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A Cross-National Investigation of the Relationship Between Infant Walking and Language Development

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The acquisition of walking has recently been linked with infant language development (Walle & Campos, 2014). If this relation reflects the consequence of an epigenetic event, then it should be present regardless of when the infant typically begins to walk, the infant's culture, and the infant's native language. This study sought to replicate the previously reported link between walking and language development in American infants and investigate whether this relation exists cross-nationally in typically developing Chinese infants exposed to Mandarin. Urban Chinese infants not only provide a distinct linguistic and cultural population in which to study this relation but also typically begin walking approximately 6 weeks later than American infants. Our results demonstrated that (1) walking infants in *both* the American and Chinese samples had greater receptive and productive vocabularies than same-aged crawling infants, (2) differences between crawling and walking infants were proportionally similar in each sample, and (3) the walking-language relation was present for

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both noun and non-noun vocabularies. These findings provide further support of a relation between infant walking onset and language development, independent of age. Avenues for future research of the processes involved in this relation, as well as additional populations of interest to investigate, are discussed.

Early developmental transitions in human infancy, such as the acquisition of new motoric skills, serve as catalysts for changes in person-environment relations. Such transformational events have been termed epigenetic because their acquisition creates experiences that facilitate new psychological skills (Gottlieb, 1983)[1]. Thus, it is not necessarily the emergence of the skill that is of great importance, but rather the functional consequences of its onset on related systems (Campos, Kermoian, Witherington, Chen, & Dong, 1997).

A commonly studied example is the onset of crawling (see Campos et al., 2000). The acquisition of crawling has been linked to infant perceptual, social, cognitive, and neurological development (Bell & Fox, 1996; Campos, Kermoian, & Zumbahlen, 1992; Campos et al., 1997; Higgins, Campos, & Kermioan, 1996; Kermoian & Campos, 1988; Tao & Dong, 1997; Telzrow, Campos, Kermoian, & Bertenthal, 1999; Zumbahlen, 1997; Zumbahlen & Crawley, 1997). The onset of walking is another major, but less studied, developmental transition. Walking is a more efficient means of movement than crawling (Sparrow & Irizarry-Lopez, 1987), offers a more flexible vantage point (Clearfield, 2004), and frees the hands to explore and share objects and events of interest (Clearfield, Osborne, & Mullen, 2008). The onset of walking has been found to result in increased infant object exploration and object sharing with caregivers (Karasik, Tamis-LeMonda, & Adolph, 2011) and corresponds with a reorganization of the parent–child relationship, leading to more positive exchanges, as well as more interpersonal conflicts, between the infant and caregiver (Biringen, Emde, Campos, & Appelbaum, 1995). The above changes in infants' interactions with their environment likely have implications for a number of psychological areas. One such area, and the focus of this paper, is infant language development.

Some researchers have speculated that changes in the infant social ecology following the acquisition of walking may be associated with language acquisition (see Iverson, 2010). The first empirical evidence clearly demonstrating a link between infants' transition to walking, and their language development was reported by Walle and Campos (2014). In both a longi-

[1]While definitions of epigenetic or epigenesis vary in the literature, use of the term in the present paper refers specifically to phenomena described by Gottlieb (1983, 1991).

tudinal and a cross-sectional study, parental report revealed that walking infants had larger receptive and productive vocabularies than crawling infants, independent of age. While it seems unlikely that the acquisition of walking directly causes an increase in infant language development, we believe that walking may act as an epigenetic event that fundamentally changes infant psychological functioning in a host of related psychological domains. As discussed previously (see Walle & Campos, 2014), walking may be associated with changes in neurological development (e.g., stepping coordination may help facilitate the development of the cerebellum and hemispheric lateralization of the brain), communicative usage and understanding (e.g., infant pointing and sharing of objects with adults may increase opportunities for labeling), physical movement and behavior (e.g., increased efficiency of movement may result in greater exploration of the environment and exposure to novel objects), and social interactions (e.g., parents may alter their speech in accordance with what is perceived to be a more competent social partner). Thus, the effects of walking on the infant may be far-reaching, and, of perhaps greater importance, likely act in concert to facilitate development in an epigenetic fashion.

If walking serves as an epigenetic event that significantly impacts language development, one would hypothesize that this relation would exist in multiple languages, in multiple cultures, and be independent of when the infant typically began to walk. Because the experimental control of infant walking onset is exceedingly difficult, and clinical delays in walking are typically associated with deficits in other areas, we sought an "experiment of nature" (Bronfenbrenner, 1977) using a population with a naturally occurring, nonclinical delay in the onset of walking. Previous research has found that normative developmental trajectories of infant motor skills vary across cultures (for a review, see Adolph, Karasik, & Tamis-LeMonda, 2010). Given the universal nature of the acquisition of upright locomotion and language in typically developing humans, we hypothesized that the relation reported by Walle and Campos (2014) would replicate with a non-Western, non-English speaking population. One population fitting the above criteria and thus selected for the present investigation is infants from Shanghai, China exposed to Mandarin Chinese, who typically begin to walk approximately 6 weeks later than American infants. The difference in age of walking onset between American and Chinese infants provides the unique opportunity to examine the relation of walking and language development using a nonclinical population with a different normative age of locomotor onset.

