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Learning to walk changes infants' social interactions

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ABSTRACT

The onset of crawling marks a motor, cognitive and social milestone. The present study investigated whether independent walking marks a second milestone for social behaviors. In Experiment 1, the social and exploratory behaviors of crawling infants were observed while crawling and in a baby-walker, resulting in no differences based on posture. In Experiment 2, the social behaviors of independently walking infants were compared to age-matched crawling infants in a baby-walker. Independently walking infants spent significantly more time interacting with the toys and with their mothers, and also made more vocalizations and more directed gestures compared to infants in the walker. Experiment 3 tracked infants' social behaviors longitudinally across the transition from crawling and walking. Even when controlled for age, the transition to independent walking marked increased interaction time with mothers, as well as more sophisticated interactions, including directing mothers' attention to particular objects. The results suggest a developmental progression linking social interactions with milestones in locomotor development.

The onset of crawling in infants marks an important developmental milestone that profoundly changes the way infants experience the environment. Many studies have found that the onset of crawling marks a cognitive as well as motor milestone. For example, crawling infants are much more likely to show wariness of heights when on a visual cliff than infants of the same age who are not crawling (e.g., Bertenthal, Campos, & Kermoian, 1994; Campos, Bertenthal, & Kermoian, 1992; Rader, Bausano, & Richards, 1980; Richards & Rader, 1981). Crawling onset also improves numerous other behaviors, including object retrieval (Kermoian & Campos, 1988) and spatial memory (Acredolo, 1978), to name just a few. In addition to cognitive changes, learning to crawl also affects infants' social behaviors (e.g., Green, Gustafson, & West, 1980; see Campos et al., 2000 for a review). For example, Campos, Kermoian, and Zumbahlen (1992) compared pre-locomotor and crawling infants' emotional expression, attachment, and attentiveness to distal events. They found that parents of crawling infants reported of their infants more anger, more affection towards the mother, more sensitivity to maternal comings and goings, and more attention to distal events. Crawling onset also coincided with changes in the parents. Mothers reported more anger towards their infants, higher expectations of compliance, and more verbal commands. Finally, crawling onset also affected mother–infant interaction, with crawling infants spending more time in interactive play games with their mothers.

Importantly, these changes in social and exploratory behaviors have been causally linked to the onset of crawling through experimental manipulation of locomotion. Pre-crawling infants were observed in a free-play session both in and out of a baby-walker, and then compared to crawling infants (Gustafson, 1984). Pre-locomotor infants in the walker behaved very differently than when they were out of the walker. Stationary infants, unable to move about the laboratory space, engaged in few social behaviors, and looked mainly at items on the floor, rather than items on the wall. In contrast, there were few

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differences between the non-locomotor infants in the walkers and crawling infants. Both of these groups of infants moved about the laboratory space, looked at the adults in the room, and interacted with the toys at comparable rates. Thus, it was the onset of independent locomotion that affected behavior, rather than specific locomotor style or posture.

How exactly does crawling produce change? Although the precise mechanism is still up for debate, Campos et al. (2000) have provided a compelling proposal. They argue that independent locomotion "is a setting event, a control parameter, and a mobilizer that changes the intra-psychic states of the infant, the social and nonsocial world around the infant, and the interaction of the infant with that world (p. 151)." By this view, locomotion alone does not cause change. Rather, the onset of independent locomotion significantly alters infants' experiences with the world and those around them, and it is these experiences that bring about developmental change.

Overall then, many cognitive and social behaviors change when infants go from being stationary to crawling. However, in humans, independent locomotion continues to develop. A few months after infants go from being stationary to crawling, they shift to another mode of locomotion: they start to walk. And the onset of walking poses another set of challenges. Now the view of the world is from an upright position, balance is a greater challenge, and hands are freed to carry things.

How does the transition from crawling to independent walking affect infants' social and exploratory behaviors? A few early studies suggest that there may be emotional changes at the onset of walking, with walking infants demonstrating more joy, elation, and willfulness (e.g., Biringen, Emde, Campos, & Appelbaum, 1995; Greenacre, 1971; Mahler, Pine, & Bergman, 1975). And a more recent study found changes in infants' social looking behavior at the onset of independent walking (Clearfield, Mullen, & Osborne, 2008).

With respect to exploratory behaviors, numerous studies have reported differences between crawling and walking infants. Crawling and walking infants engaged in different exploratory behaviors when presented with different kinds of surfaces that they needed to cross. When facing a soft, waterbed surface, walking infants spent significantly more time before beginning to cross and engaged in more exploratory touching, compared to when the same infants were faced with a standard rigid walkway. In contrast, crawling infants showed no difference in exploratory behaviors for the waterbed surface compared to the rigid surface (Gibson et al., 1987). This finding also held for crossing a visual cliff (e.g., Gibson, 1988; but see Witherington, Campos, Anderson, Lejeune, & Seah, 2005). Crawling and walking infants also engaged in different exploratory behaviors when faced with steep and shallow slopes that they needed to descend (e.g., Eppler, Adolph, Marin, Weise, & Clearfield, 2000; Adolph, 1997; Adolph, Eppler, & Gibson, 1993) and with a locomotor spatial memory task (Clearfield, 2004).

