HHS Public Access
Author manuscript
Dev Psychol. Author manuscript; available in PMC 2023 January 01.

Published in final edited form as:
Dev Psychol. 2022 January ; 58(1): 1–16. doi:10.1037/dev0001280.

Cascades in action: How the transition to walking shapes caregiver communication during everyday interactions

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Abstract

New motor skills supply infants with new possibilities for action and have consequences for development in unexpected places. For example, the transition from crawling to walking is accompanied by gains in other abilities—better ways to move, see the world, and engage in social interactions (e.g., Adolph & Tamis-LeMonda, 2014). Do the developmental changes associated with walking extend to the communicative behaviors of caregivers? Thirty infants (14 boys, 16 girls; 93% White, not Hispanic or Latino) and their caregivers (84% held a college degree or higher) were observed during everyday activities at home during the two-month window surrounding the onset of walking (*M* infant age = 11.98 months, range = 8.74–14.86). Using a cross-domain coding system, we tracked change in the rates of co-occurrence between infants' locomotor actions and caregivers' concurrent language and gesture input. We examined these relations on two timescales—across developmental time, as infants transitioned from crawling to walking, and in real time based on moment-to-moment differences in infant posture. A consistent pattern of results emerged: compared to crawling, bouts of infant walking were more likely to co-occur with caregiver language and gestures that either requested or described movement or provided information about objects. An effect of infants' real-time behavior was also discovered, such that infants were more likely to hear language from their caregivers when they moved while upright compared to prone. Taken together, findings suggest that the emergence of walking reorganizes the infant-caregiver dyad and sets in motion a developmental cascade that shapes the communication caregivers provide.

Keywords

infant locomotion; walking; caregiver communication; language input; gesture input; developmental cascades

The acquisition of new motor skills expands infants' opportunities for interactions with the objects and people in everyday life. This is evident across development. Learning to reach, for example, provides infants with new access to objects (Thelen et al., 1993). Sitting frees infants' hands and allows them to explore objects in new ways to learn about their properties (Soska & Adolph, 2014). Crawling mobilizes new social and emotional experiences with caregivers (Campos et al., 2000). And walking supports new ways to

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share objects and initiate social interactions (Karasik et al., 2011). In each case, motor skills supply infants with new possibilities for action and in turn extend outward, with consequences for development in unexpected places.

Recently, researchers have turned their attention to understanding these dynamic processes as infants transition from crawling to walking, documenting changes in infants' locomotor skills and in their social engagements with caregivers. Often, the motivation for such studies is to understand how the transition to walking relates to concurrent changes in infants' other abilities—what walking "buys" infants for locomotor exploration, visual access to the natural environment, and social interactions with objects and people (see Adolph & Tamis-LeMonda, 2014). Findings from this work consistently suggest that across the first year, as infants give up crawling in favor of walking, this transition is accompanied by substantial gains that enhance locomotor exploration in the service of social interaction. In other words, the ability to walk seems to equip infants with increased efficiency when engaging caregivers in social interactions.

The gains that accompany walking currently described in the literature, however, are examples of developmental advances within infants; that is, how walking supports possibilities for infants' other actions. Is it also possible that walking shapes the communicative behaviors of caregivers? Researchers have long been interested in bidirectional relations between the onset of independent locomotion in infancy and caregiver behavior (see Campos et al., 2000, for a review). Studies have shown links between changes in infant mobility and how caregivers perceive and interact with their infants, suggesting a *reorganization* in the infant-caregiver dyad spurred by the acquisition of new locomotor skills (Rheingold & Eckerman, 1970; Green et al., 1980; Campos et al., 1992; Biringen et al., 1995). But surprisingly little is known about whether locomotor transitions are also met with reciprocal change in caregivers' communication. The acquisition of new forms of locomotion (like walking) may not only enable possibilities for infants' own social actions; it may also shape the language and gestures produced by their caregivers.

This possibility is consistent with the idea of developmental cascades, or the view that achievements in one domain of development often have unexpected and far-reaching consequences in other developing systems (Bronfenbrenner, 1979; Masten & Cicchetti, 2010; Thelen & Smith, 1998). Here, we used the transition to walking as a developmental window to examine the presence of a potential reorganization in the infant-caregiver dyad. Specifically, we asked whether the emergence of walking in infancy acts as a setting event for downstream change in caregivers' language and gesture input and whether these disparate domains are linked by a developmental cascade. We examined these relations on two timescales—in the moment-to-moment exchanges between infant action and caregiver input in real time, and across developmental time as infants transition from crawling to walking.

The benefits of walking for social interaction

Why might walking shape caregivers' communicative input to infants? When infants walk, they spend more time in motion and travel faster and farther than when they crawl, reaching distal corners of playrooms in the laboratory and living rooms at home (Adolph et al., 2012). Moreover, as infants progress from crawling to walking, they use locomotion to explore space differently; they visit more locations and interact with more objects encountered en route (Karasik et al., 2011; Thurman & Corbetta, 2017). In the upright posture, infants' view of the world is also expanded. Exploration with eyes at a higher vantage gives infants the ability to spot distal caregivers and objects, enhancing possibilities for initiation of social interactions (Kretch et al., 2014). Indeed, infants look more at caregivers' faces when they are upright compared to prone (Franchak et al., 2018).

Home observations of infants across the transition from crawling to walking also show that relative to crawling infants, walking infants are more likely to access distal objects, carry them, and then share them by bringing them to their mothers (Karasik et al., 2011). Laboratory studies find that walkers initiate and spend more time engaged in complex social interactions with caregivers, drawing their attention to objects and producing adult-directed vocalizations and gestures during play (Clearfield et al., 2008; Clearfield, 2011). Another study, utilizing biweekly parent reporting, underscores these patterns, finding an increase in infants' initiations of joint engagement (via object sharing) after they began to walk (Walle, 2016). Even the simulation of walking produces similar effects. When given the ability to "walk" in mechanical walkers during free play in the laboratory, pre-crawling infants looked, smiled, and vocalized more to their mothers while moving upright with support as compared to stationary on the floor (Gustafson, 1984). And finally, a growing body of literature has demonstrated that the transition to walking appears to be an inflection point in infant language development, representing a period of rapid growth in both receptive and productive vocabulary, independent of age (e.g., Walle & Campos, 2014; West et al., 2019).

Caregivers' communicative input to crawling vs. walking infants

To date, a small number of studies have directly examined concurrent relations between infant locomotion and caregiver communication. In an experimental paradigm in the laboratory, researchers asked how mothers used language and gesture to encourage and discourage their infants' decisions for locomotion on an adjustable sloping walkway (Karasik et al., 2008). Novice crawlers, experienced crawlers, and experienced walkers were placed at the top of the walkway to descend slopes of varying steepness (see Adolph, 1997). As infants navigated the novel obstacle, mothers made spontaneous use of a large communicative repertoire, interleaving language and gesture into complex social messages that guided their infants' actions. Mothers communicated differently with experienced crawlers and walkers than to novice crawlers, providing more verb-based language (e.g., 'come here' or 'keep walking') and movement-focused gestures (e.g., outstretched arms that "called" the infant to descend to a particular location), perhaps keying in on their infants' advanced locomotor skills. This study provides a concrete example of how caregivers' communicative input is linked to infants' actions and attuned to locomotor experience.

Are these links also evident during everyday activities, when there are no particular goals for infants and no specific demands on caregiver communication? Some evidence comes from longitudinal work describing infants' social interactions involving objects and resulting language input from mothers during the transition from crawling to walking (Karasik et al., 2011, 2014). There were differences in the quality of infants' real-time social bids with objects as a function of locomotor status. Whereas crawlers opted to share proximal objects with outstretched arms from stationary positions, walkers were more likely to access distal objects and initiate social interactions with their mothers by moving to them with objects in hand (Karasik et al., 2011). In turn, mothers' language input was shaped by how infants shared objects—not just their locomotor status—such that moving bids (which were more likely to occur among walking infants) were best at eliciting verb-based action directives (e.g., 'stack the blocks') during communicative exchanges (Karasik et al., 2014). When crawlers shared objects by moving to their mothers, they also received the same types of language input as walkers, but less often. Taken together, these findings suggest that differences in the mechanics of locomotion between crawling and walking may enable walking to be a potentially more efficient way to initiate social interactions and elicit language input from caregivers.

However, infants hear language from caregivers regardless of their intent to share objects. A recent study measuring real-time language input to infants during daily routines at home provides initial evidence that infant locomotion influences caregiver communication more generally (Tamis-LeMonda et al., 2019). Researchers transcribed mothers' language input in relation to the specific activities within which language was embedded (e.g., book reading, object play). Interestingly, infants heard the greatest proportion of gross motor verbs (e.g., go, get, bring) when they engaged in "transitions," or time spent practicing motor skills like crawling and walking when switching between other activities.

