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How Do You Learn to Walk? Thousands of Steps and Dozens of Falls per Day

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Abstract

A century of research on the development of walking has examined periodic gait over a straight, uniform path. The current study provides the first corpus of natural infant locomotion derived from spontaneous activity during free play. Locomotor experience was immense: Twelve- to 19-month-olds averaged 2,368 steps and 17 falls per hour. Novice walkers traveled farther faster than expert crawlers, but had comparable fall rates, which suggests that increased efficiency without increased cost motivates expert crawlers to transition to walking. After walking onset, natural locomotion improved dramatically: Infants took more steps, traveled farther distances, and fell less. Walking was distributed in short bouts with variable paths—frequently too short or irregular to qualify as periodic gait. Nonetheless, measures of periodic gait and of natural locomotion were correlated, which indicates that better walkers spontaneously walk more and fall less. Immense amounts of time-distributed, variable practice constitute the natural practice regimen for learning to walk.

Keywords

infant development, learning, motor processes, perceptual motor coordination

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How do infants learn to walk? For more than 100 years, researchers have described developmental antecedents of walking, improvements in the kinematics of walking gait, and changes in the neurophysiological correlates of walking (Adolph & Robinson, in press). However, a century of research has proceeded without a natural ecology of infant locomotion. Researchers know nothing about how much infants crawl and walk, how their activity is distributed over time, how far they travel and where they go, how frequently they fall and what motivates them to persevere, and how natural locomotion changes with development. Lack of such descriptive data is a serious omission, unique to motor development. Descriptions of infants' natural activity have been instrumental for constraining theory, guiding clinical interventions, and motivating new research in other areas, such as language acquisition (Hart & Risley, 1995; Hurtado, Marchman, & Fernald, 2008; MacWhinney, 2000), cognitive development (Piaget, 1936/1952), social-emotional development (Barker & Wright, 1951; Messinger, Ruvolo, Ekas, & Fogel, 2010), symbolic play (Tamis-LeMonda & Bornstein, 1996), sleep (Kleitman & Engelmann, 1953), and natural vision (Cicchino, Aslin, & Rakison, 2011; Franchak, Kretch, Soska, & Adolph, 2011; Smith, Yu, & Pereira, 2011). But theories about the development of locomotion and therapies designed to redress atypical locomotor development are not connected to data on infants' real-world experiences with locomotion.

Why are natural descriptions so conspicuously absent from the literature on infant locomotion? One reason for the absence of data is the traditional emphasis on neuromuscular maturation. The long-held assumption that locomotion develops as a universal series of increasingly erect stages led researchers to focus on the formal structure of prone crawling postures en route to upright walking (Gesell, 1946). Similarly, the search for locomotor "primitives" led to formal comparisons between alternating leg movements in newborn stepping, treadmill-elicited stepping, and independent walking (Dominici et al., 2011; Forssberg, 1985; McGraw, 1945; Thelen, 1986; Zelazo, 1983). But age-related sequences in the topography of locomotion dodge the question of why crawlers ever bother to walk. That is, why would expert crawlers abandon a presumably stable, quadrupedal posture that took months to master in order to move in a precarious, upright posture that involves frequent falling? In fact, the question of why children persist

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in acquiring new skills that are initially less functional than the skills already in their repertoires is a central but unanswered question in developmental psychology (Miller & Seier, 1994; Siegler, 2000).

A second, related, reason for the lack of data on natural locomotion is that researchers have historically measured aspects of periodic gait—consecutive, regular steps over open ground—rather than natural locomotion in a cluttered environment where deviations from periodic gait can be adaptive and functional. Since the 1930s, researchers have described infants' movements as they take a series of continuous steps over a straight, uniform path (Bril & Breniere, 1993; Dominici et al., 2011; Hallemans, De Clercq, & Aerts, 2006; McGraw, 1945; Shirley, 1931). With the standard paradigm, it is imperative that the infants being assessed walk as quickly and as straight as possible because speed and straightness affect measures such as step length. But the first thing that researchers discover as they try to coax infants along a straight, continuous path is that infants do not readily walk this way. Instead, they stop after a few steps, speed up and slow down, swerve and change direction, and misstep or fall. Typically, such deviations from periodic gait are ignored because they invalidate standard skill measures, and thus trials must be repeated. However, in natural locomotion, modifications in step length, speed, and direction are necessary to cope with variable terrain (Patla, 1997). Without a corpus of natural infant locomotion, researchers cannot know whether standard skill measures such as step length and speed during periodic gait are related to functional skill measures in the everyday environment, such as how much infants crawl or walk, how many steps they take, how far they travel, and how frequently they fall.