There are several possible reasons why crawling and walking infants might behave differently on these tasks. First, walking infants are generally older than crawling infants, so it is possible that with age come different behaviors. In addition, walking infants have had more accumulated experience moving through the world, both crawling and walking, and this might affect their behaviors, either through more skilled movements or simply more experience.

Another possible explanation is that crawling and walking naturally afford different exploratory behaviors because of the difference in posture, especially in tasks that require locomotion (like crossing a surface or descending a slope). The clearest experimental examples of this postural specificity of learning come from Adolph's work on infants descending steep slopes and crossing over gaps (e.g., Adolph, 1997, 2000). Infants who could successfully descend very steep slopes as crawlers misjudged their ability to descend those same slopes when they began walking (Adolph, 1997). The very same infants, as soon as they could walk, plunged headfirst down slopes that were far too steep (for an upright infant). Thus, infants were unable to reconcile the information they had learned about slopes while crawling with their new skill of walking. Similar results were reported for infants' navigational memory (Clearfield, 2004). Both authors argued that walking involves a very different kind of movement through the world than crawling. Crawling and walking each involve different groups of muscles, patterns of interlimb coordination, posture, and viewpoints. Crawling infants are lower to the ground, restricting their visual field. They also tend to move with their heads down, further restricting the visual field, which affects exploratory behaviors like looking around the room. In contrast, walking infants have a much wider visual field, and are able to make eye contact and vocalizations while moving towards a caregiver (Clearfield, 2004). This ecological view of development focuses on the fit between the child's body and her environment, also known as affordances (e.g., Adolph et al., 1993).

That key idea regarding the interaction between the person and the environment is one that is shared with Dynamic Systems Theory (DST). However, DST goes one step further in positing the relationship as more than just interaction. According to DST, development is best described as the emergent product of many decentralized and local interactions that occur in real time (e.g., Thelen & Smith, 1994, 2006). These many interactions are ever-changing, and should be conceptualized as a constantly changing set of relationships among inextricably linked parts. New forms then arise from ongoing processes that are intrinsic to the system. Thus, systems can generate novelty (new behaviors like new forms of locomotion or interaction) through their own activity. Thus, we can think about development as a series of patterns of behavior that become more and less stable over time. During periods of stability, we would expect useful and efficient behaviors to be repeated. But it is during periods of instability when new forms, new behaviors, should be more likely to arise.

The onset of independent crawling has already been shown to be such a period of instability, marked by changes in cognitive, social, and exploratory behaviors. But when infants learn to walk, the crawling pattern destabilizes, allowing the patterns for standing and walking to become more stable. Thus, the question at hand is whether the transition to independent walking marks a period of instability that, similar to crawling, is related to system-wide changes. Does independent walking also serve as a control parameter that significantly alters infants' experience of the world?

The purpose of the present study was two-fold. The first goal was to explore whether the differences between crawling and walking infants' interactions with their environment might be due to the postural difference between crawling and walking. A second question was whether the transition to independent walking would result in large-scale changes in infants' social behaviors. In Experiment 1, the social and exploratory behaviors of crawling infants were observed twice in a free-play session: once while crawling and another time in a baby-walker. The central question was whether upright posture would change the social behaviors of crawling infants. In Experiment 2, the social behaviors of independently walking infants were compared to age-matched crawling infants while in a baby-walker, and Experiment 3 followed infants longitudinally across the transition from crawling to independent walking. In all experiments, the central question was whether walking independently signals a non-linear shift in social interactions. This would be evident in Experiment 1 if crawling infants behaved comparably when crawling and when in a baby-walker, and in Experiment 2 if upright infants in a baby-walker did not behave comparably to infants who could walk independently (just like Gustafson's (1984) pre-locomotor infants compared to crawling infants). Further evidence would be if, in Experiment 3, locomotor experience, not age, predicted significant changes in infants' mode of interaction.

1. Experiment 1

1.1. Method

1.1.1. Participants

Seventeen infants (8 boys and 9 girls, all Caucasian) between the ages of 9 and 11 months ($M = 9.9$ months) participated in this study. There was no attrition. All infants were able to crawl proficiently on hands and knees, meaning that they could cover 3 m of distance within 10 s (confirmed in the laboratory before testing began). According to parental reports from baby diaries, the infants had an average of 6 weeks of crawling experience (range was 2–10 weeks) and 12 infants had minimal experience in a baby-walker (less than 15 min a day). None could walk.

Infants were recruited via letters to parents based on published birth announcements. All infants received a small prize for participation.

1.1.2. Apparatus

Infants were tested in a large brightly lit room on a 3 m × 3 m floor area covered in black and white checkerboard linoleum (each square was .3 m × .3 m). The linoleum was set in the back corner of the 6.1 m × 7.3 m room, with two sides of the linoleum against the walls. A third side had a short coffee table set .6 m from the edge of the linoleum and the fourth side of the linoleum was .6 m from a long table of computers up against the far wall. There was no specific wall or barrier on the two open sides of the floor, but the arrangement of the furniture did not elicit roaming off the floor. On the floor were several toys, including blocks, a stuffed octopus, and a hammer/tool set, and several brightly colored posters were posted around the walls of the room.