Current study

The ability to walk supports effective social engagement with caregivers: walkers have better ways to move, explore features of the environment, see the world, and share objects. Does the transition to walking also shape how caregivers communicate with their infants? The existing literature on the cascading effects of infants' locomotor development on their social interactions with caregivers is limited by the reliance on comparisons of infants based on their locomotor status (e.g., crawlers vs. walkers) and consideration of only crawling and walking as behaviors of interest (see Gonzalez et al., 2019, for further discussion). Crawling infants, however, can and often do move in upright postures by using external sources of support: infants cruise along furniture or engage in supported walking with locomotor toys and people (Adolph et al., 2011). This particular type of locomotion presents an ideal contrast category to crawling and walking as it provides infants with presumably similar vantage points as when they walk but constrains opportunities for independent movement due to the need for support surfaces. However, studies have rarely included supported upright locomotion as a unique category for examination despite the fact that previous research has shown that infants' real-time behaviors may work in tandem with their umbrella status as crawler or walker to elicit communication from caregivers (e.g., Karasik et al., 2014).

Thus, this study had two overarching goals. First, we examined the relations between infant locomotion and caregiver communication on two timescales in an effort to understand whether the transition to walking (i.e., a change in locomotor status across developmental time) might trigger the cascade proposed above or whether infants' in-the-moment locomotor posture (i.e., prone vs. upright in real time) was also related to the language and gestures that caregivers produced (see Franchak et al., 2018, for a similar design). To this end, we compared caregiver input during bouts of crawling vs. supported upright locomotion before infants began to walk (i.e., pre-walk sessions) and during crawling vs. walking when walking emerged (i.e., walk sessions).

Second, motivated by the developmental cascades framework described above, we investigated the concurrent relations between infant locomotion and caregiver communication in two ways. The first was to examine rates of co-occurrence between caregiver language (verbs about actions, descriptive language about objects) and bouts of infant locomotion. Based on previous work, we expected that caregivers would be more likely to use action verbs when infants walked compared to when they crawled, especially if infants' change in skill served as a setting event for caregiver communication (e.g., Karasik et al., 2014). We also hypothesized that caregivers would be more likely to provide language input to upright vs. prone bouts as caregivers may recognize their infants to be on the cusp of walking and may change their online behavior in the context of infants' ongoing activity (e.g., Tamis-LeMonda et al., 2019).

The second was to examine rates of co-occurrence between caregiver gestures (movement gestures to beckon infants, show gestures to draw attention to and individuate objects) and bouts of infant locomotion. To our knowledge, gesture input when infants engage in locomotion during everyday interactions at home has not been previously reported in the literature. However, caregivers often produce gestures when they talk to their infants and thus, are an important feature of caregiver communication (Iverson et al., 1999). We expected higher rates of caregiver gesture when infants moved while upright compared to prone, considering that infants' upright vantage point might alert caregivers that infants can see their gestures (e.g., Alibali et al., 2001; Kretch et al., 2014). Moreover, observation of video before coding commenced led us to anticipate that movement gestures with which caregivers requested locomotion might be more abundant when walking emerged (i.e., at walk onset).

Method

Participants

Data for this study were drawn from an existing video corpus of infants' everyday experiences in the home (first reported in Iverson et al., 2007; Parladé & Iverson, 2011). In the original study, 30 infant-caregiver dyads were observed at home twice a month from infant ages 2 to 19 months to examine the development of vocal and motor behavior in infancy. Data were collected between 2002 and 2006 in two Midwestern cities. Families were recruited via published birth announcements and word of mouth. All participants provided written informed consent as approved by the Institutional Review Board at the University of Pittsburgh (STUDY20070404; "Vocal-motor and speech-gesture coordinations in infancy").

All infants were included in this study; 14 were boys and 16 were girls. Infants were typically developing and born at term free of complications. Twenty-eight infants were identified by their caregivers as White and 2 as Multiracial; none were Hispanic or Latino. Thirteen were first-born and 17 were later-born. Mothers and fathers were similar in age (*M*s = 31.36 and 32.78 years, *SD*s = 4.31 and 4.11, respectively) and education (87.4% of mothers and 80.4% of fathers held a Bachelors degree or higher). For the current dataset, 136 visits were with mothers (90.7%), 9 were with fathers (6.0%), and the remaining 5 were with grandmothers (3.3%). English was the primary language spoken in all homes.

Procedure

Infants and caregivers were observed at home every two weeks across the duration of the original study. Home visits were scheduled during times when infants were awake, alert, and ready to engage in everyday activities. Most visits occurred during the day on weekdays, but times varied based on infant age and the availability of caregivers' schedules given the frequent observations necessary for the large, longitudinal study.

At each visit, a researcher videotaped infants and caregivers going about their day for approximately 45 minutes (*M* = 43.30 min, range = 26.85–59.13). The researcher followed along with a single camera making sure to capture the infant's entire body at all times while also keeping caregivers and the surrounding environment in view as much as possible. In the event that infants separated from their caregivers, the researcher followed the infant. Caregivers were asked to continue going about their day as they typically would and to engage in the activities of their daily routines. In general, dyads spent the majority of their time proximal to one another and in one main room (usually the living room). However, infants and caregivers were free to do whatever they liked and often switched to different locations in the home. Infants played with their caregivers or on their own; and caregivers often engaged in household chores like loading and unloading dishwashers, folding laundry, and wrangling pets. At times, infants were constrained in furniture (e.g., a highchair), but these instances were rare and time constrained was not included in the durations used for analyses. Thus, these data represent snapshots of dyads' everyday lives during spontaneous activities at home.

Families were also provided with personalized baby books to track their infants' development and to use while answering questions about the onsets of new motor skills during interviews with experimenters.

Anchoring infants' observations to the onset of walking

We capitalized on the extensive longitudinal dataset and selected visits for coding that surrounded the onset of walking, thereby anchoring each infant's data to their walk onset session. We defined *walk onset* as the first day when infants took 5 continuous, independent steps with no support and without stopping or falling. This criterion was specifically chosen to capture the earliest emergence of walking. In order to identify each infant's exact age at walk onset, we cross-referenced experimenters' biweekly notes from interviews, caregivers' baby books, and video from each home observation. On average, infants began to walk at 11.98 months (*SD* = 1.31) and indeed, infants were quite new walkers at their walk onset sessions, having accumulated an average of just 5.5 days (range = 0–10) of walking experience. And although infants were new walkers at the walk onset session, they were also experienced crawlers with an average of 3.51 months (*SD* = 1.51) of crawling experience (*M* crawl onset = 8.62 months, *SD* = 1.40).

To create each infant's observational window, we selected the first biweekly session that followed the exact date of each infant's walk onset age and considered that to be the walk onset session (e.g., if walk onset age was 11.70 months, the 12-month session was identified as the walk onset session). The monthly visits prior to and following this midpoint were targeted for coding to maximize potential variability in measures of infant locomotion over time. This resulted in five time points (two before and two after walk onset) for each infant and a total of 150 sessions across the dataset.

Figure 1 shows individual timelines for each infant's observation schedule. The dashed symbols represent infants' planned ages at each session according to the original study protocol. Infants' actual ages at each session (the shaded symbols) were highly similar to their planned ages: 131/150 (87%) sessions occurred within 4 days of the planned date for that visit. The degree of overlap between the dashed and shaded symbols in the figure show the relative timing of infants' targeted and actual observation ages and indicate that with few exceptions, these time windows were tightly matched.

By definition, our milestone-based design reflected individual differences in the ages at walk onset for each infant, and thus infant ages at each session varied. As shown in Figure 1, however, age at the walk onset session was relatively similar across the 30 infants (see the lightest grey squares in the middle of the figure). Twenty-two infants fell within 1 SD of the group mean (range = 11.11–12.98); 4 infants were younger (range = 8.74–10.42 months); and 4 infants were older (range = 13.35–14.86).

We refer to the selected observational sessions as follows: the *pre-walk sessions* include the session 2 months before walk onset (walk-2) and 1 month before walk onset (walk-1); the *walk sessions* include the session representing walk onset (walk onset), 1 month after walk onset (walk+1), and 2 months after walk onset (walk+2).

Data coding

Infant locomotor and caregiver communicative behaviors were coded using Datavyu (datavyu.org), a coding tool that allows for frame-accurate identification and categorization of multiple ongoing behaviors from different actors. Before coding commenced, all coders were trained until overall percent agreement reached ≥ 90% on all coding categories on 3 consecutive videos. After training and for all variables, a primary coder scored 100% of each infant's and caregiver's video data. A second coder independently scored 25% of each video to verify inter-observer reliability. Seven coders (6 undergraduate researchers and the first author) completed all coding. Disagreements were resolved through discussion. Our coding materials are shared on Databrary.org (databrary.org/volume/1175). This study was not preregistered.

Infant locomotion.—Coders first scored each video for locomotion. All times when infants engaged in *crawling* (moving on hands-and-knees), moving *upright* with support (cruising along stationary furniture or supported walking with locomotor toys or people), and independent *walking* were identified. We coded crawling at all sessions, but limited coding of supported upright locomotion to the pre-walk sessions as we could reliably assume (from video alone) that infants required external surfaces of support to move while upright before walk onset. Similarly, coders only scored walking at the walk sessions.

