infants to walking training and nonwalking control would be ideal in identifying whether the link we are exploring is a causal one or driven by a third factor. However, such an approach is unfeasible and would be premature in the absence of evidence for an antecedent–consequent relation, such as can be identified in a longitudinal design. In Study 1, we thus used a longitudinal design to track language development as a function of walking experience. In Study 2, we followed up on these findings by exploring one aspect likely affected by the onset of walking, the social environment, that may account for the differences in infant language development observed in Study 1.

Study 1

In Study 1, we used a longitudinal design to follow a group of infants from 10 to 13.5 months of age, an age range within which walking generally emerges and early language begins to grow. Parents reported on infant locomotor and linguistic development every 2 weeks over the course of the 3.5-month investigation. Parents were told that the study's aim was to investigate infant social development, and the locomotor and language measures were part of a larger battery of questionnaires. We predicted that the acquisition of walking would correspond with significant increases in infant language development, independent of age.

Method

Sample. Forty-four infants (24 female) participated in the longitudinal study, beginning participation at either 10 or 10.5 months of age. Parents reported on the percentage of each language that their child was exposed to on a daily basis. All infants were exposed to English. On average, infants were exposed to 1.5 languages (SD = 0.62), and 86.89% of their day they heard English (SD = 22.02%). Languages other than English to which infants were exposed included Spanish (n = 14), French (n = 5), Mandarin Chinese (n = 2), Arabic (n = 1), Cantonese (n = 1), German (n = 1), Hungarian (n = 1), Italian (n = 1), Konkani (n = 1), Korean (n = 1), Russian (n = 1), Tagalog (n = 1), Tamil (n = 1), and Vietnamese (n = 1), as well as baby sign language (n = 2). Infants had an average of 0.5 siblings (SD = 0.72). The average parent age was 33 years (SD = 4 years), and parent education ranged from a high school diploma to a graduate degree, and the average education was a bachelor's degree. The average family income was $115,000 ($SD$ = $40,000; range = <$25,00 to >$150,000). Families were representative of the diverse ethnic populations of the San Francisco Bay Area, but unfortunately specific information on infant and parent ethnicity was not collected.

Families were recruited from a database of parents who had previously indicated interest in participating in research. Participating families received a $10 gift card on the infant's 12- and 13.5-month birthday. All parent reports were carefully reviewed to (a) identify infants who may have had undisclosed developmental delays and (b) exclude outliers. Data for an additional 10 infants were collected, but not included in the analyses: Six infants were excluded because of extremely low-reported receptive vocabulary size (<27 words at 13.5 months[1]), possibly indicative of developmental delays or parent reporting error; two infants were excluded because of extremely high-reported productive vocabulary size (>198 words at 13.5 months[2]); two infants were excluded because the parent did not provide the ages of locomotor milestones.

Procedure. Participating parents were e-mailed a link to complete an online survey using *Qualtrics* online survey software at 2-week intervals beginning when their infant was 10 or 10.5 months old and ending when their infant reached 13.5 months of age. Parents were allowed 5 days to complete each questionnaire at each time point, after which the link in the e-mail no longer functioned. This procedure helped maintain a strict 2-week period between time points.

Measures. The online survey consisted of two parts. Part 1 was a brief locomotor questionnaire that asked whether and when the infant achieved specific locomotor developments (i.e., crawling and walking). The onset of crawling was operationalized as the date when the infant was able to locomote on hands and knees or scoot a distance at least twice his or her body length. The onset of walking was operationalized as the infant bipedally locomoting 10 feet without falling or requiring support. These definitions were based on those used in previous investigations (see Adolph, 1997; Adolph, Vereijken, & Shrout, 2003). Parents were encouraged to refer to baby records in order to more accurately report these dates.

Part 2 of the survey consisted of an online version of the MacArthur-Bates Long Form Vocabulary Checklist: Level I (Fenson et al., 1994) (henceforth referred to as the *CDI-Long*). The CDI-Long contains a 396-item vocabulary checklist, composed of 19 semantic categories. Parents were instructed to mark words that their infant "*understands*" (i.e., receptive vocabulary) or "*understands and says*" (i.e., productive vocabulary) in any language. Extensive internal validity and test–retest reliability for the CDI-Long are reported by Fenson et al. (1994). Parents were permitted to check items that the infant could understand or produce in languages other than English, including signing.

Results

Preliminary analyses. Infants who walked (n = 28) and infants who did not acquire walking (n = 16) during the course of the longitudinal study were compared to ensure that all infants were similar at the outset of the investigation. This analysis included infants who had data at 10.5 months and compared infants who walked (n = 27) with infants who did not walk (n = 14) during the course of the study. It should be noted that the total number of infants included in this analysis differs from the total number of infants included in the final sample because three infants did not have data at 10.5 months of age.

Infants who walked and infants who did not walk during the study had similar *Receptive* (walkers = 49.22 words, SE = 6.20; never walked = 39.86 words, SE = 7.99), $t(39) = 0.90$, $p = .37$, 95% CI [−30.32, 11.59], and *Productive* (walkers = 4.59 words, SE = 0.79; never walked = 2.71 words, SE = 0.75), $t(39) = 1.53$, $p = .13$, 95% CI [−4.36, 0.60] vocabularies at 10.5 months of age.

Analytic strategy for the longitudinal data. Mixed linear modeling using a first-order autoregressive covariance structure was used to analyze the amount of variance in vocabulary accounted for by walking experience, independent of age, from 10 to 13.5 months of age. This analytic strategy allowed for the inclusion of infants with missing data at time points during the longi-

[1] Expected receptive language scores reported by Fenson et al. (1994) for the 10th percentile at 13.5 months of age is approximately 45–50 words.