The walker was a Kolcraft Tot Rider 2, with the toys on the tray removed. Two video cameras on opposite sides of the room recorded infants' behaviors and vocalizations.

1.1.3. Design

A within-subjects design was used to test the effects of locomotor posture on social and exploratory behaviors. Crawling infants were observed for 10 min while in a baby-walker and 10 min while crawling, with the order of the two conditions counterbalanced.

1.1.4. Procedure

Upon arrival to the lab, parents held their infants on their laps while the procedure was explained. Then, infants were moved to the experimental space for a brief acclimation period (no more than 5 min). To begin the data collection, infants were placed in a crawling position for the crawling condition or in the walker for the walker condition in the exact center of the floor. The mother then sat in one corner of the floor, while a female experimenter sat in the opposite corner. Two sets of toys were placed in each of the remaining corners, so there was either a person or toys in each of the four corners of the space. Both parents and experimenters were asked to maintain normal responsiveness to the infant, but not to initiate interactions or direct the infants to do anything in particular.

After 10 min, the parents were instructed to pick up their infants and carry them to the reception area for a short break. New toys were put in their respective corners and the video equipment was checked. Then, the procedure was repeated, but infants who began the study crawling were then placed in the baby-walker and vice versa. Infants who did the baby-walker condition second were given an additional 5 min acclimation period to get used to the baby-walker. All infants were able to successfully move across at least 5 squares within this acclimation period.

1.1.5. Dependent measures

The dependent measures in this study are based closely on those from Gustafson (1984).

1.1.5.1. Travel. This variable captured infants' movement about the space by recording the number of squares crossed (the infant moved out of one square and into another). Crossing a square was defined as the infant's trunk crossing the line. In other words, sitting in one square and reaching out to the next square would not count as 'crossing', but moving forwards (or backwards) in a crawling position would count as the infants' trunk crossed the line. Each square was .3 m × .3 m, so this is a loose measure of amount of distance traveled.

1.1.5.2. Interaction time. This measure captured the time in seconds that infants spent actively interacting with either of the adults or the toys. Interaction with the adults (coded separately for mother and experimenter) included talking, handing toys back and forth, sitting in the lap, or other touching behaviors. Interaction with the toys included touching, rubbing, banging, waving, or otherwise handling the objects. Note that infants in the baby-walker were easily able to squat down and/or lean over to pick up the toys, so the walker itself was not an impediment to interacting with the toys.

1.1.5.3. Gestures and vocalizations. Infants' gestures and vocalizations were coded as frequencies from the videotapes. Vocalizations were defined as any vocal utterance and gestures included pointing to an object or waving an object. Vocalizations and gestures were further categorized as either directed or undirected, where directed meant that the vocalization or gesture was paired with a look to an adult.

1.1.6. Observer agreement

A second coder blind to the experimental predictions viewed 20% of the videotapes, distributed across the conditions and experiments. Spearman's correlation coefficients and percent agreement were calculated for each of the dependent measures. For measures of travel, the mean correlation was .98 (range = .82–1.0) and the mean percent agreement was 83.4 (range = 77–100%). The mean correlation for measures of interaction was .99 (range = .99–1.0) and the mean percent agreement was 94.3% (range = 83–100%). For gestures and vocalizations, the mean correlation was .99 (range = .98–.99) and the mean percent agreement was 95.8% (range = 83–100%).

1.1.7. Analyses

Infants' behavior on the dependent measures while crawling was compared to those behaviors while in the walker. Series of *t*-tests were used to compare individual variables across conditions, and multivariate analyses of variance (within-subjects variable was 2 levels: crawling or baby-walker) were performed for each set of variables: interaction (3 levels: toy, mother or experimenter), gestures (2 levels: directed and undirected) and vocalizations (2 levels: directed and undirected) as a precaution against Type 1 errors. Because there were no differences between infants who had baby-walker experience and those who did not, all infants were included in all analyses.

1.2. Results and discussion

There were no order effects for any variables, so the data were collapsed across order. There were no differences in travel, $t(16) = .178$, n.s., with crawling infants crossing 30.23 ($SE = 7.87$) squares, compared to 27.71 ($SE = 15.25$) squares while in a baby-walker (see Fig. 1). Thus, the baby-walker did not impede infants' movements, and indeed, all infants were able to move throughout the session.