Locomotion was coded in *bouts*, or a series of steps separated by a pause in which the infant came to a complete stop for at least 0.5 s (Adolph et al., 2012; Cole et al., 2016; Lee et al., 2018). A step was defined as any up-and-down movement of the feet or knees that resulted in omnidirectional displacement of infants' bodies through space. The 0.5-s pause criterion has been used widely in the literature on infant locomotion and has been shown to be a meaningful indicator of gait termination for both crawling (Adolph et al., 1998) and walking (Bril & Breniere, 1989; Garciaguirre et al., 2007; Cole et al., 2016).

A bout of locomotion began at the first frame of video when an infant's foot or knee moved across the floor and ended at the first frame when the foot or knee came to rest at the end of the series (Adolph et al., 2012). As described in Hoch et al. (2019), we also did not split bouts of locomotion in cases where the 0.5 s-rule was exceeded but the infant appeared to still be in continuous motion when the video was viewed in real time. This ensured that coders were not over-splitting bouts, especially in sessions where infants were just starting to walk and their bouts were often very slow and precarious.

Inter-observer reliability (reflecting agreement between coders prior to discussion) was high for bout identification and steps per bout, rs = .99, ps < .001 and for identification of locomotion type (percent agreement = 93%−99%; Cohen's κ coefficients = .96-.98, ps < .001).

Caregiver communication.—In a second pass, coders focused on caregiver language and gesture during bouts of infant locomotion. We only considered bouts of locomotion with at least four steps for communication coding to increase the likelihood that infants' bouts resulted in travel through the home rather than steps taken in-place (e.g., Karasik et al., 2011; Cole et al., 2016). For each crawling, upright, and walking bout, coders identified and categorized caregivers' co-occurring language and gesture input in mutually exclusive categories.

Caregiver language was coded in five categories: action verbs, object talk, encouragement and praise, discouragement and caution, and miscellaneous. *Action verbs* were utterances that included gross motor verbs that directly requested infant movement or described infants' locomotor behaviors ('Go, Get, Bring'); and *object talk* included utterances that labeled a concrete noun or provided descriptive information about objects ('That's your green frog'). We also considered language that generally *encouraged and praised* infant locomotion ('You're almost there', 'Good job') and language that *discouraged or cautioned* locomotion ('No, Stop, Be careful'). Finally, we coded all other utterances that did not contain any of the key aspects of the above language types ('Hello, Thank you') in a *miscellaneous* category. Coders also noted when caregivers' speech was inaudible, but these instances were rare (< 1% of all bouts were scored as unintelligible for language). Agreement between coders when identifying language types was high (action verbs = 98.1%, κ = 0.81; object talk = 98.2%, κ = 0.83; encouragement and praise = 99.5%, κ = 0.72; discouragement and caution = 99.3%, κ = 0.68; and miscellaneous = 94.2%, κ = 0.81, all ps < .001)

Gestures were similarly classified into six categories: movement, show, point, request, indicate, and conventional. *Movement gestures* directly requested infant movement and included instances when caregivers beckoned to their infants with outstretched arms, hands, or fingers, patted the ground beside them, traced paths through space either toward themselves or away to specific objects and locations, or hit the floor with their fists as if mimicking a trotting horse. *Show gestures* occurred when caregivers held up an object in their infant's view. Caregivers also *pointed* to specific people, places, and things; *requested* objects from their infants by opening their hands as if to create a cup; *indicated* a specific referent by tapping on it with a finger; and used *conventional gestures* such as clapping and waving. Finally, coders also noted when caregivers' hands were not visible on video, but again, this was a rare occurrence (< 5% of all bouts were scored as uncodable for gestures). Inter-observer agreement for identifying gesture types was also high (movement = 99.8%, κ = 0.83; show = 99.3%, κ = 0.81; point = 99.9%, κ = 0.89; request = 99.7%, κ = 0.80; indicate = 99.8%, κ = 0.84; and conventional = 99.7%, κ = 0.74, all ps < .001).

We coded communication at the utterance level (a phrase or sentence for language and a single hand motion for gesture) to capture the content of caregivers' social messages holistically. Given the unconstrained nature of home observations, caregivers could produce multiple utterances of each communication type during a bout of locomotion. To ensure that each utterance was classified independently, we coded all language and gesture types in mutually exclusive categories. For example, if a caregiver said, "Bring me your bear" we coded this utterance as an *action verb* since the message requested infant movement. If the caregiver then said, "That's your blue crayon", coders credited the utterance as *object talk* since the content of caregivers' speech was geared toward describing an object. In this way, we were able to distinguish instances of each language type and credit them only one time if they ever co-occurred with infants' locomotor bouts. The same procedure was applied to gestures.

We adopted this coding approach for two reasons. First, it allowed us to measure conservatively whether caregivers produced language or gesture when infants moved and which type of communication they used. Second, coding in mutually exclusive categories prevented coders from "double-crediting" an utterance type, thereby safeguarding our analyses from violating assumptions of independence (see Karasik et al., 2008, for a similar argument).

Results

This study was designed to examine links between changing patterns of infant locomotion and concurrent communicative input from caregivers across the transition to walking. To provide a context for analysis of caregiver input, we begin by describing the distribution of infants' natural locomotion during everyday activities at home. Next, we examine the co-occurrence of caregiver language and infant locomotion to determine whether there were differences in how likely caregiver talk accompanied infants' bouts and which types of language caregivers produced when infants crawled, moved upright with support, and walked. Finally, we analyze caregivers' gestures in the same fashion to assess whether production of gestures and specific gesture types varied based on how infants moved.

Data were analyzed using repeated measures ANOVAs, with Sidak comparisons to follow up on significant main effects and interactions. For each analysis, we tested for differences in rates of communication between bout types within sessions and also examined whether and how each measure changed across sessions. Given the distribution of infants' ages at walk onset (see Method), we tested for effects of age by including it as a covariate in the ANOVAs. Results showed that age was not significantly related to any of the main study variables, all *p*s > .05. We also tested whether differences in bout length (i.e., the duration of infants' locomotor bouts in seconds) were related to the main study variables but again saw no effect in the ANOVAs, all *p*s > .05. Thus, we report all original models in the final set of analyses below. Preliminary analyses also revealed no differences between boys and girls, between first- and later-born infants, or between caregivers present during home visits (all *p*s >.05), so data were collapsed. There were no missing data.

Infant locomotion

How and how much did infants move during everyday interactions with their caregivers? Infants spent a majority of their time stationary rather than moving ($M = .82$, range = .74-.87). And though overall locomotion time occupied a smaller proportion of infants' activities at home, time spent moving increased across the five time points (M walk-2 = .13, $SD = .10$; M walk-1 = .15, $SD = .10$; M walk onset = .16, $SD = .08$; M walk+1 = .22, $SD = .11$; M walk+2 = .26, $SD = .08$), $F(4, 145) = 9.35$, $p < .001$.

Across the observation period, infants generated 7,393 bouts of locomotion, accumulating 1,405 bouts of crawling, 982 bouts of supported upright locomotion, and 5,006 bouts of walking. To further quantify infant locomotion, we examined the numbers of crawling, upright, and walking bouts that infants generated at each session. Separate analyses were conducted for comparisons at the pre-walk and walk sessions given that walking was a behavior that did not span the entire observation period. We compared crawling vs. upright bouts for the pre-walk sessions and crawling vs. walking bouts for the walk sessions. The frequency plots in Figure 2 show individual data and group means for infant locomotion. Descriptive statistics are presented in Table 1 and results of the ANOVAs are in Tables 4 and 5.

Locomotion before walk onset.—We first examined locomotion during the two sessions prior to walk onset. As shown in the clusters of circles (crawling) and triangles (upright) on the left-hand side of Figure 2, there were no differences in the number of crawling vs. upright bouts at either pre-walk session (Table 1). In other words, infants initiated just as many bouts of crawling as they did bouts of upright locomotion (i.e., cruising or supported walking) during the two months before they began to walk. We saw no change across sessions in the number of crawling bouts, but there was a significant increase in the number of upright bouts. A 2 (Bout Type: crawling, upright) x 2 (Pre-walk Session: walk-2, walk-1) repeated measures ANOVA confirmed these patterns with a significant main effect of Pre-walk Session, $F(1, 29) = 5.63$, $p < .05$, $\eta^2 = .16$, but no main effect of Bout Type or Bout Type x Pre-walk Session interaction (Table 4). Post-hoc pairwise comparisons showed a significant increase in the number of upright bouts across sessions ($p < .05$).

Locomotion at and after walk onset.—Next, we analyzed the frequencies of crawling and walking bouts for the three walk sessions. Walking was immediately favored once infants acquired the skill (see the clusters of circles and squares on the right-hand side of Figure 2). In fact, the data revealed a robust pattern such that infants consistently walked more than they crawled at all three walk sessions (Table 1). Moreover, we saw an increase in the number of walking bouts and a decrease in crawling bouts across the rest of the observation period. A 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA confirmed these patterns with significant main effects of Bout Type, $F(1, 29) = 210.56$, $p < .001$, $\eta^2 = .88$ and Walk Session, $F(2, 58) = 19.96$, $p < .001$, $\eta^2 = .41$, and a Bout Type x Walk Session interaction $F(2, 58) = 34.37$, $p < .001$, $\eta^2 = .54$. Pairwise comparisons revealed a significant increase in walking bouts between each session (ps < .01) and a decrease in crawling bouts between walk onset and the subsequent sessions (ps < .001).