A third factor contributing to ignorance about infants' natural experiences with locomotion is that researchers (including the current authors) routinely represent experience as the number of days that have elapsed since an onset date. Researchers report walking experience as the number of days between the first day of walking and the day of testing. However, this definition is misleading: New walkers walk intermittently, vacillating between days when they walk and days when they do not (Adolph, Robinson, Young, & Gill-Alvarez, 2008). More important, this definition is a conceptual misrepresentation of experience. The passage of time is only a proxy for the events that infants actually experience (Adolph & Robinson, in press; Wohlwill, 1970). Although walking experience reliably predicts improvements in standard skill measures such as step length and step width (Adolph, Vereijken, & Shrout, 2003; Bril & Breniere, 1993) and in performance of perceptual-motor tasks such as perceiving affordances of slopes (Adolph, 1997), the number of days since walking onset carries little more meaning than test age (the number of days since birth). Indeed, some researchers refer to the number of days since onset as "walking age" (Clark, Whitall, & Phillips, 1988). Possibly, sheer practice, indexed by accumulated number of steps, facilitates improvements in gait. Alternatively, particular experiences, such as surfaces encountered or falls, may teach infants to walk. Without a natural corpus of infant locomotion, there is no empirical basis for hypothesizing about underlying learning mechanisms.

The Current Study

The current study provides the first data on natural infant locomotion—time in motion and distribution of activity over time, variety of locomotor paths, and accumulated steps, distance, and falls. We had three aims. First, we compared natural locomotion in experienced crawlers and novice walkers to gain purchase on the question of why crawlers are motivated to walk. Second, we asked whether functional measures of walking skill, such as number of steps and number of falls per hour, improve with test age and walking age, as do standard skill measures like step length and step width. Third, we investigated relations between standard and functional measures of walking skill.

Presumably, most spontaneous walking occurs while infants explore the environment and interact with caregivers. Accordingly, data were collected while infants played freely under caregivers' supervision. We videotaped infants rather than relying on step counters or parent informants—two methods that proved problematic in earlier attempts to quantify infants' natural locomotion (Adolph, 2002). Because video coding was intensely detailed and laborious, we collected representative (15- to 60-min) samples of activity, as is customary in studies of language acquisition (e.g., Hurtado et al., 2008). Most samples were collected in a laboratory playroom to maximize recording quality and to eliminate individual differences in infants' home environments. We also observed infants in their homes to ensure the validity of the laboratory data for estimating natural activity. We focused on 12- to 14-month-old novice walkers, in whom improvements in standard skill measures are most dramatic, but included a sample of older, more experienced 19-month-olds, whose skill measures typically have begun to reach asymptote (Adolph et al., 2003; Bril & Breniere, 1993; Clark et al., 1988; Hallemans et al., 2006). We also observed a comparison group of 12-month-old expert crawlers.

Method

Participants and procedure

We collected 15 to 60 min of spontaneous activity for 151 infants (72 girls, 79 boys) from the New York City area. Most families were middle-class, and 73% were White. Data from 5 additional infants were excluded because of fussiness or technical problems. We observed 20 crawlers (11.8–12.2 months of age) and 116 walkers (11.8–19.3 months) in a laboratory playroom (8.66 m × 6.10 m) filled with furniture, varied ground surfaces, and toys (Fig. 1a). Infants could move freely throughout the room (Fig. 1b). To ensure that playroom observations were representative of natural locomotion, we also observed