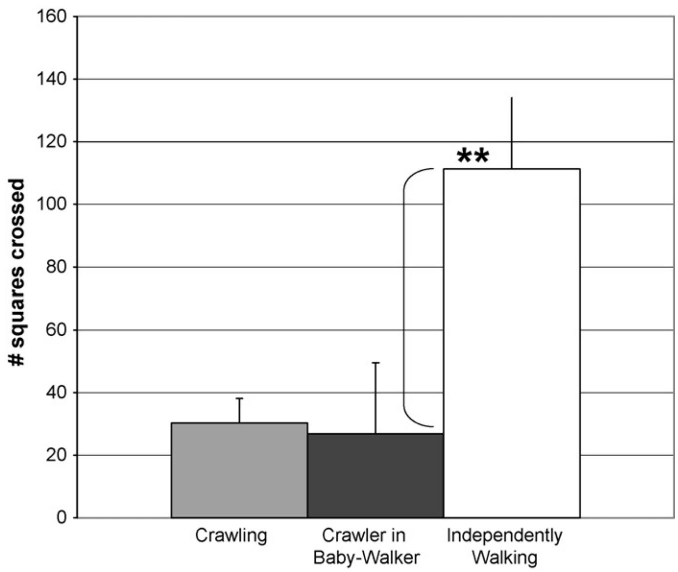

Fig. 1. Number of squares crossed by locomotor status. The data for the infants while crawling and in a baby-walker are described in Experiment 1, and the comparison between crawling infants in the baby-walker and age-matched walking infants are described in Experiment 2. $^{**}p < .01$.

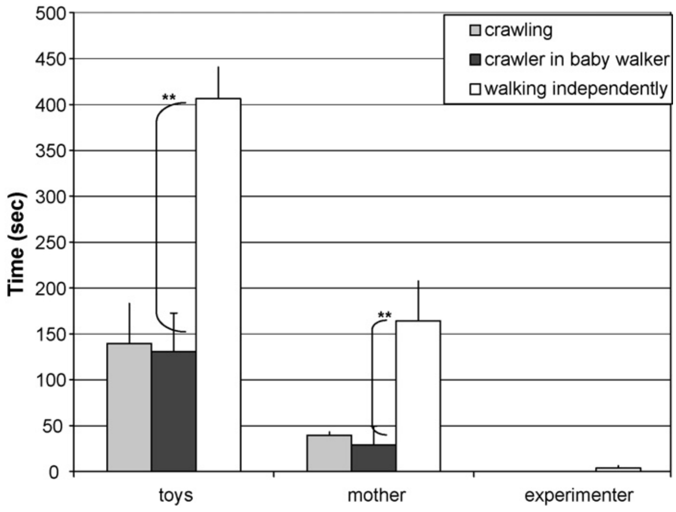

Fig. 2. Seconds of interaction with mother, experimenter and toys by locomotor status. The data for the infants while crawling and in a baby-walker are described in Experiment 1, and the comparison between crawling infants in the baby-walker and age-matched walking infants are described in Experiment 2. $^{**}p<.01$.

With respect to time spent interacting, the multivariate analysis revealed a significant main effect for who infants interacted with, $F(2)=15.37$, $p<.05$ (see Fig. 2). Infants interacted longer with the toys ($M=185.0$ s) than with either of the adults ($M=75.02$ sec with the mother, $M=.22$ s with the experimenter). There was a marginal main effect for locomotor status, ($F(1)=10.07$, $p=.053$), with infants interacting more overall while crawling ($M=360.94$ s) than while in the baby-walker ($M=259.93$ s). Critically, there was no significant interaction for interacting time by locomotor status, $F(2, 30)=1.54$, n.s. This means that being in the baby-walker did not change infants' pattern of social interactions. The individual comparisons indicated that infants spent marginally more time touching the toys while crawling ($M=139.47$ s) than while in the walker ($M=130.67$), $t(16)=1.41$, $p=.08$. There were no differences for interaction time with either adult.

A series of 2 (locomotor status: crawling or baby-walker) × 2 (Type: directed vs. undirected) Repeated Measures ANOVAs were conducted on vocalizations and gestures (see Fig. 3). For both, there was a main effect of type, with infants showing more undirected vocalizations than directed ($M=11.54$ vs. 2.66; $F(1)=18.87$, $p<.001$) and more undirected gestures than directed ($M=1.04$ vs. .54; $F(1)=9.10$, $p<.01$). There were no effects of locomotor status, nor any interactions.

Overall, the results of Experiment 1 confirm that during the first transition to independent locomotion, social behaviors are not posture-specific. When comparing infants who were crawling around a new space to those same infants in a baby-

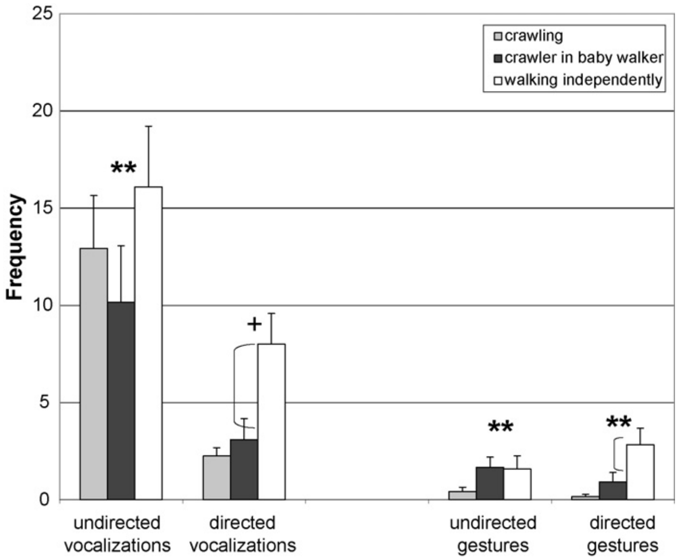

Fig. 3. Frequencies for vocalizations and gestures by locomotor status. The data for the infants while crawling and in a baby-walker are described in Experiment 1, and the comparison between crawling infants in the baby-walker and age-matched walking infants are described in Experiment 2. $^{+}p=.05$, $^{**}p<.01$.