[2] Expected productive language scores reported by Fenson et al. (1994) for the 90th percentile at 13.5 months of age is approximately 65–75 words.

tudinal investigation. Age and Walking Experience (i.e., weeks of walking experience) were included in the models as fixed effects. Participant ID was entered as a random effect to account for within-subject correlations. The numbers of infants included in the analyses at each age and weeks of walking experience are provided in Table 1.

Receptive language development. Significant main effects for predicting Receptive Language were found for Age (b = 12.48), $t(258) = 13.04$, $p < .001$, 95% CI [10.60, 14.37], and Walking Experience (b = 6.23), $t(260) = 3.86$, $p < .001$, 95% CI [3.06, 9.41]. Although the effect of Age was linear, graphical illustration of the effect of Walking Experience exhibited a non-linear trend (see Figure 1, left).

The main effect of Walking Experience on Receptive Language was further explored to investigate the presence of a nonlinear trend by adding the natural log (LN) of Walking Experience to the model. Inclusion of LN Walking Experience significantly improved the fit of the model, $\chi^2(1) = 11.21$, $p = .001$. Results showed a significant effect for Age (b = 12.45), $t(252) = 13.08$, $p < .001$, 95% CI [10.57, 14.32], and for LN Walking Experience (b = 32.40), $t(221) = 1.94$, $p = .05$, 95% CI [−0.58, 65.39], but no effect for Walking Experience (b = 0.73), $t(236) = 0.22$, p = .82, 95% CI [−5.70, 7.16]. Due to concern over loss of degrees of freedom, a final model was analyzed including only Age and LN Walking Experience. This model demonstrated significant main effects for Age (b = 13.68), $t(250) = 12.50$, $p < .001$, 95% CI [10.71, 14.31], and LN Walking Experience (b = 35.65), $t(250)$ = 4.34, $p < .001$, 95% CI [19.48, 51.82].

Pairwise comparisons within the hierarchical linear model examined infants' growth in Receptive Language as a function of Walking Experience in 2-week intervals. A Bonferroni correction was used to control for familywise error, lowering the critical p value to .01 for subsequent pairwise comparisons. Analyses revealed significant increases between crawling (M = 76.47, SE = 7.35) and walking onset (M = 86.63, SE = 7.49), $t(223) = 3.46$, p = .001, 95% CI [−15.96, −4.37], and walking onset and 2-weeks of Walking Experience (M = 95.75, SE = 7.83), $t(223)$ = 2.91, p = .004, 95% CI [−15.27, −2.95]. No significant differences were found between 2 and 4 weeks (M = 100.22, SE = 8.36), $t(222) = 1.38$, p = .17, 95% CI [−10.85, 1.90], 4 and 6 weeks (M = 102.67, SE = 9.09), $t(222) = 0.67$, p = .50, 95% CI [−9.62, 4.71], or 6 and 8 weeks (M = 107.82, SE = 10.13), $t(223)$ = 1.22, p = .22, 95% CI [−3.14, 13.44], of Walking Experience.

Productive language development. Significant main effects for predicting Productive Language were found for Age (b = 3.12), $t(264) = 7.95$, $p < .001$, 95% CI [2.35, 3.90], and Walking Experience (b = 3.39), $t(264) = 5.13$, $p < .001$, 95% CI [2.89, 4.69]. Although the main effect of Age was linear, once again, graphical illustration of the effect of Walking Experience appeared nonlinear (see Figure 1, right).

The main effect of Walking Experience on Productive Language was further explored to investigate the presence of a nonlinear trend by adding the square and cube of Walking Experience to the model. Inclusion of Walking Experience cubed significantly improved the fit of the model, $\chi^2(1) = 5.962$, $p = .02$. Results showed a significant main effect for Age (b = 3.14), $t(262)$ = 8.10, $p < .001$, 95% CI [2.38, 3.90]; Walking Experience (b = 4.14), $t(221) = 2.34$, $p = .02$, 95% CI [0.66, 7.62]; and Walking Experience cubed (b = 0.26), $t(209) = 2.16$, $p = .03$, 95% CI [0.23, 0.50], but no main effect for Walking Experience squared (b = −1.39), $t(209) = 1.56$, $p = .12$, 95% CI [−3.14, 0.37].

Pairwise comparisons within the hierarchical linear model examined infants' growth in Productive Language as a function of Walking Experience in 2-week intervals. A Bonferroni correction was again used to control for familywise error of the pairwise comparisons, resulting in an adjusted critical p value of .01. Analyses revealed a nearly significant increase between crawling (M = 11.77, SE = 2.39) and walking onset (M = 14.73, SE = 2.47), $t(225) = 2.44$, p = .016, 95% CI [−5.36, −0.57]; no significant increase between walking onset and 2-weeks walking experience (M = 16.18, SE = 2.65), $t(224) = 1.12$, p = .26, 95% CI [−1.09, 3.99]; a nonsignificant increase between 2 and 4 weeks (M = 19.38, SE = 2.90), $t(222) = 2.39$, p = .018, 95% CI [−5.83, −0.56]; a non-significant increase between 4 and 6 weeks (M = 22.15, SE = 3.23), $t(221) = 1.84$, p = .067, 95% CI [−5.74, 0.20]; and a significant increase between 6 and 8 weeks (M = 29.92, SE = 3.68), $t(223) = 4.47$, $p < .001$, 95% CI [−11.20, −4.34], of walking experience.