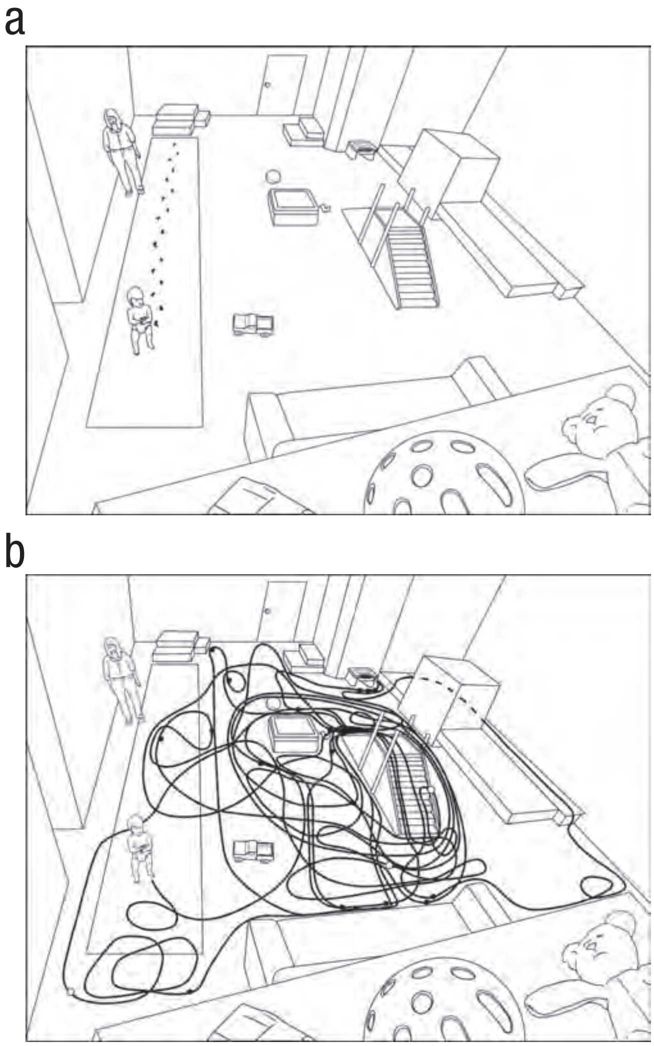

Fig. 1. Layout of the laboratory playroom (a) and an example of a natural walking path (b). Dimensions are drawn to scale. In (a), the large rectangle on the left shows the location of the gait carpet and a representative walking path over the carpet. The playroom also contained a couch, a padded square pedestal, a slide and small stairs, a narrow catwalk behind a wooden barrier, large steps at the ends of the catwalk, a set of carpeted stairs, a set of wooden stairs, a standing activity table, and a wall lined with shelves of toys. The line superimposed over the diagram in (b) shows the natural walking path of one typical 13-month-old during the first 10 min of spontaneous play. Overlapping lines indicate revisits to the same location. Filled circles represent the location of rest periods longer than 5 s; open circles denote falls.

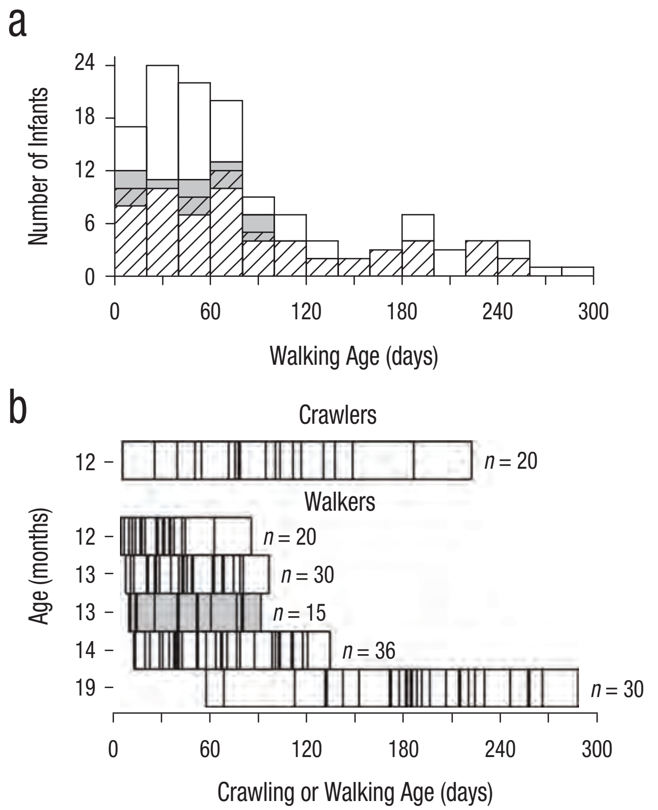

Fig. 2. Frequency histogram of walking age across the entire sample (a) and distribution of crawling and walking ages for the six groups of infants (b). In (a), striped portions of the bars denote girls, and nonstriped portions denote boys. In both (a) and (b), gray bars denote home observations, and white bars denote lab observations. Each vertical line in (b) represents one infant.