Locomotor, Cultural, and Linguistic Differences in Development

Research utilizing diverse populations permits the study of phenomena that may develop via distinct trajectories due to variability in developmental pressures and affordances. Such differences are clearly evident between American infants and infants growing up in urban China. As with most cross-cultural studies, there are myriad ways that Chinese and American infants differ that could confound comparative analyses of development. However, of critical importance is the similarity that infants in both cultures undergo a transition to walking despite such differences. Thus, investigating whether infants in both cultures show differences in vocabulary size as a function of acquiring a new motoric skill (i.e., walking) serves to highlight the phenomenon of interest. Of central importance to the present investigation is that although Chinese and American infants reach similar motoric and linguistic developmental milestones, the timing toward proficiency and environmental input for such skills is different for each population.

Research indicates that American infants typically experience motoric transitions earlier than is commonly observed in infants in urban China. Tao and Dong (1997) reported that urban Chinese infants on average began crawling at 9.5 months of age, roughly 6–8 weeks later than American infants. The authors reasoned that Chinese infants had less space for crawling due to smaller households, and Chinese parents were reluctant to have their infants crawl on the ground because of hygienic concerns. A similar delay in the onset of infant walking has been reported, with Chinese infants typically walking steadily without falling at about 13.5 to 14.5 months of age (Fan & Zhou, 1983; Jia, 2013; Li & Li, 1978), approximately 1–2 months later than American infants. This discrepancy in the onset of walking was not hypothesized to be the result of any biological or pathological factor, but rather more likely the result of economic factors, cultural factors, and parenting practices (for similar accounts, see Hopkins & Westra, 1988; Super, 1976; Werner, 1972). Thus, while one cannot randomly assign infants to early or late walking groups, a comparison of American and urban Chinese infants allows for a naturally occurring grouping of predictably early and late walkers. Furthermore, because the age of walking onset, be it "early" or "late," is typical for each population, concerns over possible deficits and delays in other domains are less likely.

If the onset of walking is related to language development, independent of age, it remains possible that cultural differences in the perceptual and social environment may result in developmental differences in the magnitude of the relation of walking and language development. Research indicates that Chinese individuals tend to focus on the contextual elements associated with objects (e.g., the relationship of a target object with background elements), whereas individuals from Western cultures are more likely to focus on discrete object properties (e.g., specific features of the target object over background elements) (e.g., Ji, Peng, & Nisbett, 2000; Masuda & Nisbett, 2001). The effects of these cultural differences can be found early in development (Chiu, 1972), and research suggests that the effect of culture, over and above differences in linguistic structure, leads to such differences in Chinese and American categorization of objects (Ji, Zhang, & Nisbett, 2004). Such cultural differences may result in qualitatively different parent labeling patterns and child perception of the environment as the child begins to walk, particularly if caregivers differ in making salient for the infant individual objects in the environment versus the relations between objects and the self.

Finally, the inclusion of Chinese infants in this study allows for a comparison of the relation of walking development with two very distinct languages: Mandarin Chinese and English. Research indicates clear differences in the syntactic and pragmatic features of Mandarin Chinese and English that together affect language development (see Tardif, Shatz, & Naigles, 1997). For example, unlike English, Mandarin Chinese is a pro-drop language in which inclusion of the subject may be optional, leading to a greater occurrence of nouns being omitted from sentences. Verbs in Mandarin Chinese are also less heavily inflected than those in English, which increases the phonological consistency of verbs across contexts. Observational data indicate that the noun bias, which is commonly found in English language environments, is less pronounced in Mandarin Chinese language environments (Tardif, Gelman, & Xu, 1999). The above differences are hypothesized to account for Mandarin Chinese infants having a greater proportion of verbs in their early linguistic development (e.g., Tardif, 1996; Tardif et al., 1999) than what is commonly found in other languages, such as English (e.g., Goldfield, 1993; Shatz, 1994). The above linguistic differences may differentially impact the relation between walking and language development, specifically with regard to semantic categories, such as nouns and non-nouns. For example, increased infant movement and exploratory behaviors following the onset of walking may generate increased caregiver non-noun usage, and languages featuring more easily identified non-nouns may allow for greater ease of these words being added to the infant lexicon. An examination of how noun and non-noun vocabulary development relates to the onset of walking is called for.

The above research indicates clear differences in Chinese and American infants' locomotor development, cultural variation in relational aspects of objects in the environment, and distinct syntactic and pragmatic features specific to Mandarin Chinese and English. Most critically, the difference in typical age of walking onset between American and urban Chinese infants will allow us to explore the relation of walking and language development, independent of age, in a nonclinically delayed locomotor group. If the relation of walking and language represents an epigenetic phenomenon, then this relation should be present despite the locomotor, cultural, and linguistic differences highlighted above. Furthermore, the cultural and linguistic differences in relational emphasis and prevalence of nouns in the language environment call for comparisons of how walking is related to each sample and whether particular types of words are differentially related with walking, specifically nouns.