Discussion

To our knowledge, this is the first longitudinal study to investigate infant language development across the transition from crawling to walking. Although we cannot determine causality in the present study, the analyses of the longitudinal data from Study 1 demonstrated main effects of age and walking experience as significant independent predictors of language development. Trend analyses revealed a log-linear model for receptive vocabulary, in which the onset of walking was related to immediate increases in receptive language development and that this relation then less-

Table 1
Study 1: Total Number of Infants Included in the Longitudinal Analyses for Each Locomotor Development Group by Age

Age (months)	Crawling (n =)	Walk onset (n =)	2 weeks walking (n =)	4 weeks walking (n =)	6 weeks walking (n =)	8 weeks walking (n =)	Total (N =)
10	10	1	2				13
10.5	37	1	1	2			41
11	32	3	1	1	1		38
11.5	26	5	3	1	1	2	38
12	25	2	4	3	1	0	35
12.5	21	4	3	5	3	1	37
13	15	3	4	2	5	3	32
13.5	14	5	3	4	3	5	34

Note. Fluctuations in the total number of infants included at each age reflect missing data during the longitudinal investigation.

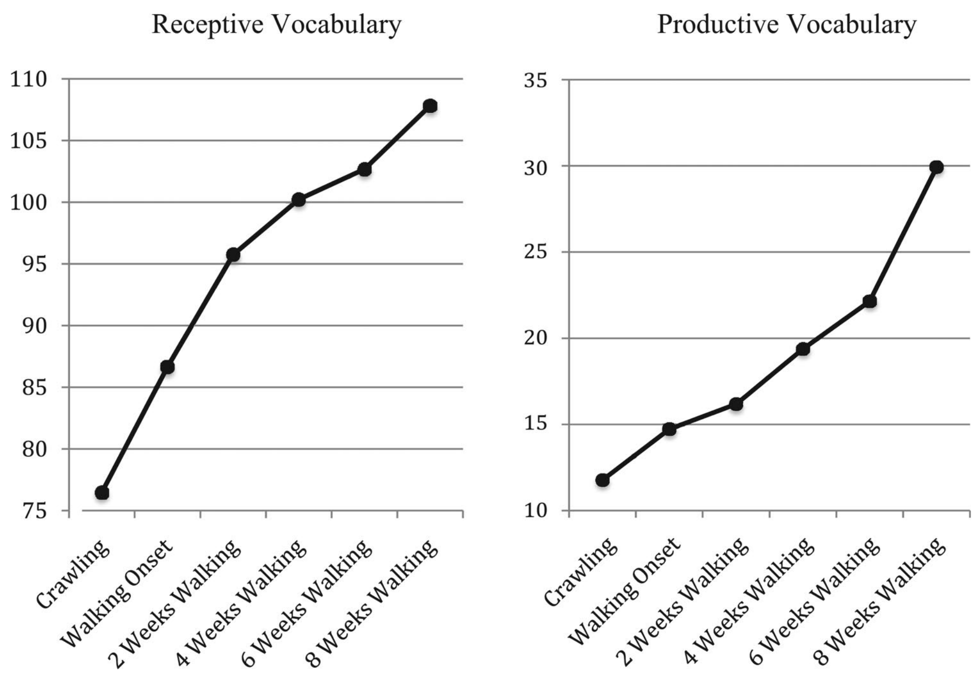

Figure 1. Study 1: Infant Receptive (left) and Productive (right) Vocabulary as a function of Walking Experience, independent of Age. Scores shown represent estimated marginal means.

ened after 2 weeks of walking experience. Interestingly, the relation between productive language and walking experience demonstrated a cubic trend, showing an increase following the acquisition of walking, which then leveled off over the next 2 weeks before regaining its significant growth from 4 to 8 weeks of walking experience.

Differences in the growth curves for receptive and productive language as a function of locomotor experience may suggest that infant productive vocabulary must "catch up" with the gains in receptive vocabulary. Receptive vocabulary development has routinely been found to precede increases in productive vocabulary (e.g., Bates, Bretherton, & Snyder, 1988; Goldin-Meadow, Seligman, & Gelman, 1976). For example, underlying skills related to language acquisition that may be affected by the onset of walking (e.g., bids for parental attention, engaging in joint attention, following communicative cues) may occur rapidly as infant exploration increases and parent–infant social communication becomes more distal. However, the productive gains may take more time to become evident as gains in receptive vocabulary are made.

In light of the above findings indicating a clear link between walking and language development, a second study was carried out to (a) confirm whether a significant difference between crawling and walking infants' receptive and productive vocabulary size exists and (b) explore how factors in the social environment may predict such differences, specifically parent vocalizations to the infant and parent and infant proximity and movement.

Study 2

A naturalistic observation of parent–infant dyads explored how specific social behaviors related to group and individual differences in language development as a function of locomotor status (crawling vs. walking). As highlighted in the introduction, past research has demonstrated that the parent–infant social ecology changes during locomotor transitions. Specifically, walking infants have been found to demonstrate changes in their communicative patterns with parents and increased willfulness and exploratory behaviors. Thus, measures of parent language input, parent and infant movement, and infants' proximity to the parent were included in Study 2 to examine how features of the infant's social environment might be related to infant language development. Specifically, we posited that amount of infant movement, time spent by the infant in locations distant from the parent, and amount of language directed to the infant by the parent would be related to infant language development as a function of the infants' locomotor status (crawling vs. walking).

A cross-sectional, age-held-constant design was used in Study 2. The age range of 12–13 months was selected because 12.5 months of age was the first age at which a relatively even proportion of infants was crawling and walking in Study 1.