Caregiver language and infant locomotion

We first examined caregiver language input during bouts of infant locomotion. We conducted two sets of analyses. The first assessed the relative frequencies with which bouts of crawling, supported upright locomotion, and walking were paired with any language input (i.e., at least one utterance of any type was spoken). The second focused on the types of language caregivers produced when their infants moved. For all analyses, we calculated proportions to control for individual differences in the base rates of infants' bouts of locomotion. Each proportion reflected the number of bouts of each locomotion type that contained language input out of the total number of bouts of that type at each session. We compared crawling vs. upright bouts for the pre-walk sessions and crawling vs. walking bouts for the walk sessions. These data are presented graphically in Figure 3 and numerically in Tables 2, 4, and 5.

Co-occurrence of caregiver language and infant locomotion.—Infants' real-time locomotor posture was related to caregivers' overall language input. When considering crawling alone, bouts were paired with language from caregivers at a steady rate across the five time points (see the solid line in Figure 3A), $F(4, 145) = 0.95$, $p = .44$, $\eta^2 = .03$. However, relative to crawling while prone, bouts of locomotion while upright—be they cruising or supported walking during pre-walk sessions or walking during walk sessions—were 2–3 times as likely to co-occur with caregiver language (Table 2). The dotted (upright) and dashed (walking) lines in Figure 3A show the stability of these patterns across the observation period. A 2 (Bout Type: crawling, upright) x 2 (Pre-walk Session: walk-2, walk-1) repeated measures ANOVA confirmed a significant main effect of Bout Type, F(1,

29) = 16.48, $p < .001$, $\eta^2 = .36$. And similarly, a 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA also confirmed a significant main effect of Bout Type, $F(1, 29) = 61.98$, $p < .001$, $\eta^2 = .68$. However, neither ANOVA showed effects of Pre-walk or Walk Session or Bout Type x Session interactions (see Tables 4 and 5). Post-hoc comparisons showed significant differences between crawling, upright, and walking bouts at the pre-walk and walk sessions respectively, all *p*s < .05.

Types of caregiver language input.—We further characterized the content of caregivers' language input by identifying the types of language they produced and whether these varied for crawling, upright, and walking bouts. We shifted the denominator in the analyses on language types to control for potential variation in the base rates of caregiver speech paired with bouts of infant locomotion. For example, the proportion of walking bouts paired with an action verb reflected the total number of infants' walking bouts with a co-occurring action verb out of the total number of walking bouts that contained any language input at all (i.e., the proportion described in the previous analysis).

Preliminary inspection of the data revealed that the *encouragement and praise* and *discouragement and caution* categories were relatively infrequent for crawling ($M = .01$, $SD = .04$), upright ($M = .02$, $SD = .12$), and walking ($M = .03$, $SD = .08$) bouts. Moreover, very few caregivers (range = 3–8) produced these language types at each session. Thus, the analyses presented below include only *action verbs* and *object talk*.

Action verbs.: We first examined caregivers' use of action verbs that directly requested infant movement or described infants' locomotor behaviors (e.g., go, get, bring). There were striking differences in the relative frequencies with which action verbs accompanied infants' bouts of locomotion, suggesting a potentially unique effect of locomotor status. As shown by the solid line in Figure 3B, there was a decrease in the rate with which caregivers produced action verbs when infants crawled across the observation period, however, this change did not reach significance, $F(4, 145) = 2.36$, $p = .06$, $\eta^2 = .06$. We found no differences in rates of co-occurrence between action verbs and bouts of upright locomotion (the dotted line in Figure 3B) and action verbs and bouts of crawling at either pre-walk session (Table 2). Moreover, rates of action verbs to upright bouts did not change significantly over time. Indeed, the ANOVA showed no main effects of Bout Type, Pre-walk Session, or a Bout Type x Pre-walk Session interaction, all *p*s > .05 (Table 4).

Once infants started walking, however, there were significant and robust differences in the rates with which walking bouts were accompanied by action verbs vs. crawling bouts (the dashed vs. solid lines in Figure 3B). Infants were more than twice as likely to hear action verbs when they walked at their walk onset session and substantially more likely to have caregivers use an action verb when they walked during the sessions one and two months post-walk onset (Table 2). Moreover, this effect was consistent as we saw no change in the walking data between sessions. A 2 (Bout Type: crawl, walk) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA confirmed these relations with a significant main effect of Bout Type, $F(1, 29) = 44.88$, $p < .001$, $\eta^2 = .61$. There was no effect of Walk Session or a Bout Type x Walk Session interaction (Table 5). Pairwise comparisons showed significant differences between crawling and walking bouts at all three walking time points, *p*s < .01.

Object talk.: We next assessed language about objects. This included descriptive utterances that provided information about everyday objects around the home (e.g., 'That's your green frog'). There was some stability over time in the rates with which bouts of crawling were accompanied with object talk across the observation period (the solid line in Figure 3C), $F(4, 145) = 1.28$, $p = .28$, $\eta^2 = .03$. As was the case for action verbs, there were also no differences in the proportions of upright bouts (the dotted line in Figure 3C) vs. crawling bouts that co-occurred with object talk at the pre-walk sessions (Table 2). And similar to the crawling data, rates of object talk to upright bouts did not significantly change over time. The ANOVA showed no main effects of Bout Type or Pre-walk Session, and no Bout Type x Pre-walk Session interaction, all *p*s > .05 (Table 4).

There were also no differences in the rates of walking and crawling bouts paired with object talk at walk onset ($p = .13$). However, differences emerged in the two sessions after walk onset, such that infants' walking bouts were 2–3 times as likely to co-occur with language about objects as their crawling bouts (the dashed vs. solid lines in Figure 3C, Table 2). Interestingly, neither the crawling nor walking data changed significantly over time. A 2 (Bout Type: crawl, walk) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA only showed a significant main effect of Bout Type, $F(1, 29) = 61.48$, $p < .001$, $\eta^2 = .68$, but no effect of Walk Session or a Bout Type x Walk Session interaction (Table 5). Post-hoc comparisons showed significant differences between crawling and walking bouts at the two post-walk onset sessions, *p*s < .001.

Caregiver gesture and infant locomotion

We next examined caregiver gesture input during bouts of infant locomotion. We examined both the overall rates of co-occurrence between caregivers' gestures and infants' locomotor bouts and asked about the specific types of gestures that caregivers produced. As in the language analyses reported above, we calculated all gesture variables as proportions to control for potential differences in the base rates of infants' bouts of crawling, supported upright locomotion, and walking at each session. For example, the proportion of walking bouts with co-occurring caregiver gesture input reflected the total number of walking bouts that contained gesture out of the total number of walking bouts at that session. Again, we compared crawling vs. upright bouts for the pre-walk sessions and crawling vs. walking bouts for the walk sessions. These data are presented graphically in Figure 4 and numerically in Tables 3, 4, and 5.

Co-occurrence of caregiver gestures and infant locomotion.—In general, caregivers were less likely to communicate with their infants via gesture ($M = .04$, $SD = .06$) than language ($M = .22$, $SD = .19$) when infants moved (collapsed across crawling, upright, and walking bouts). Moreover, when they did occur, gestures were rarely produced in isolation (only 18% of bouts) and instead were more likely to appear alongside language (82% of bouts). Though the base rates of caregiver gesture input were lower than those for language, the general patterns of change over time and in relation to differences between types of locomotion were quite similar.

Infant's locomotor status was related to caregivers' gesture input. As shown by the solid line in Figure 4A, there was general stability in the rates with which crawling bouts were paired with gesture from caregivers, $F(4, 145) = 0.56$, $p = .69$, $\eta^2 = .02$. We found no differences in rates of co-occurrence between gesture to bouts of crawling vs. gesture to bouts of supported upright locomotion (the dotted line in Figure 4A) at either pre-walk session (Table 3). Moreover, rates of gesture to upright bouts did not significantly change over time. The ANOVA showed no main effects of Bout Type or Pre-walk Session, and no Bout Type x Pre-walk Session interaction, all *p*s > .05 (Table 4).

At walk onset and the two subsequent sessions, infants' walking bouts were more than twice as likely to co-occur with caregiver gesture as compared to their crawling bouts (see the dashed vs. solid lines in Figure 4A, Table 3). But again, we saw no significant change over time for walking. A 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA confirmed these patterns with a significant main effect of Bout Type, $F(1, 29) = 26.27$, $p < .001$, $\eta^2 = .48$. There was no effect of Walk Session and no Bout Type x Walk Session interaction (Table 5). Post-hoc comparisons showed no significant difference between crawling and walking bouts paired with caregiver gesture at walk onset ($p > .05$); but these differences were significant at the subsequent walk sessions, *p*s < .05.