The Present Investigation

This study employed an age-held-constant design to compare crawling and walking infants of two distinct cultures, specifically American infants and Chinese infants. The question of primary importance was whether the relation between infant walking onset and language development would be present cross-linguistically and cross-nationally. We hypothesized that walking infants would have larger receptive and productive vocabularies than same-aged crawling infants in both the sample of American infants and the sample of Chinese infants exposed to Mandarin Chinese. We also predicted that the differences in receptive and productive language between crawling and walking infants would be proportionally similar for the American and Chinese samples. Finally, given the differences in noun and non-noun development in English and Mandarin Chinese, we sought to explore the relation of walking onset on noun and non-noun receptive and productive vocabulary. Although there are differences in noun and non-noun prevalence and emphasis between English and Mandarin Chinese, we believed that the effect of walking would be broad enough to affect both nouns and non-nouns alike. Thus, we hypothesized that the effect of walking would be similarly present for both types of words in each sample.

METHOD

Participants

American infants

Forty infants (21 crawling infants, 8 female; 19 walking infants, 10 female), each 12.5 months of age, were recruited from [a major urban area]. Infant language exposure was assessed via parental report. The average American infant heard English spoken for 88% of their day and was exposed to 1.45 languages. Other languages to which infants were exposed included Spanish (n = 13), French (n = 4), Mandarin Chinese (n = 2), Arabic (n = 1), Cantonese (n = 1), Hungarian (n = 1), Italian (n = 1), Japanese (n = 1), Konkani (n = 1), Korean (n = 1), Russian (n = 1), Tagalog (n = 1), Tamil (n = 1), as well as baby sign language (n = 2). The average parent age was 34 years (SD = 4 years) and parent education ranged from having a high school diploma to a graduate degree, with most parents having a bachelor's degree. The average household income was $92,000. The American sample was ethnically representative of the diverse population of the local area. The majority of infants in the American sample were only children (only child = 25; 1 sibling = 10; 2 siblings = 5).

Chinese infants

Forty-two infants (21 crawling infants, 11 female; 21 walking infants, 8 female) between 13 and 14.5 months of age recruited in Shanghai, China, were included in the Chinese infant sample. This age range of walking onset was determined by the motor development norm used by local pediatricians in Shanghai. The tighter age range for the American infant sample was the result of investigators being able to draw participants from an existing database of families, whereas such a database was not available from which to recruit Chinese infants. Walking and crawling infants did not significantly differ in age (Walking infants: M = 13.89, SD = 0.37; Crawling infants: M = 13.75, SD = 0.31, $t(42)$ = 1.37, p = .18). Parents reported on their infant's language exposure. The average Chinese infant was exposed to primarily Mandarin and Shanghainese (or the Shanghai dialect), a dialect of Chinese commonly spoken in Shanghai (97%). Very few infants (3%) had exposure to English words through daycare centers, and the exposure never exceeded 10% of all language input. All infants were exclusively Hans, the majority ethnic group in the Chinese population. Parent education ranged from middle school to a graduate degree, with the average parent having a bachelors or bachelors equivalent degree. The average family income was ¥100,000 (approximately $14,700, based on the exchange rate when the data were collected), which is comparable in value to the income from the American sample. All infants in the Chinese sample were the only child in their family when entering the study.

Measures

Locomotor development

Parents completed a basic locomotor questionnaire to report on specific motoric milestones and their onsets. Specific to this study, parents reported when their infant began crawling and walking. Crawling onset was operationalized as when the child began self-locomoting a distance of twice his or her body length. Walking onset was operationalized as the infant locomoting bipedally a distance of 10 feet without falling or needing assistance. These definitions were based on previous investigations involving infant locomotor development (see Adolph, 1997; Adolph, Vereijken, & Shrout, 2003; Walle & Campos, 2014).

Language development

All families completed a version of the MacArthur-Bates Communicative Development Inventory. Families in the American sample completed an online version of the MacArthur-Bates Long Form Vocabulary Checklist: Level I (CDI) (Fenson et al., 1994). This language assessment tool contains a 396-item checklist that allows parents to mark words that their child "understands" (receptive vocabulary) or "understands and says" (productive vocabulary). The overall questionnaire consists of 19 semantic categories (e.g., toys, people, games, and routines). Parents were permitted to mark words that their infant understood or produced in languages other than English, including signing.

Families in the Chinese sample completed the Mandarin version of the MacArthur-Bates Long Form Vocabulary Checklist: Level I (Tardif, Fletcher, Zhang, Liang, & Zuo, 2008), or Putonghua CDI (PCDI). The PCDI contains a 411-item checklist that allows parents to mark words that their child "understands" or "understands and says." The overall questionnaire consists of 20 semantic categories, and parents were permitted to mark words that their infant understood or produced in Mandarin or dialects spoken at home, including Shanghainese.

Internal validity and test–retest reliability have been established for the English CDI by Fenson et al. (1994) and for the PCDI by Tardif et al. (2008). Examination of the developmental norms reported by Fenson et al. (1994) and Tardif et al. (2008) indicates that Chinese infants' Mandarin receptive, but not productive, vocabularies are typically larger than those of American infants. Tardif et al. (2008) noted these differences, but did not believe it to be the result of parental biases in reporting, and both language groups share similar patterns in vocabulary growth from 8 to 16 months. Subsequent comparisons of CDI and PCDI scores in the present investigation used proportions rather than raw scores to account for these differences.