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walker, there were no differences in how far the infants moved across the floor, who they interacted with, or gestures and vocalizations. The only posture-related difference that emerged was in how long the infants spent interacting with the toys. Infants spent marginally more time interacting with the toys when crawling. One might argue that this is because crawling infants had easier access to the toys, which were on the floor. However, even while in a baby-walker, infants spent nearly 3 min interacting with the toys, and the difference between the two groups was only 15 s out of a total of 10 possible minutes. Because this result was only marginally significant in the individual comparisons and not significant in the multivariate analysis, it may very well be due to chance.

Overall, these results replicate Gustafson's (1984) second experiment where pre-locomotor infants in a baby-walker were compared to crawling infants. The significance of that manipulation was that she provided non-locomotor infants with an opportunity to move, and compared those infants to crawling infants. Her comparison was a between-subjects comparison, and she found no differences in behaviors. The present study found the same patterns of results (i.e., no differences based on posture) in a within-subjects design. Even in the same infants, changing their posture from crawling to upright locomotion did not affect the manner in which they moved through the space, looked around, or interacted with adults.

As described earlier, other studies have found distinct differences in exploratory behaviors between crawling and walking infants (e.g., Adolph, 1997; Gibson et al., 1987). However, one notable difference between those studies and the present study is that those earlier studies all involved some threat or risk to the infant, either descending a steep slope or crossing an unstable surface. The level of risk differed based on the locomotor posture of the infants (e.g., crossing a waterbed surface was much more stable in a crawling position than a walking position). The present study presented no such risk. Here, infants were merely exploring a new space. The fact that all of the infants did engage in exploratory behaviors (moving about the space, interacting with people and objects) is suggestive of more baseline levels of simple exploration, without the additional challenge of solving a locomotor problem. This may explain the lack of differences between the postures.

However, if infants did not show different behaviors because the task did not elicit them, then comparing independently walking infants to those in a baby-walker should also yield no differences. If, on the other hand, the transition to walking independently is a more global change, then independently walking infants should behave differently than those in a walker. Experiment 2 tests whether exploratory and social behaviors are comparable between crawling infants in a baby-walker and independently walking infants. This comparison addresses the questions: (1) does independent walking mark a second significant transition in social and exploratory behaviors? and (2) to what extent is that difference due to being upright?

2. Experiment 2

2.1. Method

2.1.1. Participants

An additional 16 infants (8 boys and 8 girls) between the ages of 9 and 12 months ($M = 10.1$ months; matched in age with the infants in Experiment 1) participated in this study. There was no attrition. All infants were able to walk proficiently, meaning that they could cover 3 m of distance within 10 s (confirmed in the laboratory before testing began). This was also the definition used to calculate the onset of independent walking. According to parental reports through baby diaries, the infants had an average of 6 weeks of walking experience (range was 2–10 weeks). Infants were recruited in the same manner as Experiment 1.

2.1.2. Apparatus, procedure, dependent measures and analyses

The apparatus, measures and analyses were identical to that in Experiment 1, except that infants explored the space while walking independently only.

2.1.3. Design

A between-subjects design was used to compare to the independently walking infants to Experiment 1's crawling infants in the baby-walker condition.

2.2. Results and discussion

There were significant differences between walking infants and walker-assisted infant for travel (see Fig. 1). Independently walking infants entered significantly more squares ($M = 111.27$) compared to walker-assisted infants ($M = 27.71$), $t(30) = 3.11$, $p < .01$.

A multivariate analysis on the time spent interacting with the adults and toys revealed significant main effects for both locomotor status ($F(1) = 48.45$, $p < .0001$, with walkers interacting more than infants in the baby-walker) and for the object of interaction ($F(2) = 41.67$, $p < .0001$, with all infants spending more time with the toys than with either adult). Importantly, there was also a significant interaction, $F(2, 30) = 10.13$, $p < .001$ (see Fig. 2). Although both groups of infants spent more time interacting with toys than with their mothers, the independently walking infants showed a much steeper increase than the infants in baby-walkers.

Separate multivariate analyses (2 (locomotor status: crawler in baby-walker and independent walking) × 2 (type: directed vs. undirected) were conducted for vocalizations and gestures. For vocalizations, there was a significant main effect for type,

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with more undirected vocalizations than directed, $F(1) = 18.87$, $p < .001$ (see Fig. 3, left side), and a marginal main effect for locomotor status, with walkers vocalizing more than crawling infants in the baby-walker ($F(1) = 4.06$, $p = .05$). There was no significant interaction for vocalizations. With respect to gestures, there was a significant interaction between locomotor status and type, $F(1,22) = 7.94$, $p < .01$ (see Fig. 3, right side). There were no differences between the groups in undirected gestures, but independently walking infants made significantly more directed gestures compared to crawling infants in a baby-walker.