Method

Sample. Seventy-five parents of crawling or walking infants completed the MacArthur-Bates Short Form Vocabulary Checklist: Level I (Fenson et al., 2000). This sample was used to replicate the main finding of Study 1, specifically that the acquisition of walking is related to increased language development. Crawling infants (18 female, 20 male; M_{age} = 12.55 months, range = 11.87–13.15 months) had an average of 3.64 months of crawling experience (range = 0.82–6.74, SD = 1.51). Walking infants (20 female, 17 male; M_{age} = 12.63 months, range = 12.03–13.45) had an average of 2.04 months of walking experience (range = 0.30–4.27, SD = 1.07) and an average of 5.22 months of total locomotor experience (range = 2.56–8.65, SD = 1.30). Crawling and walking onset were operationalized using the same criteria as in Study 1. Parent education ranged from a high school diploma to a graduate degree, and the average education was a bachelor's degree. The average family income was \$90,000 (SD = \$40,000; range = <\$25,00 to >\$150,000). Unfortunately, no data were collected on parent or child ethnicity. All participants were recruited from the San Francisco Bay Area.

A random subset of 44 parent–infant dyads (20 crawling dyads: seven mother–daughter, 11 mother–son, one father–daughter, one father–son; 24 walking dyads: 11 mother–daughter, 11 mother–son, two father–daughter) was also observed in a 10-min naturalistic free-play session. This subset was used to extend the findings from Study 1 and explore one possible underlying mechanism for the developmental differences in language, specifically the infant's social environment. The subset of dyads did not differ from the larger sample in age, locomotor experience, socioeconomic status, parent education, or language development.

Procedure.

Walking assessment. All infants completed a walking assessment to determine locomotor status (crawling vs. walking). This assessment was based on the procedures used by Adolph et al. (2003), and the classifications were operationally the same as the locomotor criteria used in Study 1. The walking assessment took place in the free-play space (described below) prior to the naturalistic observation. Infants had 1 min to cross a distance of 10 feet to the parent. Infants needed to successfully walk unsupported to the parent without falling on at least two of three trials to be classified as walking. All infants who did not meet the walking criteria were able to crawl the distance to the parent and thus classified as crawling.

MacArthur-Bates Short Form Vocabulary Checklist: Level I. During the lab visit, each parent was asked to complete the MacArthur-Bates Short Form Vocabulary Checklist: Level I, henceforth referred to as the CDI-Short. The CDI-Short consists of an 89-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) in any language. This questionnaire is a reliable and valid instrument for collecting data on infant language development (see Fenson et al., 2000). The CDI-Short was used in place of the CDI-Long to minimize parent fatigue in completing paper-and-pencil questionnaires.

Free-play session. A 10-min naturalistic free-play session was observed to assess the social environment of each parent–infant dyad. During the observation, parents were asked to sit in a chair and complete a lengthy questionnaire on the infant's motoric development, which also served to occupy the parent and allow the infant to more freely explore the room. Although parents began the observation seated in this chair, no explicit instruction was given that the parent must remain in the chair while completing the questionnaire. Parents regularly checked on their infant by looking up or calling to their infant, and were free to move about the room to engage with their infant. The infant was free to explore the comfortable 3 m × 5 m space, closed off by a baby gate on one side (see Figure 2). The room was set up to contain numerous items of interest (e.g., plants, remotes, drawers) in various locations accessible to crawling and walking infants that we believed would encourage communicative acts and elicit a range of responses by the infant and parent.

A small, mounted video camcorder positioned behind the gate captured the entire space. A researcher was present on the other side of the gate, but did not engage with the parent or the infant unless (a) the parent had a question or (b) the infant was in danger of physical harm. The researcher watched the space via a monitor that the parent could not see and occluded the researcher from

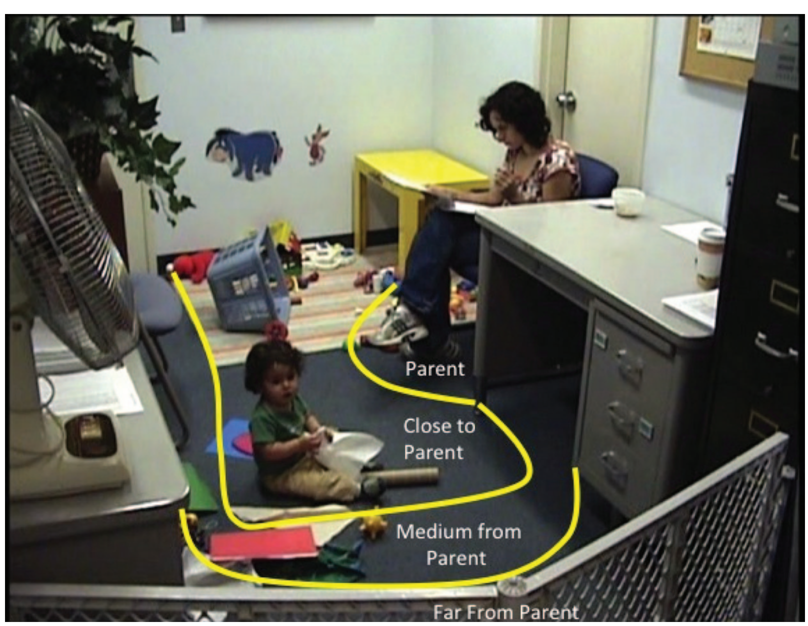

Figure 2. Study 2: Image of the free-play setting and the four areas used to code the location of the infant and parent.

view. Although parents were told at the beginning of their visit that *all* procedures would be filmed, the observation occurred at the end of the 90-min visit, and researchers did not remind parents of the video camera. Thus, although all parents were informed that all aspects of the visit would be recorded, the timing of the observation and the lack of reminding parents of this statement allowed for a more naturalistic observation of parent–child interactions. Verbal report confirmed that parents did not remember that they were being filmed during the free-play observation.

Coding.