RESULTS

American sample

American crawling and walking infants' receptive and productive vocabulary scores are presented in Figure 1. The American walking infants had significantly larger receptive vocabularies ($M = 135.32$, $SE = 14.45$) than crawling infants ($M = 84.76$, $SE = 11.88$), $t(40) = 2.73$, $p = .01$, $d = 0.86$, 95% CI [−88.144 to −12.96]. The American walking infants also had larger productive vocabularies ($M = 28.58$, $SE = 4.64$) than crawling infants ($M = 11.76$, $SE = 2.16$), $t(40) = 3.39$, $p = .003$, $d = 1.17$, 95% CI [−27.34, −6.30]. These findings replicate the differences between locomotor groups in American infant samples reported by Walle and Campos (2014).

Because walking infants had significantly more self-produced locomotion (SPL) experience (months since crawling onset) ($M = 4.92$, $SE = 0.32$) than crawling infants ($M = 3.50$, $SE = 0.34$), $t(37) = 2.99$, $p = .005$, $d = 1.01$, 95% CI [−2.38, −0.45][2], regression analyses including Walking Status (crawling versus walking) and total SPL were conducted to determine the independent effects of each variable on infant language development. For receptive vocabulary, the effect of total SPL was not significant, $\beta = .23$, $t(37) = 1.38$, $p = .18$, whereas a marginal effect remained for Walking Status, $\beta = .33$, $t(42) = 1.97$, $p = .058$.[3] For productive vocabulary, the effect of total SPL was not significant, $\beta = .22$, $t(37) = 1.36$, $p = .18$, but the effect of Walking Status remained significant, $\beta = .39$, $t(37) = 2.42$, $p = .021$.

Chinese sample

Similar to their American counterparts, Chinese walking infants displayed larger receptive and productive vocabularies than Chinese crawling infants (see Figure 2). Receptive vocabulary was significantly larger for walking infants ($M = 241.28$, $SE = 16.23$) than crawling infants ($M = 186.90$, $SE = 15.25$), $t(42) = 2.44$, $p = .019$, $d = 0.77$, 95% CI [−99.48, −9.28].

[2]Three parents in the American sample failed to report infant age of crawling onset.

[3]The loss of power resulting from three participants not having total SPL scores and the inclusion of a covariate likely accounts for this relation becoming marginal.

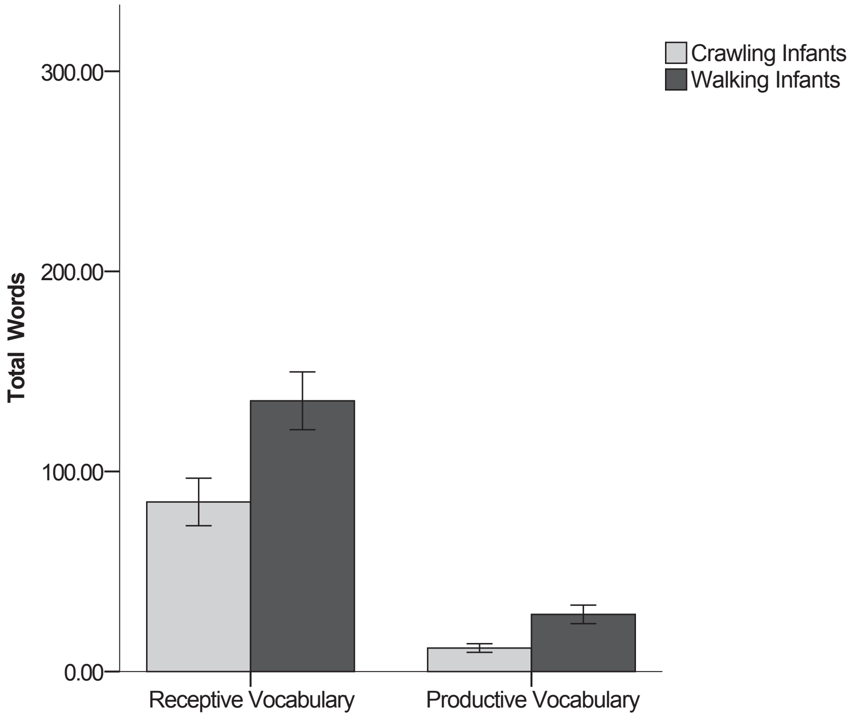

Figure 1 Mean number of words understood and produced by American crawling infants and walking infants using the CDI vocabulary checklist. Error bars represent +/− 1 standard error.

Productive vocabulary was also significantly larger for walking (M = 21.67, SE = 2.78) than crawling infants (M = 7.90, SE = 1.30), $t(42) = 4.49$, $p < .001$, $d = 1.42$, 95% CI [−20.04, −7.48]. An analysis of covariance was conducted to rule out the possibility of an age effect for the Chinese sample because of the larger age range. Locomotor Status remained a significant predictor of receptive vocabulary, $F(1,39) = 3.98$, $p = .05$, after partialing out Age, $F(1,39) = 6.97$, $p = .01$. Locomotor Status also significantly predicted productive vocabulary, $F(1,39) = 17.10$, $p < .001$, independent of Age, $F(1,39) = 2.22$, $p = .14$.