Types of caregiver gesture input.—We next asked about the types of gestures that caregivers produced when infants moved. We calculated proportions for the analyses on gesture types in the same way as for language types. For example, the proportion of walking bouts accompanied by a movement gesture reflected the total number of infants' walking bouts in which coders identified a co-occurring movement gesture out of the total number of walking bouts that contained any gesture input at all (i.e., the proportion described in the previous analysis).

Preliminary inspection of the data revealed that *pointing*, *requesting* objects, *indicating* referents by tapping on them, and using *conventional* gestures like clapping and waving comprised roughly 5% of the gesture input that co-occurred with bouts of crawling (range = .01.03), supported upright locomotion (range = .01-.06), and walking (range = .00-.08). Thus, given the low base rates of these gesture types, the analyses presented below include only *movement* and *show* gestures.

Movement gestures.: We first analyzed movement gestures with which caregivers directly requested locomotion from their infants (e.g., beckoning with outstretched arms, hands, or fingers). We found no significant differences in the rates of upright vs. crawling bouts paired with movement gestures at each pre-walk session (see the overlap between the dotted and solid lines in Figure 4B, Table 3). Moreover, rates of movement gestures to upright bouts remained steady across sessions. Indeed, the ANOVA showed no main effects of Bout Type or Pre-walk Session, and no Bout Type x Pre-walk Session interaction, all *p*s > .05 (Table 4).

There were also no differences in the proportions of walking and crawling bouts paired with movement gestures at walk onset ($p = .10$). However, dramatic differences emerged over time for these bout types, such that the rate with which caregivers produced movement gestures when infants crawled dropped to zero at both post-walk onset sessions (Table 3). Similarly, the proportion of walking bouts that co-occurred with movement gestures also decreased sharply after walk onset but remained consistent across the rest of the observation period (the dashed line in Figure 4B). A 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA confirmed these patterns of change with significant main effects of Bout Type, $F(1, 29) = 11.51$, $p = .002$, $\eta^2 = .28$ and Walk Session, $F(2, 58) = 10.25$, $p < .001$, $\eta^2 = .26$. There was no Bout Type x Walk Session interaction (Table 5). Pairwise comparisons revealed significant differences between crawling and walking bouts at the two post-walk onset sessions (*p*s < .01); and showed significant decreases in both crawling and walking bouts between walk onset and the subsequent sessions (*ps* < .05).

Show gestures.: Caregivers also showed objects by holding them up and individuating them in their infant's field of view. The rate of showing while infants crawled (the solid line in Figure 4C) was low and stable over time, $F(4, 145) = 0.31$, $p = .67$, $\eta^2 = .02$. There were no differences in how likely caregivers were to produce a show gesture when their infants moved upright with support (the dotted line in Figure 4C) or crawled at either pre-walk session (Table 3). And in fact, there were also no significant differences when we examined change over time in the upright data. The ANOVA confirmed these patterns with no main effects of Bout Type or Pre-walk Session, and no Bout Type x Pre-walk Session interaction, all *ps* > .05 (Table 4).

There were also no differences in the co-occurrences of walking and crawling bouts with show gestures at walk onset ($p = .32$). Instead, robust differences emerged after walk onset, such that show gestures grew to be more than three times as likely to co-occur with bouts of walking than with bouts of crawling and remained that way across the rest of the observation period (see the dashed vs. solid lines in Figure 4C, Table 3). A 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk+1, walk+2) repeated measures ANOVA confirmed these differences with significant main effects of Bout Type, $F(1, 29) = 36.28$, $p < .001$, $\eta^2 = .56$ and Walk Session, $F(2, 58) = 6.94$, $p = .004$, $\eta^2 = .17$, and a significant Bout Type x Walk Session interaction, $F(2, 58) = 7.58$, $p = .001$, $\eta^2 = .21$. Post-hoc comparisons revealed a significant increase in walking bouts paired with show gestures between walk onset and the subsequent sessions (*p*s < .01) but showed no change over time for crawling bouts (*p*s > .05).

Discussion

The overall goal of this study was to examine the possibility of a developmental cascade between two seemingly unrelated domains: infant locomotion and caregiver communication. Specifically, we asked whether the transition to walking marked a moment of reorganization in development as evidenced by change in the rates and content of caregivers' language and gesture input. And indeed, it did. Infants were consistently more likely to receive social messages rich with language and gestures that either requested or described movement or provided information about objects when they walked compared to when they crawled. Moreover, an effect of infants' real-time locomotor posture was only apparent for rates of overall language input. Collectively, all measures of communication examined in this study provided robust evidence in support of the presence of a developmental cascade.

This study advances our understanding of the dynamic relations between infants' locomotor actions and caregivers' communicative behaviors in three ways. First, we utilized a densely sampled, longitudinal corpus of video data and took a milestone-based approach in which we aligned each infant's observational window to their attainment of walking (see Figure 1). This allowed us to examine change in infants' locomotor behaviors and caregivers' co-occurring language and gesture input as they related to the emergence of walking. Second, we examined whether changes in caregiver input were prompted by the transition to walking (i.e., a change in locomotor status) or whether these relations were due to infants' real-time locomotor posture (prone vs. upright). We tested this by including supported upright locomotion (e.g., cruising and supported walking) as a contrast category for comparison to crawling in the pre-walk sessions. Third, not only did we examine caregiver language input, but we also measured change in caregivers' gesture production when infants moved. This aspect of communication has been understudied in the context of everyday interactions between infants and caregivers at home and especially in relation to infants' locomotor development.

Walking shapes language and gesture input from caregivers

Examining the ecology of caregiver communication as anchored to infant locomotion allowed us to uncover whether the way in which infants moved related to how likely caregivers were to provide language and gesture input. We replicated and extended previous reports of natural locomotion in our longitudinal sample (e.g., Adolph et al., 2012; Lee et al., 2018). Most noteworthy was the strong preference for and increase in walking at and after its emergence (see Figure 2). And although crawling substantially decreased across the observation period, there was relatively little change over time in the rates of co-occurrence between caregivers' language and gesture input and infants' bouts of crawling. Put differently, caregivers were generally consistent in how likely they were to communicate when their infants crawled. This finding was unexpected but striking considering that the numbers of crawl bouts at the pre-walk sessions were higher than those at the walk sessions. Of course, our analyses controlled for differences in these base rates, but this underscores the possibility that as infants transition to walking, previous forms of locomotion (albeit experienced ones, like crawling) may not elicit caregiver communication as effectively as their newer counterpart.

Caregiver language input was shaped by infants' real-time behaviors *and* by the transition to walking. Across the five sessions, infants were more likely to hear language when they moved while upright (cruising, supported walking, or independent walking) compared to when they were prone (Figure 3A). However, this pattern was not evident when we examined specific *types* of caregiver talk, as bout-level differences were only apparent when infants became walkers (Figures 3B-C). Previous work has shown a prevalence of action verbs in caregivers' language input when infants shared objects by moving to their mothers (Karasik et al., 2014) and more generally, when infants moved about the home (Tamis-LeMonda et al., 2019). Thus, we were especially interested in examining this category to see whether differences in how infants moved mattered for how likely they were to hear action verbs. As predicted, walking differentially elicited this type of caregiver talk, such that infants' walking bouts were substantially more likely to be paired with verb-based language. Moreover, this effect held at all walk sessions and was not apparent when we compared bouts of crawling and supported upright locomotion at the pre-walk sessions.

Action verbs may serve as a way for caregivers to regulate their infants' locomotor pursuits. Infants move more when they walk; they cover more ground and locate objects in distant rooms, often outside their caregivers' immediate purview (Adolph et al., 2012). Thus, it is possible that caregivers used action verbs to "sway" their infants' locomotor actions during walking bouts. Indeed, caregivers requested steps from their walkers ('Come on over'), directed infants to retrieve and deliver objects from opposite ends of living rooms ('Get that one', 'Bring it here'), and commented on episodes of locomotor play (e.g., by saying, 'Are you walking with Mr. Bear?' as an infant pushed a stuffed animal inside of a stroller).

Infant walking also influenced caregiver language about objects, though differences between crawling and walking bouts were only evident in the two sessions after walk onset. Research has shown that walking infants explore their environments more effectively after acquiring about a month of walking experience: they visit more locations and are more likely to travel and retrieve distal objects during everyday play (Thurman & Corbetta, 2017; Karasik et al., 2011). If infants are more likely to discover new objects as walkers, caregivers may gain more opportunities to "follow-in" and provide descriptive labels about the very objects infants located during bouts of walking. This type of exploration-communication loop seemingly occasioned by one month of walking experience may explain the increase in the co-occurrences of object talk and walking that we observed.