Vocalizations. Each parent vocalization was coded to measure infants' language environment. The *content* of each vocalization was transcribed to assess total number of words and sentences. The *referent*(s) of each vocalization, or what the vocalization was about, was also coded. A vocalization could have any number of referents, but only those that could be clearly discerned were coded. Four parents' vocalizations were unable to be coded, three because the parent spoke a language other than English, and one due to a technical malfunction.

Location. Infant and parent location were coded to measure the amount of time spent by each individual in each area of the room. Location was coded by assigning nine distinct locations to the room. These locations were then grouped into four areas based on how many locations the infant would need to travel through to get to the parent chair. The four defined areas were Parent Chair (zero locations from parent chair), Near to Parent Chair (one location, approximately 1 m, from parent chair), Medium From Parent Chair (two locations, approximately 1.6 m, from parent chair, and Far From Parent Chair (three locations, approximately 2.1 m, from parent chair). Location data from one dyad were lost due to a technical malfunction.

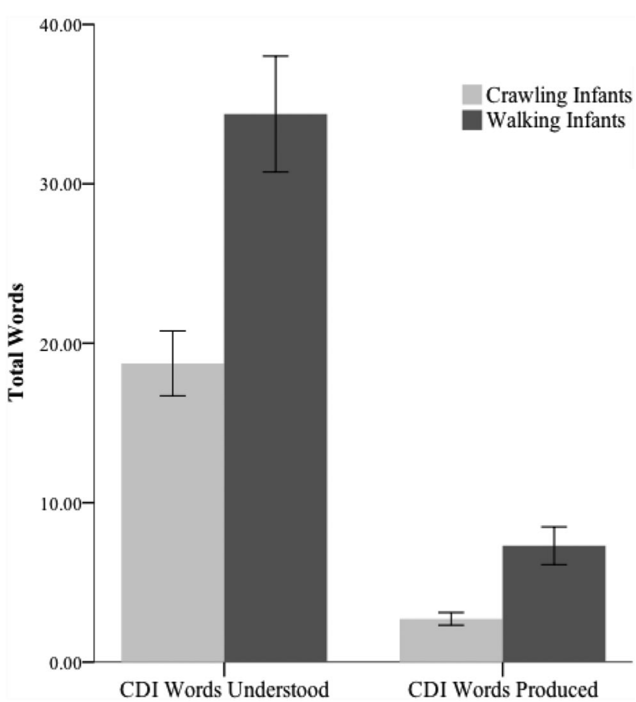

Figure 3. Study 2: Mean values of Receptive and Productive Vocabulary for crawling and walking infants on the Communicative Development Inventory-Short (CDI). Error bars represent ±1 standard error of the mean.

Table 2
Study 2: Multiple Regressions Predicting Receptive Vocabulary From Language Input, Parent Movement, Infant Movement, and Their Interactions With Locomotor Status

Predictor	Receptive vocabulary ΔR^2	Receptive vocabulary β
Step 1	0.16*	
Locomotor Status		0.40*
Step 2	0.42***	
Locomotor Status		0.08
Language Input		0.74***
Parent Movement		−0.62***
Infant Movement		0.45***
Step 3	0.15**	
Locomotor Status		0.13
Language Input		0.14
Parent Movement		−0.13
Infant Movement		0.54*
Language Input × Locomotor Status		0.79**
Parent Movement × Locomotor Status		−0.69***
Infant Movement × Locomotor Status		−0.08
Total R^2	0.68***	

* $p \leq .05$. ** $p \leq .01$. *** $p \leq .001$.

Movement. As described above, parent and infant movement patterns are affected by the infant's quality of locomotion (e.g., crawling, walking). To explore whether activity level was related to language development, amount of parent and infant movement were coded by counting the frequency with which each individual changed location. Movement data from one dyad were lost due to a technical malfunction.

Reliability. A researcher naïve to the purpose of the study coded all free-play observations for all variables listed above. A second researcher, also naïve to the purpose of the study, coded 20% of the observations for all variables listed above. Interrater agreement for vocalizations and referents were based on each coder selecting the same code, infant location codes were counted as in agreement if coders' time stamps were within 1 s of each other, and verbal content was counted as in agreement if the entire vocalization was identical. Reliability was very good for all measures (all κs> .85).

Results

No infant or parent gender differences were found for any of the measures; thus, data from male and female infants and parents were collapsed for subsequent analyses. The lack of gender effects on infant language development was likely the result of (a) the small sample size and (b) the relatively small effect size of gender on infant language development (see Fenson et al., 1994).

Locomotor status and language scores. The main effect of Locomotor Status on language development was examined. Confirming the findings from Study 1, walking infants had significantly larger Receptive (crawlers = 18.74, SE = 2.04; walkers = 34.38, SE = 3.63), $t(73) = 3.76$, $p < .001$, $d = .87$, 95% CI [−23.98, −7.30], and Productive Vocabularies (crawlers = 2.71,