The main question addressed in Experiment 2 was whether independent walking marks a second significant transition in social and exploratory behaviors, as seen in the differences in behavior between walking infants and age-matched crawling infants placed in a baby-walker. Independently walking infants traveled more distance than walker-assisted infants, and spent significantly more time interacting with the toys, and also interacting with their mothers. In addition, independent walkers made more vocalizations and more directed gestures, in which they pointed at or waved a toy while looking at their mothers.

These differences all reflect independent walkers' higher level of engagement in their social environment. The crawlers in the baby-walker spent less than 1 min, on average, interacting with their mothers. Instead they tended to slowly move to one set of toys and play with them in that spot (as demonstrated in their reduced travel but high toy interaction times). In contrast, the walking infants were much more socially engaged throughout the session. Not only did they spend 3 times as long interacting with their mothers, and more than twice as much time playing with the toys, but they also made more vocalizations and directed gestures. This is significant, because the directed gestures were defined as holding up a toy (or pointing at one) while looking at an adult. That act is an *initiation* of a social interaction. The fact that walkers did that, coupled with the large increase in toy and mother interaction time, reflect prolonged bouts of playing with the toys and their mothers at the same time. That reflects a much more mature mode of social engagement than that seen in the crawling infants in the baby-walker.

Importantly, the infants in the baby-walker could have done this – their hands were free to gesture, but they did not. These infants could reach the toys, because they held the toys nearly as much as when they were on their hands and knees. And these infants were age-matched to the walking infants, so age or maturation also cannot explain this pattern of results. Instead, it may be that learning to walk independently creates a system-wide shift in interaction style. In order to directly test the impact of learning to walk on infants' social interactions, Experiment 3 tracked infants longitudinally across the transition from crawling to walking.

3. Experiment 3

3.1. Methods

3.1.1. Participants

Participants were 14 infants (9 boys, 5 girls), all Caucasian except for one Hispanic participant. All participants were observed monthly for 6 months; testing began when the infants were 9 months (±2 weeks) and ended at 14 months (±2 weeks). One infant missed one session due to illness. There was no other attrition.

3.1.2. Longitudinal design

Infants were tested six times in total, beginning at 9 months of age. All infants were crawling at this visit. Each infant then returned to the lab once a month on the infant's monthly birthday until the infant was 14 months old (the age by which infants are typically walking independently). This design tracked the transition from crawling to walking while holding age constant, thus teasing apart the influences of age and locomotor experience. Walking onset was determined in two ways: maternal reports and experimenter observation of at least 3 m of consecutive steps, independent of any external supports, such as furniture. Table 1 provides infants' age at walking onset.

3.1.3. Apparatus, procedure and data coding

All factors were identical to Experiments 1 and 2, except that different experimenters participated in data collections, so that the experimenter was a stranger on each visit.

Table 1
Age at infants' first walking session.

Age at first walk session	Number of infants
10 months	1
11 months	3
12 months	4
13 months	3
14 months	1
15 months (after study ended)	2

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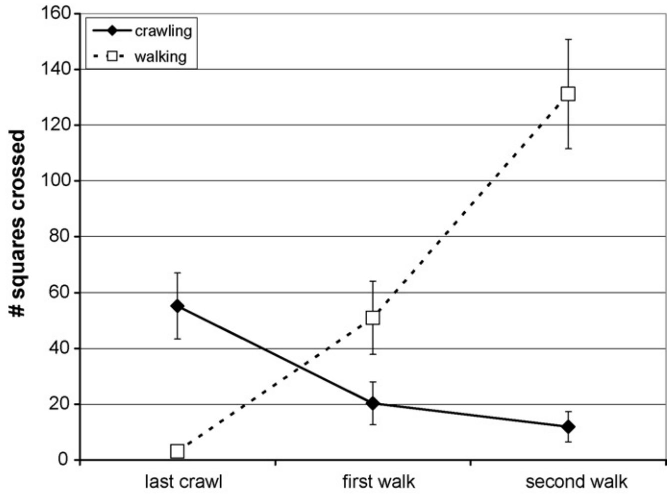

Fig. 4. Number of squares crossed, both crawling and walking, by session. Infants crawled significantly more in their last crawl session compared to their first walk session and infants walked significantly more in successive sessions.

3.2. Results and discussion

The contribution of walking onset was tested in two ways. First, a series of Repeated Measures ANOVAs were conducted, with session as the within-subjects factor (3 levels: infants' last crawling session before they walked, and first and second walking session) and 4 between-subjects factors: travel (1 level: number of squares crossed), interaction (3 levels: toy, mother and experimenter), vocalizations (2 levels: directed and undirected) and gestures(2 levels: directed and undirected). Because only 12 of the 14 infants began walking during the study, only these infants were included in this analysis.