Why did infants' real-time locomotor posture shape rates of overall caregiver language input but not types of caregiver talk? One possibility relates to opportunities for social interaction. When infants cruise, they are bound to the limits of couches and coffee tables with a handful of objects strewn atop; as support surfaces end, so do opportunities for locomotion and potentially social interaction. Similarly, in order to engage in supported walking, infants require a caregiver's hand or stability from locomotor toys. In both cases, infants cannot venture off and explore in the ways afforded by independent walking. Thus, even though caregivers were more likely to talk when infants were upright as compared to prone across the observation period, there may have been fewer opportunities that called for the specific types of talk measured here when infants moved upright with support as pre-walkers. For example, the impetus to request an infant to cruise to one end of a couch with action verbs may not be the same as coaxing an infant's first independent walking steps. Moreover, the divided nature of walking with support and attending to objects may have resulted in fewer object retrievals on the part of infants and in turn, fewer opportunities for caregivers to provide descriptive information.

Caregiver gesture input was exclusively shaped by the transition to walking. Not only were caregiver gestures more than twice as likely to co-occur with bouts of walking than with bouts of crawling (Figure 4A), but bout-level differences in specific gesture types were also only apparent at the walk sessions (Figures 4B-C). Why might this be the case? When infants crawl, their view of the world consists primarily of the floor in front of them (Kretch et al., 2014). However, while walking, infants' enhanced access to visual information may enable them to reap the communicative benefits of caregivers' gestures. Caregivers may be sensitive to their infants' new visual perspective, and this may be reflected in the higher rate of gesture input to bouts of walking. Some support for this possibility comes from research indicating that adults gesture at higher rates when a communicative partner is seated in front of them, as opposed to when the partner is visually unavailable (i.e., seated behind a screen; Alibali et al., 2001). Of course, it is likely that infants enjoy the same vantage points while cruising or supported walking, but the lack of differences between crawling and upright bouts at the pre-walk sessions suggests that caregivers did not consider upright pre-walking behaviors in the same way as walking when communicating with gestures. This finding speaks directly to the potential of walking as an organizer of caregiver communication (see Iverson, 2010, 2021, for further discussion).

The unfolding of a developmental cascade

The content of caregivers' gestures was also shaped by infants' ability to walk, and more specifically, by infants' walking experience. In fact, the change we observed in rates of each gesture type over time strongly suggests that changes in infant locomotion are dynamically linked to caregiver communication. Thus, we provide a process account of the proposed cascade pathway as it unfolds across developmental time, as infants accumulated walking experience.

At walk onset, the main focus of caregiver communication appeared to be to promote infant locomotion. Not only were walking bouts more likely to co-occur with verbs that directly requested movement (Figure 3B), but as we anticipated, caregivers were also most likely to use movement gestures when infants walked at their walk onset session (Figure 4B). Recall that at this session, infants were brand new walkers (averaging just 5.5 days of walking experience) and still in the process of learning to move in their new, and often wobbly, upright posture. Regardless, caregivers produced verb-based language and movement-focused gestures that directly requested walking and often beckoned infants to travel to particular objects and people.

Perhaps caregivers were implicitly attuned to their infants' skills and provided them with immediate support—a communicative "push" when making real-time decisions to walk. Indeed, another study on the sloping walkway suggests that walking infants only deferred to their mothers' social messages of encouragement when their own exploratory behaviors were least trustworthy in making decisions for locomotion (Tamis-LeMonda et al., 2008). Just like the infant perched at the top of a slope, our novice walkers might also have been uncertain about their new skills, perhaps hesitating when initiating steps, and consequently eliciting timely input that scaffolded their persistence with walking.

In the two months following walk onset, walking proficiency improves rapidly (see Adolph et al., 2012). And our results on the rates of co-occurrence between infants' walking bouts and caregivers' language and gesture input reveal just how important two months of walking experience might be. The two sessions after walk onset were characterized by stability and instability in patterns of caregiver input. Caregiver language remained stable over time, such that infants' walking bouts were consistently paired with action verbs and object talk (Figures 3B-C). However, the opposite was true for gesture input. Movement gestures exhibited a dramatic decrease after walk onset, but show gestures grew substantially to co-occur with nearly half of infants' walking bouts (Figures 4B-C).

These striking patterns of change may reflect that caregivers are sensitive to their infants' developing skills and accordingly modify how they communicate (e.g., Karasik et al., 2008). Specifically, they underscore the possibility that caregivers may have altered their gestural focus from scaffolding a new motor skill to capitalizing on opportunities for more complex social exchanges about objects. Indeed, walking reshapes the mechanics of social interactions: it frees infants' hands and affords increased efficiency to approach caregivers and retrieve the objects of their show gestures. In turn, these instances may have resulted in moments of sustained attention around objects, which have been shown to be prime labeling events (Yu et al., 2019). Taken together, these results may provide an early foundation for uncovering a mechanistic explanation for the observed growth in infant language development following the onset of walking (Walle & Campos, 2014; West et al., 2019).

Finally, it is important to note that infants are not always in motion. Indeed, our data show that infants spent a majority of their observation time stationary. It is therefore possible that movement itself may shape the rates and content of caregivers' gesture input. For example, although the other gesture types identified in this study (e.g., pointing, requesting objects) rarely occurred while infants locomoted, they may have been more likely to appear while infants were stationary, perhaps during seated object play proximal to their caregivers. Future research should examine caregiver gesture input during times when infants are stationary (sitting, standing) in addition to times when they engage in locomotion.

Limitations and future directions

This study documented the relations between infants' locomotor actions and caregivers' communicative behaviors across the transition to walking and suggests that learning to walk results in a reorganization in the language and gesture input that caregivers provide. However, several limitations must be considered when interpreting these findings. First, we only observed infants and their caregivers for 45 minutes, gathering a snapshot of dyads' daily lives in our videos. However, our observations do not necessarily equate to the daylong repertoires of infants' and caregivers' activities. Indeed, the issue of capturing large-scale, naturalistic data has spurred numerous methodological advances, such as the application of Ecological Momentary Assessment to collecting data on infant posture (e.g., Franchak, 2019), the use of LENA to record infants' natural language environments for up to 16 hours (e.g., Bergelson et al., 2019), and the creation of wearable, mobile sensing devices that continuously collect multiple streams of data "in the wild" (e.g., de Barbaro, 2019).

Second, our sample constrains potential generalizability as it was rather homogeneous; families were largely White, educated, and all infants were typically developing. Prior research has highlighted vast differences in the early communicative environments of infants from varying socioeconomic and cultural backgrounds (e.g., Sperry et al., 2018; Wang & Vallotton, 2016). Moreover, it is becoming increasingly clear that infants at elevated likelihoods for developmental delays (e.g., Autism Spectrum Disorder) experience diverse developmental trajectories in motor development and social interaction (e.g., West, 2019). Thus, it is important for future research to study cascades in greater context; that is, in samples of varying demographic composition, in home environments with different spatial configurations, and in populations of infants that cover the gamut of typical and atypical development.

Finally, we examined the presence of a developmental cascade in one particular case, the transition to walking. It is also possible that communication from caregivers similarly changes during the acquisition of other skills—learning to reach for objects in infancy, to ride a bicycle in childhood, or even drive a car in adolescence. The developmental cascade documented here likely represents a single instance of a broader phenomenon that may serve to bolster patterns of action that cultures and communities value. Future research should examine cascades around other points of developmental transition, especially during moments of skill acquisition.

Conclusions

Developmental achievements in infancy—first looks, first smiles, first words, and in our case, first steps—equip infants with new ways to act in and interact with the world. In the case of infant locomotion, it appears that the transition to walking is met with change in caregiver communication via a developmental cascade. Infants were more likely to receive language and gesture input about actions and objects alike when they walked compared to when they crawled. In sum, we suggest that the ability to walk not only transforms infants' own actions, but it also sets in motion a cascade in development that shapes the communication that caregivers provide.

Acknowledgements

This article is based on a thesis submitted to the University of Pittsburgh in partial fulfillment of the requirements for the degree of Master of Science by JLS. The research was supported by grant number R01 HD041607 from NICHD to JMI.

We are grateful to Bianca Calabretta, Kaitlyn Cortez, Owen Marty, Christina Miceli, Ellora Mohanty, and Angelique Ogunsemowo for their help with video coding. We thank Celia Brownell and Klaus Libertus for their discussions of the data. Special thanks to the Infant Communication Lab at the University of Pittsburgh and to the infants and families who made this research possible.

Portions of these data were presented at the 2019 and 2021 meetings of the Society for Research on Child Development. The coding materials associated with this study are shared on Databrary.org (databrary.org/volume/1175) and are available from the corresponding author upon request. This study was not preregistered. The authors declare they have no conflict of interest.