As with the American sample, Chinese walking infants also had more self-produced locomotion (SPL) experience (months since crawling onset) (M = 4.98, SE = 0.18) than crawling infants (M = 4.39, SE = 0.24), although this effect was only marginal, $t(42) = 1.93$, $p = .06$, $d = 0.60$, 95% CI [−1.20, 0.03]. Thus, regression analyses including Walking Status

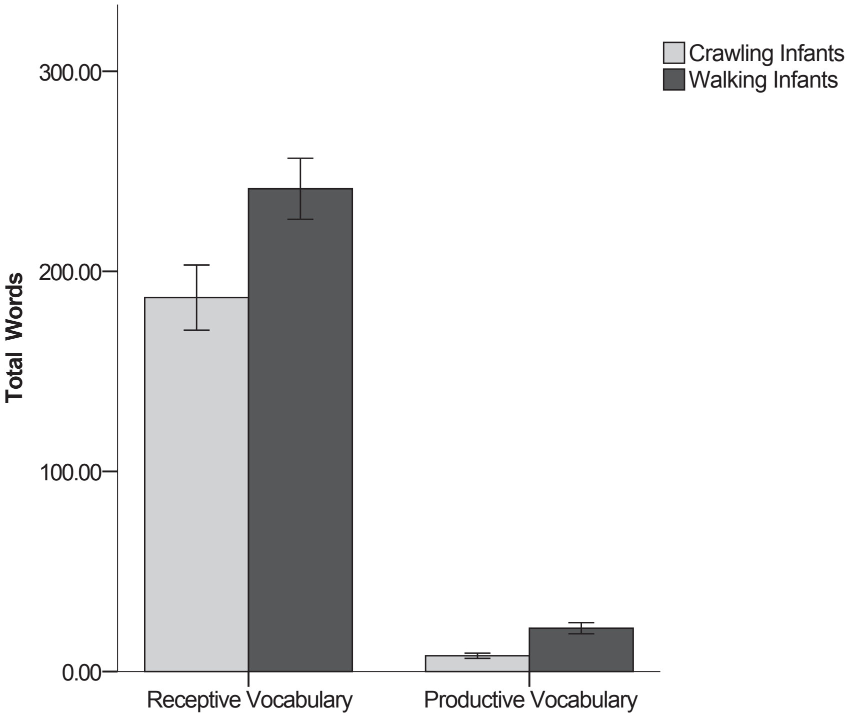

Figure 2 Mean number of words understood and produced by Chinese crawling infants and walking infants using the PCDI vocabulary checklist. Error bars represent +/– 1 standard error.

(crawling versus walking) and total SPL were conducted to determine the independent effects of each variable on infant language development. For receptive vocabulary, the effect of total SPL was not significant, $\beta = .10$, $t(42) = 0.62$, $p = .54$, whereas a significant effect remained for Walking Status, $\beta = .33$, $t(42) = 2.13$, $p = 0.04$. Similarly, for productive vocabulary, the effect of total SPL was not significant, $\beta = -.08$, $t(42) = -0.58$, $p = .57$, and the effect of Walking Status remained significant, $\beta = .60$, $t(42) = 4.43$, $p < .001$.

Differences in the differences: American versus Chinese infant language differences

Having established the presence of language differences between crawling and walking infants in both the American and Chinese samples, a subsequent set of analyses was conducted to determine whether these differences were of similar magnitude between the two cultures. As noted above, the English and Mandarin CDIs contain a different number of total items in their respective vocabulary checklists. Furthermore, because the Chinese infants were older due to their normative delay in walking onset, their receptive language scores were larger on average compared with the American infants (productive vocabulary size was similar between the two samples, which is consistent with the English and Mandarin Chinese norms reported by Fenson et al., 1994 and Tardif et al., 2008, respectively). Thus, a test of proportions was carried out to examine whether the language differences between crawling and walking infants were comparable for the American and Chinese infant samples. Differences between proportions of the language samples were calculated as follows:

$$\left(\frac{\begin{array}{c}\text{Mean US Crawling}\\ \text{Infant Vocabulary}\end{array}}{\begin{array}{c}\text{Mean US Walking}\\ \text{Infant Vocabulary}\end{array}}\right) - \left(\frac{\begin{array}{c}\text{Mean Chinese Crawling}\\ \text{Infant Vocabulary}\end{array}}{\begin{array}{c}\text{Mean Chinese Walking}\\ \text{Infant Vocabulary}\end{array}}\right) = \text{Proportional Difference}$$

Proportional differences in receptive vocabulary for crawling and walking infants did not significantly differ between American (proportion = 0.63, $SE = 0.01$) and Chinese (proportion = 0.78, $SE = 0.01$) infants (proportional difference = 0.15, $SE = 0.10$), $z = 1.50$, $p = 0.14$. Similarly, the differences in productive vocabulary were also statistically similar in the American (proportion = 0.41, $SE = 0.01$) and Chinese (proportion = 0.37, $SE = 0.01$) samples (proportional difference = 0.04, $SE = 0.11$), $z = 0.40$, $p = 0.67$. These findings indicate that the differences in crawling and walking infants' language development were statistically similar between the American and Chinese samples.