fifteen 12.8- to 13.8-month-old walkers in their homes. Caregivers were instructed to interact normally with their infants and to mind their safety. In both settings, an experimenter recorded infants' movements with a handheld camera. In the laboratory, two additional fixed cameras recorded side and overhead views to aid coding.

Crawling and walking age were determined from parental reports of the first day that infants traveled 10 ft across a room without stopping. Walking age was unavailable for 5 infants. Figure 2a shows a frequency distribution of walking age and sex, and whether infants were observed in the lab playroom or in their homes. Figure 2b shows the distribution of crawling and walking ages for the six groups of infants: twenty 12-month-old crawlers (observed in the lab for 20 min), twenty 12-month-old walkers (observed in the lab for 20 min), thirty 13-month-old walkers (observed in the lab for 30 min), thirty-six 14-month-old walkers (observed in the lab for 15 min), thirty 19-month-old walkers (observed in the lab for 30 min), and fifteen 13-month-old walkers (observed at home for 60 min). Notably, in the 12-month-olds, crawling age (M = 97.6 days) was considerably larger than walking age (M = 29.7 days), $t(38) = 5.41$, $p < .01$ (see the top two rows of Fig. 2b). Across the entire sample, walking age ranged from 5 to 289 days. Walking age overlapped among the 12- to 14-month-olds, and there was no difference in walking age between 13-month-olds observed at home (M = 47.4 days) and in the lab (M = 45.9 days), $p > .10$.

At the end of the laboratory sessions, we collected two standard measures of walking skill as infants walked a straight path over a pressure-sensitive mat (3.6 m × 0.89 m; GAITRite System, CIR Systems, www.gaitrite.com; see Fig. 1a): step length (front-to-back distance between consecutive footfalls) and step width (side-to-side distance between feet). We estimated crawlers' average step length (distance between consecutive knee contacts) from the number of steps taken to crawl a 3.6-m path. Three walkers and 1 crawler did not contribute usable data.

Data coding

A primary coder scored 100% of the video data for the duration of time crawling or walking, number of crawling or walking steps, and number of falls. *Time crawling or walking* was the duration of a single step or series of steps flanked by rest periods of at least 0.5 s; onsets were scored from the video frame when the walker's foot (or crawler's knee) left the floor, and offsets were scored from the video frame when the foot or knee touched the floor in the last step of the series. Coders did not score time in motion for the home observations because they could not determine bout onsets and offsets reliably. A *step* was considered any up-and-down motion of a leg that changed the infant's location on the floor. *Falls* were scored when infants lost balance while crawling or walking, and their bodies dropped to the floor unsupported. A second coder independently scored 25% of each infant's data. Interrater agreement was high for time crawling or walking, number of steps, and number of falls, *r*s > .95, *p*s < .01.

To characterize the overall amount of natural locomotion, we calculated the accumulated time crawling or walking, number of steps, and number of falls for each infant and then expressed the data as proportions or hourly rates to allow comparisons across groups that were observed for different amounts of time. We estimated the total distance that infants walked, as if stringing their steps together end to end, by multiplying each infant's total step number by his or her average step length on the gait carpet.