For travel, given that infants were transitioning from crawling to walking, the number of squares crossed was coded separately for crawling and walking. Thus, some infants showed a few walking steps in their last crawling session; however, these infants still mostly crawled, and did not meet the criteria for first walking session, which required the ability to walk for at least 3 m unassisted. Likewise, some infants who met the criteria for walking still occasionally reverted to crawling. However, infants crawled significantly more in their last crawl session (55.27 squares) compared to their first walk session (19.27; $F(2,10) = 7.85$, $p < .01$; see Fig. 4). And infants walked significantly more in successive sessions, $F(2,10) = 21.49$, $p < .001$ (3.09 squares in last crawling session, 53.18 in first walking, and 131.18 in second walking session). When number of squares crossed is pooled across both crawling and walking, there are no significant differences between sessions, $F(11) = 1.06$, n.s.

The interaction data was analyzed with a 2 (type: toy vs. mother) × 3 (session: last crawl, first and second walk) Repeated Measures ANOVA (because the average interaction time with the experimenter was less than 2 s and more than half of the infants spent no time with the experimenter, these data were omitted from analyses). There was a main effect of type, $F(1) = 25.24$, $p < .001$, with infants interacting significantly more with the toys overall than with their mothers (see Fig. 5). Critically, there was a significant interaction, $F(2,22) = 11.37$, $p < .0001$, centered on infants' first walking session. In that session, infants interacted with their mothers significantly more and with toys significantly less compared to both their last crawl and second walk sessions.

There were no main effects or interactions for vocalizations. However, for gestures, there was a main effect for session, with infants gesturing more during their first walking session ($M = 18.34$) compared to their last crawl session ($M = 11.8$), ($F(2) = 5.32$, $p < .01$. There was also a significant interaction, $F(2,1) = 24.43$, $p < .0001$. Infants made more directed gestures in their first ($M = 10.92$) and second walking sessions ($M = 13.50$), compared to their last crawling session ($M = 3.58$), while infants' undirected gestures significantly decreased between their first walk session ($M = 7.42$) and second walk session ($M = 3.42$). Indeed, this increase in directed gestures may explain the decrease in interaction time in infants' second walking session. Infants with more sophisticated ways to communicate from afar, through directed gestures, are thus able to get their mothers' attention without being near them (see Fig. 6).

A second way to test the influence of locomotor experience is to compare the walking and crawling infants at the same age. At 12 months of age, 8 of the infants were walking (M experience = 3.37 weeks) and 6 of the infants were still crawling. Thus, the next series of analyses focused exclusively on the 12-month session, and reflected the same pattern of results.

With respect to travel, a t-test revealed that walking 12-month-olds crossed significantly more squares (32.69 squares) than crawling 12-month-olds (5.69 squares), $t(12) = 2.19$, $p < .05$. Although there were no differences in interaction times with the experimenter or with the toys, walking 12-month-olds interacted significantly more with their mothers (440.4 s) than crawling 12-month-olds (175.2 s), $t(12) = 2.50$, $p < .05$. Again, while there were no differences in vocalizations, the number and types of gesture replicated the findings of Experiment 2. There was a significant main effect for locomotor status, with walking infants gesturing more than crawling infants, $F(1) = 11.74$, $p < .01$, and also a significant interaction, $F(1,1) = 10.817$,

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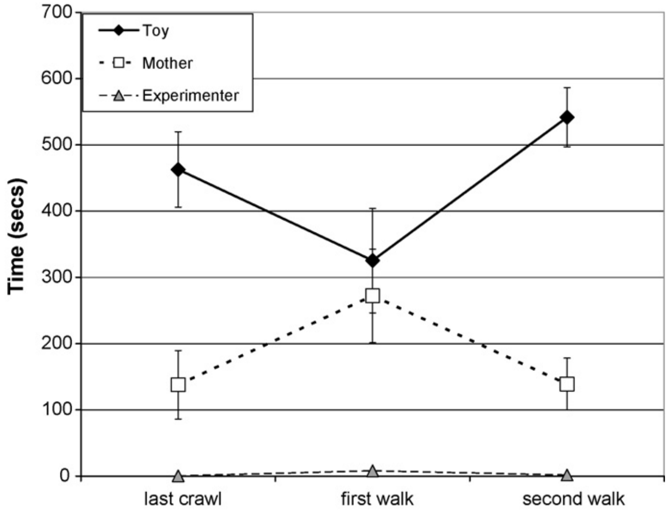

Fig. 5. Seconds of interaction with the toys, mother and experimenter by session. Infants interacted with their mothers significantly more and with toys significantly less compared to both their last crawl and second walk sessions.