Noun and non-noun vocabularies

A final set of analyses was conducted for each sample to explore whether differences in language development were specific to nouns.[4] Scores on the CDI were separated into two categories: the noun categories identified by Fenson et al. (1994) and non-noun categories. For each sample, we first compared crawling and walking infants' receptive and productive vocabulary size of nouns and non-nouns. We then examined the proportion of nouns to non-nouns of each sample (nouns/(nouns + non-nouns) and we

[4]The present sample sizes do not permit exploring locomotor differences for each semantic category because the correction factor would severely minimize the power of the analyses.

compared these proportions for crawling and walking infants to explore whether walking differentially affected nouns or non-nouns.[5]

American sample

American walking infants (M = 92.58, SE = 10.81) had significantly larger receptive vocabularies for nouns than crawling infants (M = 55.10, SE = 8.09), $t(40) = 2.81$, $p = .008$, $d = 0.88$, 95% CI [−64.50, −10.47]. Interestingly, this difference was also found for non-noun vocabularies, with walking infants (M = 42.74, SE = 3.91) understanding more non-noun words than crawling infants (M = 29.67, SE = 3.93), $t(40) = 2.35$, $p = .02$, $d = 0.76$, 95% CI [−24.33, −1.81]. A similar pattern of findings was present for productive vocabulary size. American walking infants produced more nouns (M = 21.63, SE = 3.47) than crawling infants (M = 8.29, SE = 1.59), $t(40) = 3.50$, $p = .002$, $d = 1.14$, 95% CI [−21.20, −5.49] and also produced more non-nouns (M = 6.95, SE = 1.33) than crawling infants (M = 3.48, SE = 0.69), $t(40) = 2.32$, $p = .028$, $d = 0.74$, 95% CI [−6.53, −0.41].

The proportion of nouns to non-nouns for the American sample was significantly above 0.50 for receptive vocabulary (M = 0.65, SE = 0.01), $t(40) = 13.01$, $p < .001$, $d = 4.11$, 95% CI [0.13, 0.17], as well as productive vocabulary (M = 0.72, SE = 0.03), $t(39) = 7.79$, $p < .001$, $d = 2.49$, 95% CI [0.17, 0.28]. We then examined whether the proportion of nouns to non-nouns was similar for crawling and walking infants. The proportions for receptive vocabulary did not significantly differ between walking (M = 0.67, SE = 0.02) and crawling (M = 0.64, SE = 0.01) infants, $t(40) = 1.30$, $p = .20$, $d = 0.42$, 95% CI [−0.08, 0.02]. A similar result was found for productive vocabulary, with walking (M = .77, SE = 0.03) and crawling (M = 0.68, SE = 0.05) infants having similar proportions, $t(39) = 1.75$, $p = .09$, $d = 0.58$, 95% CI [−0.21, 0.02].

Chinese sample

Chinese walking infants (M = 127.24, SE = 8.78) also had significantly larger receptive vocabularies for nouns than crawling infants (M = 96.90, SE = 9.59), $t(42) = 2.33$, $p = 0.03$, $d = 0.74$, 95% CI [−56.61, −4.06]. This difference was also present for non-noun vocabulary, with walking infants (M = 114.05, SE = 7.08) understanding more words than crawling infants

[5]One American infant and three Chinese infants had productive vocabulary scores equal to 0 and thus were treated as missing data in calculating the mean proportion of nouns to non-nouns for productive vocabulary.

(M = 90.00, SE = 7.53), $t(42) = 2.33$, $p = .03$, $d = 0.74$, 95% CI [−44.93, −3.17]. Productive vocabulary showed a similar pattern of findings. Chinese walking infants produced more nouns (M = 7.38, SE = 1.31) than crawling infants (M = 3.57, SE = 0.56), $t(42) = 2.38$, $p = .01$, $d = 0.75$, 95% CI [−.72, −0.89] and also produced more non-nouns (M = 14.29, SE = 1.78) than crawling infants (M = 4.33, SE = 0.99), $t(42) = 4.89$, $p < .001$, $d = 1.55$, 95% CI [−14.10, −5.80].

Chinese infants' proportion of noun to non-noun vocabulary was significantly higher than 0.50 for receptive vocabulary, (M = 0.52, SE = 0.01), $t(42) = 2.03$, $p = .05$, $d = 0.63$, 95% CI [0.00, 0.04], but significantly lower than 0.50 for productive vocabulary, (M = 0.41, SE = 0.03), $t(39) = 2.78$, $p = .01$, $d = 0.89$, 95% CI [−0.16, −0.03]. Again, we examined differences in crawling and walking infants' proportion of nouns to non-nouns. The proportions did not significantly differ for receptive vocabulary between walking infants (M = 0.52, SE = 0.01) and crawling infants (M = 0.51, SE = 0.02), $t(42) = 0.60$, $p = 0.55$, $d = 0.19$, 95% CI [−0.05, 0.03]. However, productive vocabulary proportion of nouns to non-nouns was significantly different for walking (M = 0.32, SE = 0.03) and crawling (M = 0.51, SE = 0.06) infants, $t(39) = 2.97$, $p = 0.01$, $d = 0.88$, 95% CI [0.06, 0.32], indicating that non-noun vocabulary was differentially positively affected by the acquisition of walking in the Chinese infants.

DISCUSSION

The present investigation replicated and extended previous research indicating a link between the acquisition of infant walking and language development. Our results in the American infant sample replicated the findings of Walle and Campos (2014), demonstrating that walking infants have significantly larger receptive and productive vocabularies than same-aged crawling infants. The present study also extended this link cross-nationally and cross-linguistically with a sample of infants from Shanghai, China. The walking Chinese infants also had significantly larger receptive and productive vocabularies than same-aged crawling infants. This finding emerged despite Chinese infants acquiring walking approximately 6 weeks later than the American infants. Replication of this finding in a nonclinically delayed walking group supports the view of walking as an epigenetic event that is associated with language development independent of when this locomotor transition occurs or in what linguistic or cultural context. Furthermore, the relation of language with walking was present even after controlling for infants' total self-produced locomotor experience. This further supports the conclusion that a qualitative shift in language development occurs with the acquisition of walking.