Results

How did functional skill measures compare between 12-month-old crawlers and walkers? As expected, novice walkers fell more times per hour (*M* = 31.5) than expert crawlers did (*M* = 17.4), *t*(38) = 2.52, *p* < .02 (Fig. 3a), although the prevalence of falls in expert crawlers was unexpected. However, walkers walked more than crawlers crawled (Figs. 3b–3d): Walkers spent a larger proportion of time in motion (*M* = .33) than crawlers (*M* = .20), *t*(38) = 3.04, *p* < .01; walkers accumulated more steps per hour (*M* = 1,456.1) than crawlers (*M* = 635.9), *t*(38) = 3.78, *p* < .01; and walkers traveled greater distances per hour (*M* = 296.9 m) than crawlers (*M* = 100.4 m), *t*(36) = 4.05, *p* < .01. When we reconsidered falls taking into account the differences in activity between crawlers and walkers, differences in fall rate disappeared (Figs. 3e–3g): For every fall,

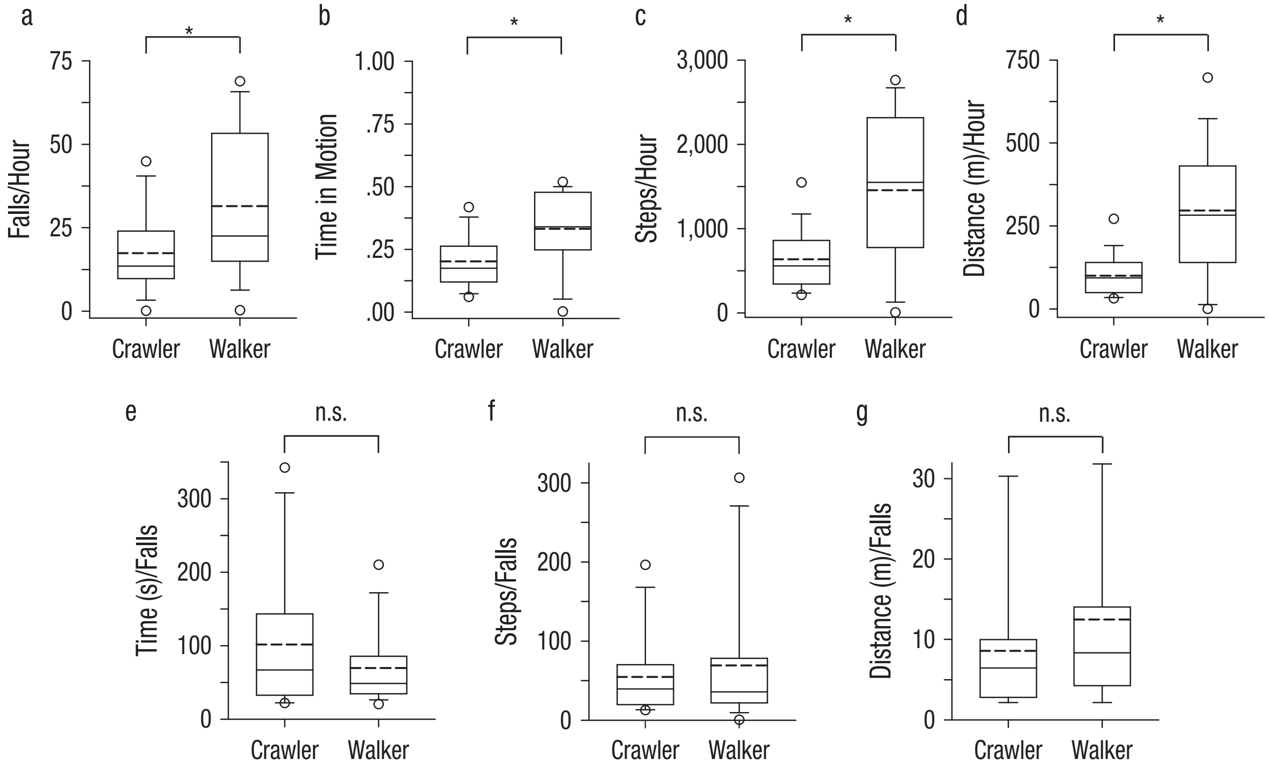

Fig. 3. Comparisons between 12-month-old expert crawlers and 12-month-old novice walkers: (a) number of falls per hour, (b) proportion of time in motion, (c) number of steps per hour, (d) distance traveled per hour, (e) accumulated time in motion for each fall, (f) accumulated number of steps for each fall, and (g) accumulated distance traveled for each fall. Solid horizontal lines in these box plots denote medians, and dashed horizontal lines denote means; circles denote outliers beyond the 10th and 90th percentiles; boxes include the 25th to 75th percentiles; tails denote the 10th and 90th percentiles. Asterisks indicate significant differences between the two groups, *p* < .05.