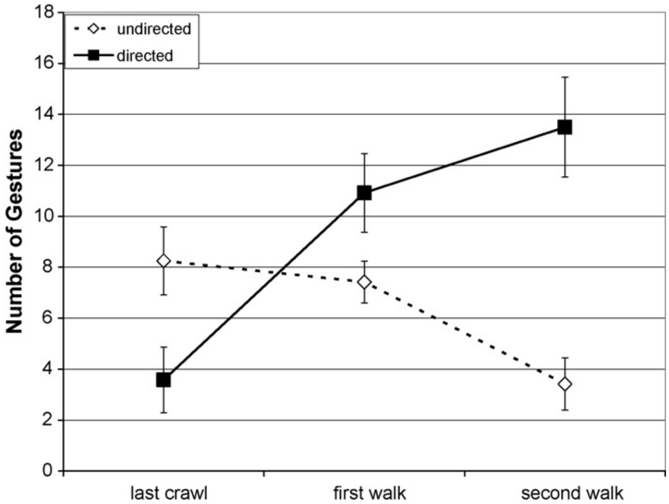

Fig. 6. Number of directed and undirected gestures by session. Infants made significantly more directed gestures in their first and second walking sessions compared to their last crawling session, while infants' undirected gestures significantly decreased between their first walk session and second walk session.

$p < .01$. The crawling 12-month-olds made significantly more undirected gestures ($M = 8.33$ vs. 1.33 directed) while the walking 12-month-olds made more directed gestures ($M = 14.12$ vs. 6.38 undirected).

The results of this longitudinal study replicate and extend the findings from Experiments 1 and 2, that learning to walk independently significantly changes infants' interactions with their mothers and with objects in their environment. This interpretation is strengthened by the data at 12 months, when the walking 12-month-olds were compared to the crawling 12-month-olds, and again, the same pattern held. Crawling infants interacted less with their mothers than walking infants, and demonstrated fewer communicative gestures. Walking infants, in contrast, engaged not just in more interaction time with their mothers, but also more sophisticated interactions, including directing mothers' attention to particular objects. This more mature mode of interaction did not come about through age or more experience in the world, but rather, the transition to independent walking itself changed how infants interact with others.

4. General discussion

Taken together, these experiments suggest a developmental progression that links social and exploratory behaviors with the transition to independent walking. Previous research has found that proximity is critical in initiating interactions between mothers and infants, so the onset of crawling is seen as a milestone in social development (see Campos et al., 2000 for a review). At crawling onset, infants can move to be closer to their mothers, which can be seen as an initiation of an

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encounter. Independent walking then goes a step further, where infants can initiate interactions that involve an object (by bringing the object to the adult), thus getting an adult involved in what the infant wants to play with. Now infants can direct adults' attention to something that the infant is interested in, rather than only focusing on what the adult wants.

The present results are a first step in experimentally understanding infants' social interactions when they shift from crawling to walking. Earlier studies have noted changes in euphoria (Greenacre, 1971), willfulness (e.g., Mahler et al., 1975), and social referencing (Clearfield et al., 2008) but these are mood/emotional differences, not necessarily interaction differences. The present findings suggest that becoming an independent walker changes more than infants' moods, but actually changes how infants interact with other people.

Importantly, that new mode of interaction appears to include engaging in joint attention, where infants direct their mothers' attention, through gestures, to an object of interest. Joint attention has been the focus of hundreds of studies because it facilitates infants' communication and language skills (e.g., Bates, 1976). In the first 6 months of life, infants begin to demonstrate the more basic skills of following the gaze of another to an object of interest and infant-initiated joint attention is known to emerge early in the second year of life (Bates, 1976). Infant-initiated joint attention is a way for infants to share experiences with others (e.g., Mundy, Kasari, & Sigman, 1992; Rheingold, Hay, & West, 1976), but more importantly, it marks the beginnings of social cognition, where infants recognize that they can influence others' attention through social means (e.g., Brooks & Meltzoff, 2002; Tomasello, 1995). This early social cognition has even been linked to social competence in pre-school children (e.g., Van Hecke et al., 2007). Understanding the full developmental landscape, including motor development, at the onset of infant-initiated joint attention could give us a deeper understanding of how these critical behaviors develop.

These results raise many questions about what mechanism might be responsible for the changes in social behaviors that are associated with independent walking. One possibility is that these changes are maturational, where infants become more socially active with age. This is unlikely, because infants were age-matched across all experiments. Another option is that general locomotor experience accounts for the changes, where walking infants have passed some threshold for experience moving through the world. However, this too is unlikely, given the longitudinal comparison at 12 months of age (where locomotor experience was the same between the 12-month-olds who were crawlers and the 12-month-olds who were walkers).

A more likely possibility is that independent walking serves as a control parameter, resulting in a reorganization of infant experiences (e.g., Schnierla, 1957), where walking operates "through a complex formula of intervening maturation-experience variables in a causal nexus" (p. 102). In other words, we can think of the developing infant as a complex system made up of many individual elements embedded in a rich context. During periods of stability, all the elements of the system work together smoothly. During periods of instability, the system is open to multiple flexible solutions and the emergence of new forms. The transition to independent walking appears to be one of those periods of instability. Under this explanation, processes such as perception, attention, memory, cognition, and social behaviors all shift to accommodate infants' new mode of moving through the world, and each process affects and is affected by the changes in the other processes. From this dynamic view, learning to walk becomes much more than simply a motor milestone; instead, it becomes the core of system-wide changes across many developing domains.

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