The observed receptive and productive vocabularies for American and Chinese infants were consistent with reported norm values by Fenson et al. (1994) and Tardif et al. (2008). Proportional analyses indicated that the differences between Chinese crawling and walking infants' receptive and productive vocabularies were comparable to those from the American sample. This suggests that the functional relation between walking and language may be similar for typically developing early and later walkers. Additionally, it warrants noting that although the relation of walking and language was similar across samples for receptive and productive language, Chinese infants' productive vocabulary was much closer in size to American infants' than were each group's respective receptive vocabularies. It is possible that the similarity in productive vocabulary size between the two samples is indicative of the development and coordination of physiological aspects specific to productive language, such as the vocal tract, the diaphragm, and respiration (see Boliek, Hixon, Watson, & Morgan, 1996; Openshaw, Edwards, & Helms, 1984; Thelen, 1991; Vorperian et al., 2005), that may correspond with the acquisition of upright locomotion. Thus, while the Chinese infants' receptive vocabularies likely grew during the 6-week period of maturation over and above that of the American infants, postural constraints may have restricted this age effect from manifesting in their productive vocabulary. Of course, this is only one possible explanation for the findings and further research examining how physical aspects of speech production may change following the acquisition of upright locomotion is required.

Our results also indicate that the distinct linguistic features specific to Mandarin Chinese and English did not affect the link between infant walking and language development. Specifically, walking was associated with the development of nouns and non-noun vocabularies in both the American and Chinese samples, despite the greater proportion of non-nouns understood and produced by Mandarin Chinese infants. This may indicate that walking has a more general association with language learning or that walking changes the language environment in a way that affects nouns and non-nouns alike. For example, walking may be linked with an increase in noun labels, as a result of increased object sharing, as well as an increase in the prevalence of non-nouns, such as verbs used to describe infant actions and adjectives resulting from a richer language input to a social partner believed more competent. Thus, the functional changes related with the onset of walking may affect the infant in such a way that is independent of the qualities of the language to which the infant is exposed.

Finally, both the American and the Chinese infants showed a noun bias in their receptive and productive vocabularies, but this bias was much more pronounced for the American sample. These results are consistent with previous research indicating a less pronounced noun bias for Mandarin-speaking infants (e.g., Tardif et al., 1999). A closer examination compared the proportions of nouns to non-nouns of crawling and walking infants in each sample. For American infants, the noun bias in receptive and productive vocabulary was similar in size for both crawling and walking infants. However, although Chinese infants' receptive vocabularies showed a similar ratio of nouns to non-nouns between locomotor groups, Chinese walking infants' productive vocabularies had a significantly greater proportion of non-nouns to nouns than did Chinese crawling infants. This finding is further explored in the subsequent section.

Taken together, the present study supports the view that the acquisition of walking is an epigenetic event that is related to infant language development, independent of age, across two different languages and cultures.

Follow-up questions and considerations

While the present empirical investigation supports the link between walking acquisition and language development, there remain a number of unanswered questions and considerations for future research.

Mechanisms

First and foremost, this study only begins to scratch the surface of elucidating the underlying mechanisms affected by this locomotor transition. Language learning is a multifaceted developmental process. The acquisition of walking is likely to have significant psychological consequences in a number of areas, some of which likely relate to language development (see Walle & Campos, 2014). One such capacity could be infants' understanding of communicative cues directed toward referents outside of their visual field, which has been found to develop in the second year of life (Butterworth & Cochran, 1980; Butterworth & Jarrett, 1991; Deák, Flom, & Pick, 2000). It is possible that walking infants' increased ability to pivot and look behind them may improve infants' understanding of the self in relation to objects in space. Such development could increase infants' understanding of the referent of pointing gestures to objects outside the infant's visual field, and hence, to the labeling of objects in such positions. Another aspect relevant to the affordances of walking is gesture, an important tool for infant language learning (e.g., Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Walking infants demonstrate greater gesturing than crawling infants (Clearfield et al., 2008; Karasik et al., 2011), and more mobile bids for attention, which in turn elicit differential maternal responses (Karasik, Tamis-LeMonda, & Adolph, 2013). Thus, walking infants may help create richer and more infant-driven language learning contexts. It is also possible that infants' increased first-hand experience with gesturing helps facilitate appreciation of the communicative intent of others' gestures (see Sommerville, Woodward, & Needham, 2005). Research is needed to explore how changes in various psychological domains may mediate the relation between walking and language development. Additionally, while this study included infants within the normative age ranges of typical walking onset in each country, it remains possible that infants who walk earlier are simply more advanced across the board than infants who walk later. Although the developmental language trajectories reported in the longitudinal study by Walle and Campos (2014) provide some evidence contrary to a general maturational explanation, inclusion of tasks *not* expected to be impacted by motoric development would serve as effective tests of discriminant validity to help rule out this alternative explanation. More broadly, we do not believe that a general maturational account of the findings need necessarily be at odds with an effect of motoric development. An infant may be precocious in many areas, and yet the onset of walking may still have a unique relation with developmental outcomes, such as language.