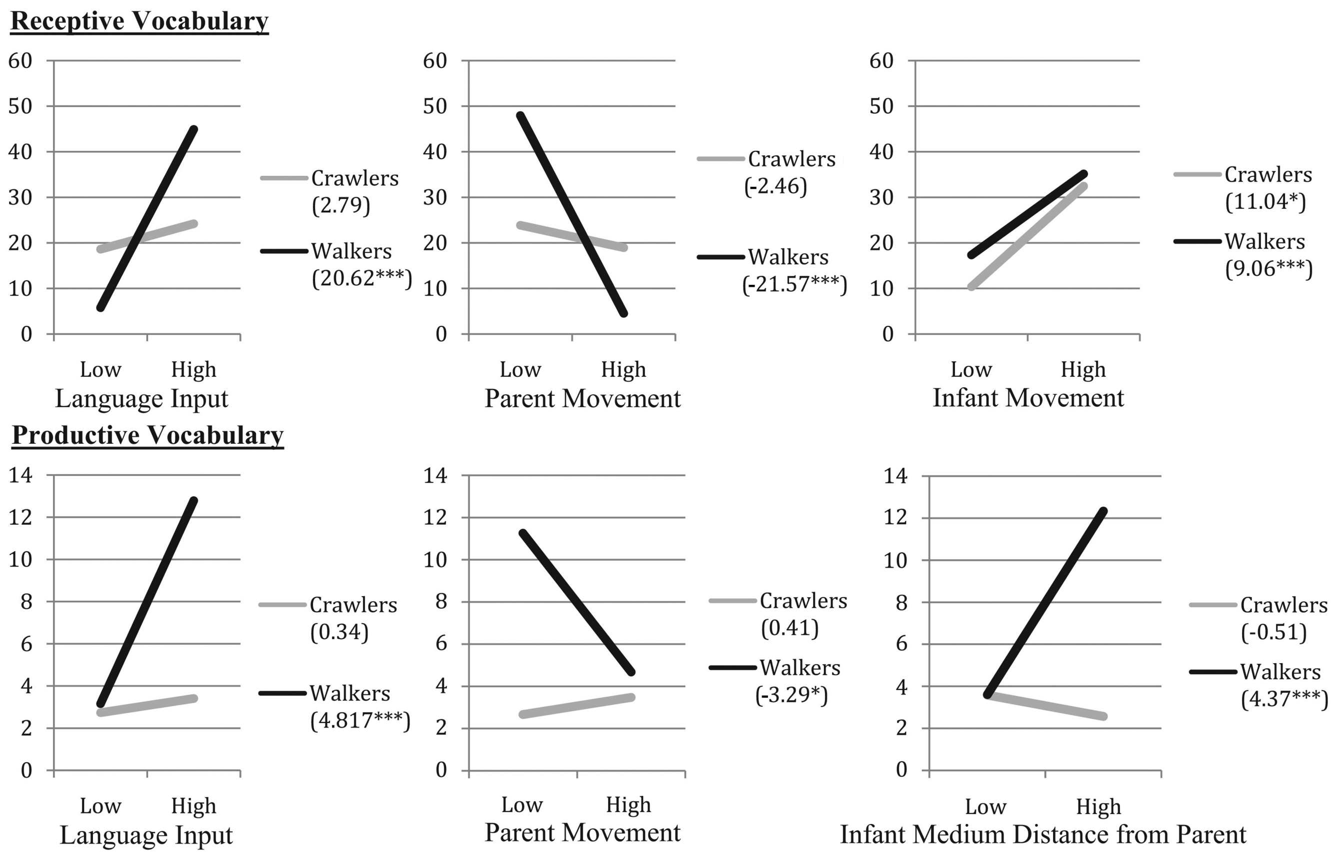

Figure 4. Study 2: The top three graphs show the effects of Language Input, Parent Movement, and Infant Movement × Locomotor Status interactions in predicting Receptive Vocabulary. The bottom three graphs show the effects of Language Input, Parent Movement, and Infant Medium Distance from Parent × Locomotor Status interactions in predicting Productive Vocabulary. The graphs show vocabulary size (indicated on the *y*-axis) at low (1 *SD* below the mean) and high (1 *SD* above the mean) levels for each variable. The numbers in parentheses are unstandardized simple slopes. * $p \leq .05$. *** $p \leq .001$.

SE = 0.40; walkers = 7.3, *SE* = 1.18), $t(73) = 3.67$, $p = .001$, $d = .86$, 95% CI [−7.10, −2.07], than crawling infants (see Figure 3).

Relations of infant language scores to the social environment. Language development was further explored by examining its relations to the parent–infant social environment observed in the free-play session. The number of words, sentences, and referents directed by the parent to the infant were all highly correlated with one another ($r > .91$ among all variables). Thus, a latent construct of Language Input was created by standardizing and combining the number of words, sentences, and referents the parent communicated to the infant.

No significant group differences were found between crawling and walking infants' social environments: Language Input, $t(39) = 0.13$, $p = .90$, $d = 0.04$; Parent Moves (crawlers = 27.32, *SE* = 2.61; walkers = 8.88, *SE* = 1.92), $t(41) = 1.14$, $p = .26$, $d = 0.34$, 95% CI [−2.80, 10.00]; Infant Moves (crawlers = 27.32, *SE* = 4.43; walkers = 39.29, *SE* = 4.81), $t(41) = 1.79$, $p = .08$, $d = 0.56$, 95% CI [−25.50, 1.54]; Infant Close to Parent (crawlers = 142.01, *SE* = 38.93; walkers = 224.87, *SE* = 31.32), $t(41) = 1.68$, $p = .10$, $d = 0.51$, 95% CI [−182.58, 16.85]; Infant Medium from Parent (crawlers = 83.97, *SE* = 25.91; walkers = 95.44, *SE* = 12.83), $t(41) = 0.40$, $p = .70$, $d = 0.13$, 95% CI [−70.82, 47.88]; Infant Far from Parent (crawlers = 49.94, *SE* = 15.63; walkers = 54.40, *SE* = 12.27), $t(41) = 0.23$, $p = .82$, $d = 0.07$, 95% CI [−44.00, 35.08]).

Hierarchical multiple regressions were conducted to test whether Locomotor Status interacted with behaviors of the parent and infant in predicting Receptive and Productive Language. The predictors were the composite Language Input Score, infant duration in each of the four areas of the room, total number of parent moves, and total number of infant moves.[3] From these predictors, a best fitting model was created for each dependent variable.