Table 1. Correlations Between Test Age, Walking Age, and Skill Measures

Measure	Walking age	Step length	Step width	Time walking	Steps/hour	Distance/hour	Falls/hour
Test age	.86** (124)	.71** (111)	−.60** (111)	.20* (114)	.46** (129)	.65** (111)	−.35** (129)
Walking age		.74** (106)	−.68** (106)	.28** (109)	.48** (124)	.68** (106)	−.33** (124)
Step length			−.65** (111)	.28** (111)	.51** (111)	.76** (111)	−.28** (111)
Step width				−.24* (111)	−.42** (111)	−.55** (111)	.32** (111)
Time walking					.85** (114)	.72** (111)	.14 (114)
Steps/hour						.92** (111)	−.09 (129)
Distance/hour							−.17 (111)

Note: Degrees of freedom are shown in parentheses.
$^{*}p < .05$. $^{**}p < .01$.

walkers accumulated 1.2 min in motion, on average, and crawlers accumulated 1.7 min; walkers accumulated 69.2 steps for each fall, on average, and crawlers accumulated 54.7; walkers traveled 12.5 m for each fall, on average, and crawlers traveled 8.6 m; all ps $> .10$.

Across the entire data set, walking infants averaged 2,367.6 steps per hour, traveled 701.2 m per hour, and fell 17.4 times per hour. However, like periodic gait, natural walking develops (see Fig. S1 in the Supplemental Material available online). As shown in the top two rows of Table 1, test age and walking age were significantly correlated with both standard measures of walking skill (step length, step width) and functional measures of walking skill (proportion of time walking, number of steps per hour, distance traveled per hour, number of falls per hour): Older infants (as identified by both chronological and walking age) took longer, narrower steps during periodic gait over the gait carpet. And during free play, older infants spontaneously spent more time walking, took more steps, traveled farther distances, and fell less frequently, all ps $< .01$. The significant correlations between age and functional skill measures remained even when time in motion was partialed out (Table 2), all ps $< .01$, which means that functional skill measures reflect more than overall activity level. Also, infants observed in their homes appeared similar to infants observed in the laboratory playroom; t tests comparing home ($n = 15$) and lab ($n = 70$) observations of infants with equivalent walking age showed no differences in number of steps per hour or number of falls per hour, ps $> .10$ (Figs. S1d and S1e).

Table 2. Partial Correlations Between Test Age, Walking Age, and Skill Measures Controlling for Time Walking

Measure	Steps/hour	Distance/hour	Falls/hour
Test age	.55** (113)	.75** (110)	−.39** (113)
Walking age	.49** (108)	.71** (105)	−.39** (109)
Step length	.54** (110)	.84** (110)	−.33** (110)
Step width	−.43** (110)	−.57** (110)	.36** (110)
Steps/hour		.84** (110)	−.39** (113)
Distance/hour			−.40** (110)

Note: Degrees of freedom are shown in parentheses.
$^{**}p < .01$.

Infants who were better walkers on the gait carpet were also better walkers during free play: Standard and functional skill measures were significantly correlated (Table 1), and these correlations remained after time in motion was partialed out (Table 2). Time walking, number of steps per hour, and distance traveled per hour were inherently intercorrelated (Table 1) because infants who took more steps had to cover more ground and spend more time in motion. However, number of falls per hour was not correlated with time walking, number of steps per hour, or distance traveled per hour (Table 1) because although infants who walked more had more opportunities to fall, they were also better walkers and thus fell less. When time in motion was partialed out, number of falls per hour was significantly negatively correlated with number of steps per hour and distance traveled per hour (Table 2), and all functional measures were consistent: Better walkers took more steps, traveled farther distances, and fell less frequently.

Although standard and functional skill measures were correlated, periodic gait on the gait carpet and natural locomotion during free play looked very different (Figs. 1a and 1b). Our impression from scoring the video files was that infants' natural paths twisted through most of the open space in the room. We confirmed that impression in 7 randomly selected novice walkers (mean walking age = 57.7 days) and 7 experienced walkers (mean walking age = 190.3 days) in the first 10 min of play. We superimposed 105 grid squares over the open areas of the playroom and scored each time the infants entered each square. All infants rambled throughout the room and spontaneously played near the couch and on the slide, pedestal, catwalk, carpeted stairs, and wooden stairs. The number of different grid squares entered was similar between novices ($M = 49$) and experts ($M = 57$), but experts made more return trips to the same squares. Novices entered or reentered 128.3 grid squares, on average, and experts entered or reentered 205.9 grid squares, $t(12) = 2.71$, $p < .05$.