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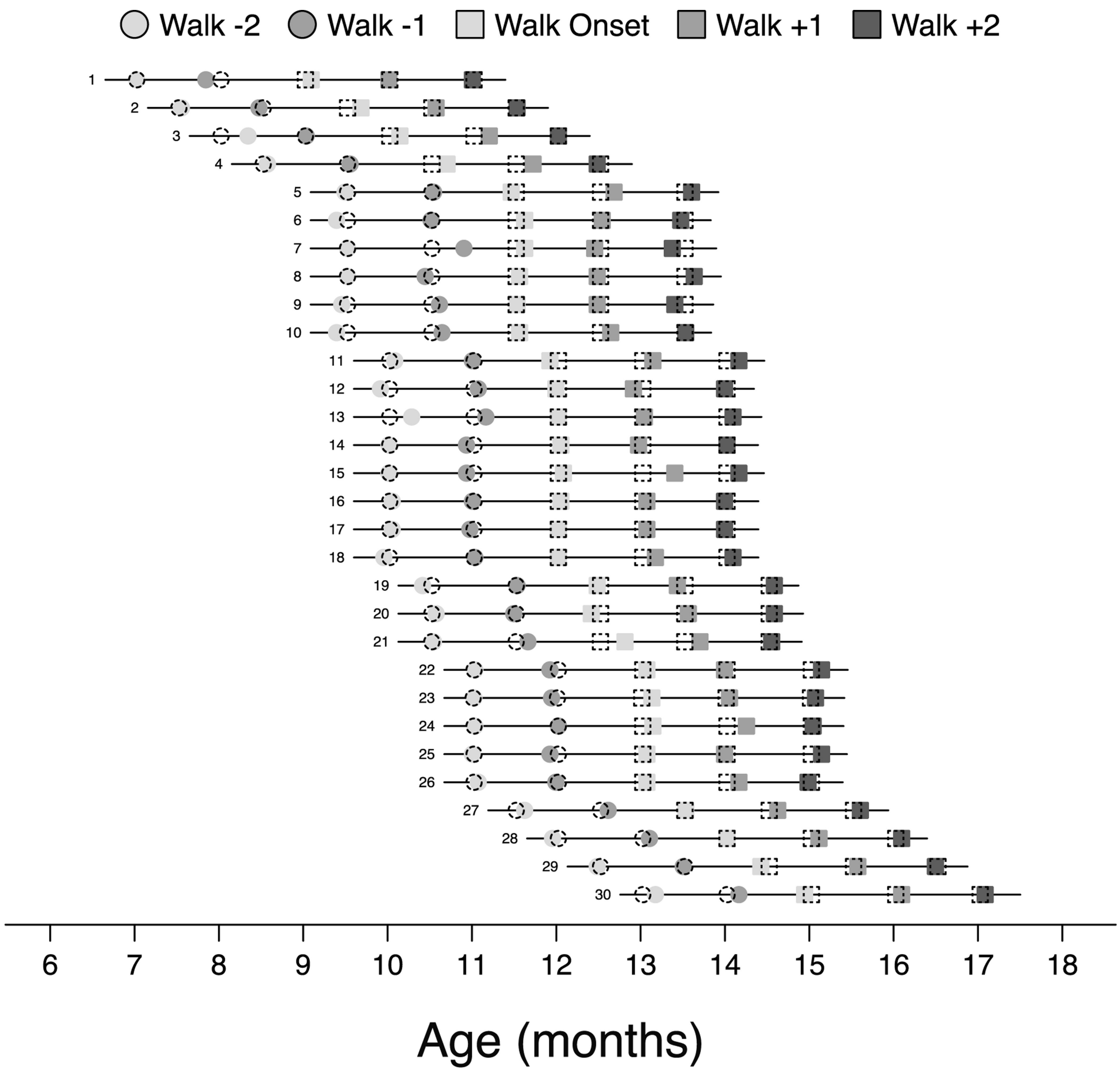

Figure 1.

Timelines of the five observational sessions across the transition to walking for all 30 infants. Each row represents one infant. Rows are ordered by age at walk onset. Dashed symbols represent the planned ages at each home visit according to the original study protocol. Shaded symbols denote actual ages at each session. The gradient of circles represents the two pre-walk sessions, and the gradient of squares represents the three walk sessions. The degree of overlap between dashed and shaded symbols denotes accuracy in the timing of sessions.

Figure 2.

Frequencies of crawling (circles), upright (triangles), and walking (squares) bouts across the observation period. Symbols represent individual data and horizontal lines describe group means. Asterisks denote statistical significance in pairwise comparisons between bout types: *$p < .05$, **$p < .01$, ***$p < .001$

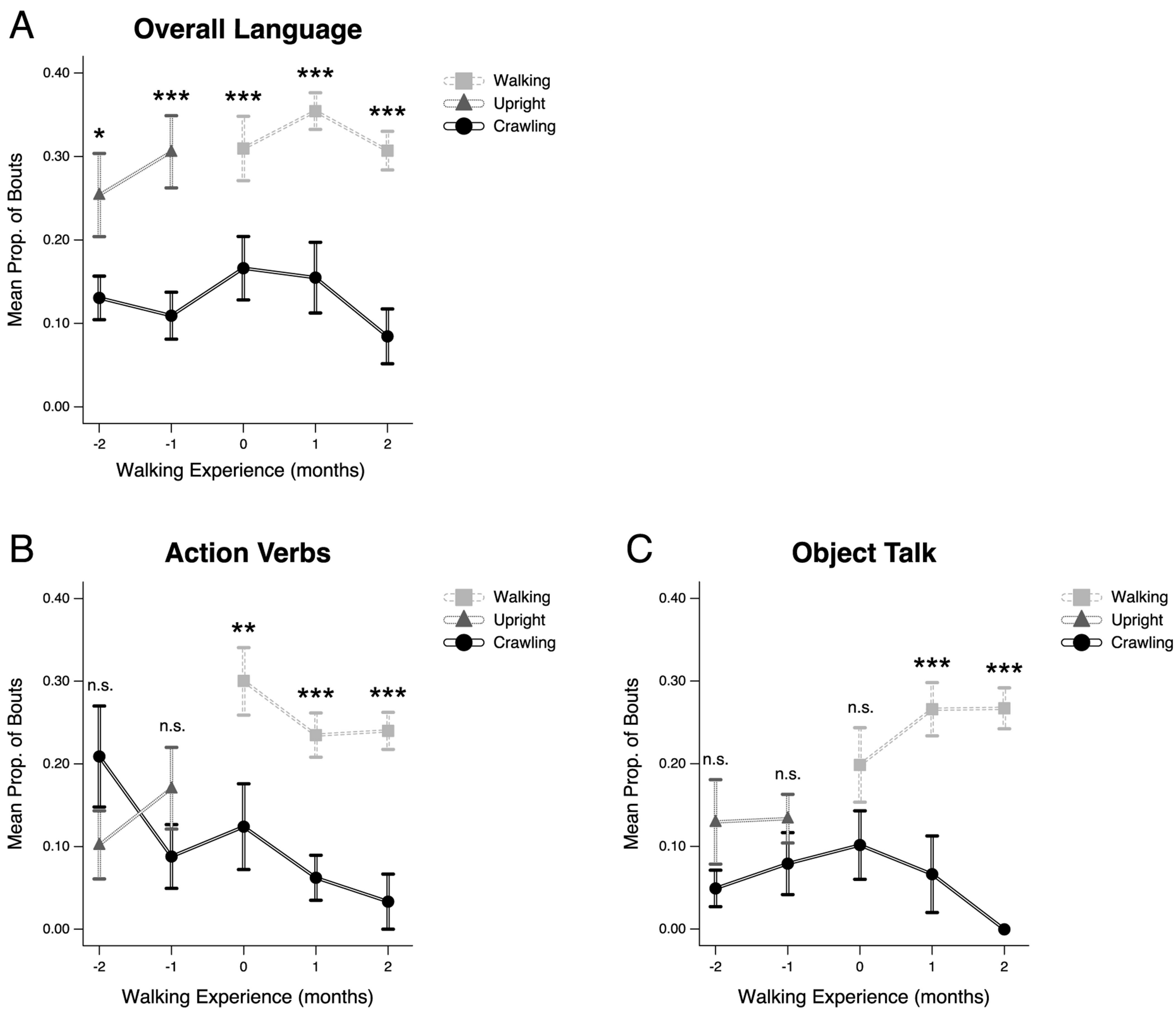

Figure 3.