Predicting receptive CDI-Short scores. As presented in Table 2, Infant Movement significantly predicted infant Receptive Vocabulary, and significant interactions were found between Language Input × Locomotor Status and Parent Movement × Locomotor Status. Inclusion of the above variables in a single model accounted for 68% of the variance for receptive vocabulary. Figure 4

[3] The variance inflation factor did not exceed the cutoff of 7 (Neter, Wasserman, & Kutner, 1989), thus multicolinearity was not an issue.

Table 3
Study 2: Multiple Regressions Predicting Productive Vocabulary From Language Input, Parent Movement, Infant Medium Distance From Parent, and Their Interactions With Locomotor Status

Predictor	Productive vocabulary ΔR^2	Productive vocabulary β
Step 1	0.19**	
Locomotor Status		0.43**
Step 2	0.23**	
Locomotor Status		0.33*
Language Input		0.59***
Parent Movement		−0.32†
Infant Medium Distance From Parent		0.21
Step 3	0.12†	
Locomotor Status		0.36*
Language Input		0.05
Parent Movement		0.06
Infant Medium From Parent		−0.07
Language Input × Locomotor Status		0.57
Parent Movement × Locomotor Status		−0.38
Infant Medium Distance from Parent × Locomotor Status		0.38*
Total R^2	0.44***	

† $p \leq .10$. * $p \leq .05$. ** $p \leq .01$. *** $p \leq .001$.

(top) shows the simple regression lines of receptive vocabulary for low and high levels of each predictor as a function of Locomotor Status.

Predicting productive CDI-Short scores. As presented in Table 3, a significant interaction was found between Infant Medium Distance from Parent × Locomotor Status, and trends were found for the interaction terms Language Input × Locomotor Status and Parent Movement × Locomotor Status. Inclusion of these variables in a single model accounted for 44% of the variance for productive vocabulary. Figure 4 (bottom) shows the simple regression lines of Productive Vocabulary for low and high levels of each predictor as a function of Locomotor Status.

Discussion

Walking and language development. The present findings support the findings from Study 1 that infant language development undergoes a significant change following the acquisition of walking. Infant receptive and productive vocabularies showed increases as a function of locomotor quality (i.e., crawling vs. walking), independent of total locomotor experience.

Walking, language development, and the social environment. The free-play observation was informative for exploring potential mechanisms that may account for differences in language development between locomotor groups. Specifically:

1. Infant movement during the observation predicted receptive vocabulary size for both crawling and walking infants. More active infants may (a) be getting into more items that in turn prompt communicative sharing and (b) move back and forth from the parent to the external environment, similar to the emotional "refueling" described by Mahler, Pine, and Bergman (1975), prompting interactions with the parent upon the infant's return.

2. Walking infants who received more language input from the parent during the observation had larger receptive and productive vocabularies, whereas language input was unrelated to receptive and productive vocabulary for crawling infants. Walking infants may use high levels of language input differently than crawling infants, but the specific mechanisms that account for this difference cannot be determined from the present study (although some explanations are speculated upon below).

3. Walking infants whose parents moved less frequently during the observation had larger receptive and productive vocabularies. Parents' physical intervention and close engagement in their infant's environment may differentially impact crawling and walking infants' linguistic development, such that walking infants make use of the distal communicative efforts by the parent in gaining the same information. Parent–infant dyads in which the parent moves less frequently may also have different communicative interaction styles (e.g., more responsive infants may respond to the parent's first vocalization, lessening the need for the parent to physically intervene).

4. Walking infants who spent more time at a medium distance from the parent had larger productive vocabularies, but no such relation existed for crawling infants. It is possible that infants spending time out of the parent's physical reach, but in a location nearby, creates a context in which distal communication is both more necessary and more used.

General Discussion

The present empirical investigation demonstrates that the acquisition of walking predicts both receptive and productive language development, independent of age. Study 1 clearly demonstrated this effect by using a longitudinal design to follow infant language development before, at, and after the onset of walking. Study 1 also revealed that language development progresses differently as a function of walking experience for receptive and productive language, showing log-linear and cubic trends, respectively. In Study 2, we used an age-held-constant design and replicated the significant difference between walking and crawling infants. Furthermore, we explored in Study 2 one possible mechanism through which the onset of walking may affect language development: the social environment. Observational findings indicate that variations in the social environment differentially predicted the language development of crawling and walking infants.

Interestingly, the acquisition of walking appears to have a greater relation with productive than receptive language development. One possible explanation for this may be because infants' productive vocabulary is much smaller than their receptive vocabulary between 11 and 14 months of age—infants had more room to grow, and thus the improvement in productive language was more pronounced than receptive language. A second possibility is that walking is associated with physiological aspects related to language production, such as the functioning of the larynx and diaphragm, facilitating greater ease in forming words. The acquisition of bipedal locomotion in hominid evolution is tied to a number of anatomical and psychobiological differences between humans and other species specific to vocal production (see Lieberman, 1973; MacWhinney, 2005; Negus, 1949), most notably the vocal tract (Hill, 1972), which undergoes extensive physical development during human infancy (Vorperian et al., 2005). Although we are not suggesting that walking accounts for the development of the vocal tract, the coemergence of infant walking and a more adultlike vocal tract encourages empirical work investigating the consequences of upright posture on infant breathing and vocalizing.

As stated in the introduction, developmental transitions typically affect a broad range of psychological phenomena. In keeping with the exploratory spirit of the present investigation, below we propose some additional mechanisms that may be impacted by the onset of walking, and thus could account for the developmental shift in language development following the acquisition of upright locomotion. In doing so, we purposefully maintain a broadly focused theoretical lens in the hope that researchers from a wide range of developmental areas may further investigate the present findings.