Universality

Although the presence of a relation between walking and language in the Chinese sample lends support that this phenomenon may be wide reaching in human development, it by no means provides evidence that this is a universal finding. Normative ages for locomotor transitions vary across cultures (for a review, see Adolph et al., 2010). For example, infants from Jamaica (Hopkins & Westra, 1990) and Uganda (Geber & Dean, 1957a,b; Kilbride, Robbins, & Kilbride, 1970) begin to walk at 10 months and 9–11.7 months, respectively, approximately 6–12 weeks earlier than is common for American infants (and 16 weeks earlier than Chinese infants). Such precocity is believed to be at least partially explained by cultural differences (see Hopkins & Westra, 1988; Super, 1976; Werner, 1972). Research examining the walking and language link using infants from other cultures who typically begin walking at different ages would be very informative. In all such studies, inclusion of age-matched early and later walking infants across samples could help identify skills specifically related to the acquisition of walking and those resulting from maturation. In addition to cross-cultural difference in motoric development, parent–infant interaction patterns associated with motoric development may also be of importance. For example, caregivers in the Gusii tribe of Kenya are more likely to hold infants after the onset of walking than is observed in other cultures (LeVine et al., 1994) and do not typically conversationally engage infants in the first 2 years of life (LeVine et al., 1994; Richman, Miller, & LeVine, 1992). Study of populations that naturally vary in childcare practices would allow for a natural control of infant exploratory behavior and social interaction. Another population of interest would be infants who sign (both with and without hearing impairments). It would be fascinating to examine the possible role of hands-free locomotion in facilitating these infants' communicative abilities.

Measurement

This study was limited by its reliance on parental report. Although extensive validation for both the CDI and PCDI has been reported, these measures rely on parents to accurately report their child's vocabulary. It is possible that parents of walking infants may attribute greater language to their infants because of differences in their perception of the infant (e.g., walking infants may be judged as more intentional or more competent). Naturalistic observation of mother–child interactions and direct testing of word comprehension and production would provide converging research to assess infant language development before and after the onset of walking. Additionally, although the proportional differences between crawling and walking infants were similar between the present samples, it is entirely possible that the process of language learning for each sample is unique. Thus, the same outcome may have been reached through different, culturally specific, processes. Finally, this study relied on parent report of locomotor development, particularly the onset of walking. While the onset of walking tends to be a memorable event, it is possible that our operationalization of a walking infant may have resulted in some error of parental reporting for when children met the specified criteria. Thus, in person assessment of infant locomotor development is advised in future investigations.

Semantic differences

The lack of statistical power prevented the current study from comparing specific CDI and PCDI semantic categories. Comparison of American and Chinese infants' vocabulary size of nouns and non-nouns demonstrated that both were affected by the onset of walking. Additionally, anecdotally, we can report that this pattern appears similar across semantic categories. However, research is needed to more thoroughly explore these differences and specifically look at various types of words (e.g., verbs, adjectives, pronouns, quantifiers, spatial words, people, manipulable objects). Of particular interest is further exploration of the finding that Chinese walking infants' non-noun productive vocabulary may be disproportionately affected by the acquisition of walking. Although we are unsure how to account for this finding, we offer some speculation. Tardif et al. (2008) reported that Chinese infants demonstrated significantly more production of non-nouns in their early vocabularies than American infants. The onset of walking may encourage this difference. It is possible that parental use of the pro-drop feature of Mandarin Chinese becomes more salient to infants as the infant becomes more physically active following the acquisition of walking. This could result in increased parent, and subsequently infant, labeling of actions over objects. Additionally, Chinese infants may begin to appreciate the utility of the pro-drop feature of their language at this point in development. Whereas American infants predominantly use nouns in early one-word utterances (e.g., "Ball" to communicate "Give me the ball") (see Nelson, 1973), Chinese infants may incorporate the pro-drop feature of their language and thus use non-nouns in one-word utterances more frequently (e.g., "Give" to communicate "Give me the ball"). Unpacking this finding emphasizes the importance of a longitudinal design that incorporates both naturalistic and laboratory observations of infant language and parent–infant interaction.

Heterogeneity of the sample

It is possible that the binary classification of infant locomotion used in this study may have missed important differences in infant walking skill. Learning to walk is a slow process (see Adolph et al., 2003) and the longitudinal findings by Walle and Campos (2014) indicate distinct, nonlinear developmental trajectories for receptive and productive language. Further research is needed to explore how differences in motoric skill and proficiency may affect language development. Additionally, we strongly encourage a follow-up longitudinal study including Chinese infants from both urban and rural areas. As discussed earlier in this paper, the discrepancy in the timing of walking onset in [US city] and Shanghai is likely the result of non-biological factors, as all children in this study were typically developing. However, anecdotal reports from Chinese pediatricians suggest that infants in rural China typically begin walking at ages similar to American infants, possibly because of increased physical space for movement and differences in caregiving practices in urban settings. These infants would serve as an excellent reference group: although they are being raised in the linguistic and cultural setting of mainland China, their walking onset would be expected to be more similar to American infants.

Conclusion

Taken together, the present research more clearly indicates the "what" (i.e., infant walking acquisition is related to language development), but considerable additional research is needed to investigate the "why." This lingering question remains daunting in its openness. However, we are optimistic that careful and creative research will help reveal the interrelated factors of this complex relationship.

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