Comparisons of the mean proportions of crawling, upright, and walking bouts that co-occurred with (A) overall language input, (B) verbs about actions, and (C) descriptive language about objects. Solid lines are data for crawling bouts; dotted lines for upright bouts; and dashed lines for walking bouts. Error bars show standard errors. Asterisks denote statistical significance in pairwise comparisons between bout types: *$p < .05$, **$p < .01$, ***$p < .001$

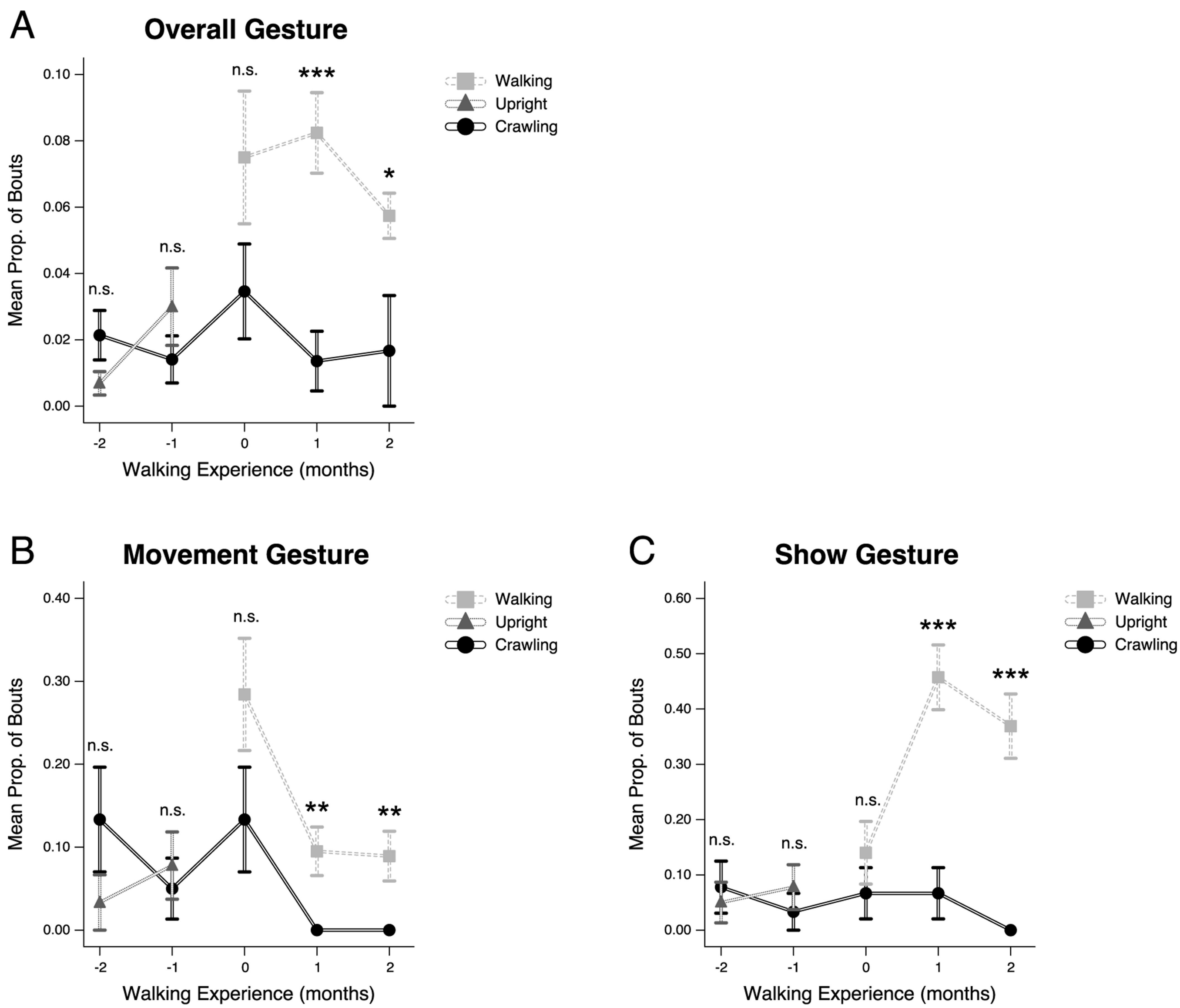

Figure 4.

Comparisons of the mean proportions of crawling, upright, and walking bouts that co-occurred with (A) overall gesture input, (B) movement gestures that beckoned infants, and (C) show gestures that individuated objects in space. Solid lines are data for crawling bouts; dotted lines for upright bouts; and dashed lines for walking bouts. Error bars show standard errors. Asterisks denote statistical significance in pairwise comparisons between bout types: $*p < .05$, $**p < .01$, $***p < .001$

Table 1

Descriptive statistics for infant locomotion across the observation period

	Pre-walk Sessions			Walk Sessions		
	Walk −2	Walk −1		Walk Onset	Walk +1	Walk +2
Infant locomotion (*M, SD, range*)						
Bout type						
Crawling	14.63, 13.81 (0–49)	16.90, 12.72 (0–40)	Crawling	10.37, 8.30 (0–29)	3.03, 4.01 (0–17)	1.90, 2.12 (0–8)
Upright	12.33, 17.09 (0–66)	19.80, 18.94 (0–72)	Walking	33.10, 26.52 (1–118)	51.30, 25.52 (3–97)	82.33, 31.01 (17–137)

Table 2

Descriptive statistics for the rates of co-occurrence between infant locomotion and caregiver language input across the observation period

	Pre-walk Sessions			Walk Sessions		
	Walk −2	**Walk −1**		**Walk Onset**	**Walk +1**	**Walk +2**
Caregiver language and infant locomotion (*M, SD*)						
Overall language						
Crawling	0.13 (0.14)	0.11 (0.15)	Crawling	0.17 (0.21)	0.15 (0.23)	0.08 (0.18)
Upright	0.25 (0.27)	0.31 (0.24)	Walking	0.31 (0.21)	0.35 (0.12)	0.31 (0.13)
Action verbs						
Crawling	0.21 (0.33)	0.09 (0.21)	Crawling	0.12 (0.28)	0.06 (0.15)	0.03 (0.18)
Upright	0.10 (0.23)	0.17 (0.27)	Walking	0.30 (0.22)	0.23 (0.15)	0.24 (0.12)
Object talk						
Crawling	0.05 (0.12)	0.08 (0.21)	Crawling	0.10 (0.23)	0.07 (0.25)	0.00 (0.00)
Upright	0.13 (0.28)	0.13 (0.16)	Walking	0.20 (0.25)	0.27 (0.18)	0.27 (0.14)

Table 3

Descriptive statistics for the rates of co-occurrence between infant locomotion and caregiver gesture input across the observation period

	Pre-walk Sessions			**Walk Sessions**		
	Walk −2	**Walk −1**		**Walk Onset**	**Walk +1**	**Walk +2**
Caregiver gesture and infant locomotion (*M, SD*)						
Overall gesture						
Crawling	0.02 (0.04)	0.01 (0.04)	Crawling	0.03 (0.08)	0.01 (0.05)	0.02 (0.09)
Upright	0.01 (0.02)	0.03 (0.06)	Walking	0.08 (0.11)	0.08 (0.07)	0.06 (0.04)
Movement gesture						
Crawling	0.13 (0.35)	0.05 (0.20)	Crawling	0.13 (0.35)	0.00 (0.00)	0.00 (0.00)
Upright	0.03 (0.18)	0.08 (0.22)	Walking	0.28 (0.37)	0.10 (0.16)	0.09 (0.16)
Show gesture						
Crawling	0.08 (0.26)	0.03 (0.18)	Crawling	0.07 (0.25)	0.07 (0.25)	0.00 (0.00)
Upright	0.05 (0.20)	0.08 (0.22)	Walking	0.14 (0.31)	0.46 (0.32)	0.37 (0.32)

Table 4

Results of the 2 (Bout Type: crawling, upright) x 2 (Pre-walk Session: walk −2, walk −1) repeated measures ANOVAs for each measure

	2 (Bout Type: crawling, upright) x 2 (Pre-walk Session: walk −2, walk −1)								
	Bout Type			**Pre-walk Session**			**Bout Type x Pre-walk Session**		
Measure	***F***	***p***	η^2	***F***	***p***	η^2	***F***	***p***	η^2
Infant locomotion									
Number of bouts	0.01	.94	< .001	5.63	.02	.16	2.16	.15	.07
Language & locomotion									
Overall language	16.48	< .001	.36	0.19	.67	< .01	1.02	.32	.03
Action verbs	0.06	.81	< .01	0.38	.54	.01	3.05	.09	.10
Object talk	3.89	.06	.12	0.39	.54	.01	0.11	.74	< .01
Gesture & locomotion									
Overall gesture	0.01	.92	< .001	0.84	.37	.03	4.25	.05	.13
Movement gesture	0.68	.42	.02	0.15	.70	< .01	2.22	.15	.07
Show gesture	0.04	.84	< .01	0.05	.83	< .01	0.78	.38	.03

Table 5

Results of the 2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk +1, walk +2) repeated measures ANOVAs for each measure

	2 (Bout Type: crawling, walking) x 3 (Walk Session: walk onset, walk +1, walk +2)								
	Bout Type			**Walk Session**			**Bout Type x Walk Session**		
Measure	***F***	***p***	η^2	***F***	***p***	η^2	***F***	***p***	η^2
Infant locomotion									
Number of bouts	210.56	< .001	.88	19.96	< .001	.41	34.37	< .001	.54
Language & locomotion									
Overall language	61.98	< .001	.68	1.43	.25	.05	1.12	.33	.04
Action verbs	44.88	< .001	.61	2.89	.06	.09	0.16	.85	< .01
Object talk	61.48	< .001	.68	0.43	.65	.02	2.72	.07	.09
Gesture & locomotion									
Overall gesture	26.27	< .001	.48	0.78	.46	.03	0.78	.46	.03
Movement gesture	11.51	< .01	.28	10.25	< .001	.26	0.38	.69	.01
Show gesture	36.28	< .001	.56	5.94	< .01	.17	7.58	< .01	.21