Possible Explanations for the Differences in Language Development

Language development is an extraordinarily complex process. Numerous factors likely play a role in helping to explain the present findings (e.g., cerebral development, maturation related to phonology, coheritability of verbal and motoric skills, imitation, representation, symbolic processes, memory, communicative understanding, the language environment, and bidirectional social interactions). Although this study cannot exhaust all possible processes accounting for the differences in language development following the onset of walking, we explore some candidate contributors to the above findings.

Communicative understanding. Infant understanding of intentionality and modalities of communication are critical for typical language development (see Iverson & Goldin-Meadow, 2005; Tomasello, 1992). Hands-free locomotion affords the infant a number of exploratory and expressive channels with which to interact with the environment, and the typical age range of walking onset corresponds with infant appreciation of others' intentions (e.g., Brooks & Meltzoff, 2005; Woodward, 2003). Furthermore, parents commonly respond to infant gesturing with labeling (e.g., Golinkoff, 1986; Masur, 1982), and occurrences of infant gesturing that are followed by parent labeling increases the likelihood of the label entering the infant's vocabulary (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). It is possible that the onset of walking results in changes in the quality of infant pointing (Conrad, 1994) and showing behaviors, which in turn could increase infant understanding of the communicative value of such actions, thereby altering how infants interpret and use the showing and pointing of others.

Cognitive development. Another explanation may involve resulting changes in infant cognition following the acquisition of walking. The onset of walking has been linked to a number of gains in attentional and memory capacities (see Campos et al., 1997). More flexible and precise attention to the communication of others likely facilitates language development. For example, infant gaze-following at 10 months predicts language development in the second year of life (Brooks & Meltzoff, 2008), and increased memory may allow the infant to retain such communication. More complex levels of infant representation (see Bretherton & Bates, 1984) and imitation (see Uzgiris & Hunt, 1975), which appear between 11 and 15 months of age, might also contribute to walking infants' increased language development.

Parent attribution. Changes in parents' attributions toward their infants following the onset of walking may also be relevant. Mothers report that walking infants are distinctly more independent in their actions (Biringen et al., 1995), and anecdotal evidence from the present investigation supports this observation. Parents of walking infants often reported that their infant suddenly "had a personality" and "was a little person," perhaps altering how these parents communicate and attribute behaviors to their infant. Differences in parenting style and effectiveness may affect many areas of development (e.g., locomotion, communication, cognition) and help explain the present findings.

Neurological development. The acquisition of walking may also impact regions of the brain related to language development. For example, walking likely impacts the functioning of the cerebellum, which is involved in postural balance and movement, and has been linked to language development and impairments (see Stoodley & Stein, 2011). Children with language impairments are often significantly delayed in a number of locomotor transitions, particularly the onset of walking (Trauner, Wulfeck, Tallal, & Hesselink, 2000), and delay in walking onset has been associated with later language deficits in children at risk for dyslexia (Viholainen, Ahonen, Cantell, Lyytinen, & Lyytinen, 2002). Although conclusions regarding the causal nature of these relations is premature, further investigations examining the link between motoric and language development with these populations would be informative.

Bidirectional influences. Relations between language development and language environment are likely bidirectional (e.g., Bloom, 1993). Our results may indicate that walking infants' larger receptive and productive vocabularies prompt richer social and linguistic contexts, which in turn perpetuate language development. Because each locomotor group was observed to receive similar environmental input and the effect of language input was apparent for walking, but not crawling, infants, we can only conclude that the language input was somehow used in a distinctive fashion specific to walking infants. Infant development in areas relating to language acquisition likely results in a more competent language learner. Multiple researchers of language development have postulated that infant understanding of underlying features of language changes in the second year of life, including referential understanding (e.g., Lock, 1980; McShane, 1979), conceptual understanding (e.g., Gopnik & Meltzoff, 1986; Nelson & Lucariello, 1985), and use of word learning constraints (e.g., Markman, 1991; Mervis & Bertrand, 1993). The development of such capacities is facilitated by a number of developmental factors occurring in the second year of life, one of which may be the acquisition of walking.

Limitations and Future Directions

The two studies described above represent an extensive first step in investigating the relations between walking acquisition and infant language development. However, limitations do exist in the present research. First, although the longitudinal design used in Study 1 was effective in tracing language development as walking emerges, not all infants began to walk. Following all infants until walking was acquired would have enriched the present investigation to ensure that even late walkers showed an increase in language development following the onset of walking. It is also possible that parents of walking infants attribute greater understanding and intentionality to their infants than do parents of crawling infants, thereby inflating the scores for the walking infants. Convergent assessments to confirm the validity of the infant language measures may help rule out this possibility (for a review of language assessment tools, see Fenson et al., 1994). It would also be informative to explore factors that facilitate the acquisition of walking (e.g., body proportion, temperament, household environment, parenting style) to determine the role of such factors in the observed boost in language development.

Longitudinal naturalistic observations are also needed to explore the differences in language development found in the present investigation. Conducting naturalistic observations prior to, at, and following the acquisition of walking would be very informative for examining how walking impacts the social environment, and the relation of such changes to language development. Furthermore, the present observational context standardized infants' opportunity to explore and engage with the environment and mirrored situations in which parent attention is divided. However, comparisons with other parent–child observational studies (reviewed above) may be limited due to differences in the observational context.

Finally, just as the onset of walking seems to precede changes in a multitude of psychological phenomena, multiple processes are likely to contribute to the observed differences in language development. Our findings linked language development with the social environment, but research is needed to examine how the onset of walking precedes or may organize other areas of development linked with language development (some of which have been highlighted above). Component processes involved in language learning may be influential and dependent on one another (see Diesendruck, 2007; Shatz, 2007), highlighting the need to examine the interplay between such factors.

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