Although infants accumulated thousands of steps during the observation periods, they spent most of the time stationary. They were under no obligation to move, and one 12-month-old did not take any walking steps. On average, infants walked only 32.3% of the time. Walking was distributed over time in primarily short bursts of activity. The raster plot in Figure S2 in the Supplemental Material shows the even distribution of walking bouts for the 60 infants observed for 30 min, ranked by walking age. Raster plots of the other 56 infants for whom we scored bout duration showed similarly even distributions. On average, 46% of bouts consisted of one to three steps, and 23% consisted of a single step—too short to qualify as periodic gait and too short for calculating standard measures of walking skill. There was no difference in duration, step number, or step rate between walking bouts that ended in falls and those that did not, *p*s > .10.

Discussion

A remarkable thing about basic skills acquired during infancy is the apparent ease and rapidity of their acquisition. Infants learn to walk, talk, think, play, and perceive objects and events in the course of natural activity. Thus, descriptions of natural activity play a critical role in guiding research, theory, and application. The development of locomotion is a notable exception: Until now, research, theory, and clinical intervention have proceeded without a natural ecology of infant locomotion. By collecting such a corpus, we aimed to address the question of why expert crawlers transition to walking, investigate developmental changes in natural locomotion and whether they relate to improvements on standard measures, and provide an empirical basis for hypothesizing about learning mechanisms.

Why walk?

Our inclusion of a comparison group of expert crawlers provided some clues to the long-standing puzzle of why infants who are skilled crawlers abandon crawling for a precarious, new, upright posture. To our surprise, expert crawlers were not more skilled than novice walkers. Functional measures of locomotor skill showed that crawlers crawled less than walkers walked, took fewer steps, and traveled shorter distances. Moreover, falling was common: All but one crawler fell. As expected, falling was far more common in novice walkers: One racked up 69 falls per hour. But when we reconsidered fall rate to take into account the differences in activity between crawlers and walkers, the difference in fall rates disappeared, and walkers were no longer at a disadvantage. In fact, when we reanalyzed standard measures of locomotor skill (measures of crawling or walking over a straight, uniform path) in infants observed longitudinally (originally reported in Adolph, 1997), step length and speed increased steadily from infants' 1st week of crawling to their 19th week of walking, and showed no decrement over the transition from crawling to walking (Adolph, 2008). In other words, assessments of both standard and functional skill measures indicate that new walkers reap all the benefits of an upright posture without incurring additional risk of falling. Thus, part of the answer to "why walk?" is "why not?"

Development of natural locomotion

After 100 years of studying the development of walking by coercing infants to walk at a steady pace along a straight, uniform path, researchers can say with certitude that standard measures of walking skill (e.g., step length and step width) improve with test age and walking age. We replicated that century-old finding. More newsworthy is our finding that natural locomotion also improves: Functional measures of walking skill obtained from spontaneous locomotion during free play (number of steps, distance traveled, and number of falls per hour) improve with test age and walking age. These findings held up after statistically adjusting for time walking, which means that older, more experienced walkers not only walk more, but also walk better. Just as standard skill measures are intercorrelated, functional skill measures were highly consistent. When time walking was partialed out to statistically adjust for activity, analyses showed that infants who took more steps and traveled farther distances fell less frequently.

Moreover, we found that standard and functional skill measures were significantly correlated. Thus, this study provides the first evidence of construct validity for standard skill measures in terms of natural infant walking. This set of findings is remarkable because periodic gait (Fig. 1a) looks notably different from natural locomotion (Fig. 1b).

Possible learning mechanisms

Researchers need to reconsider the long-held tradition of using walking age to represent walking experience. Walking age signifies only the elapsed time since walking onset. Like test age, walking age is a robust predictor of various developmental outcomes, but it is not an explanatory variable. In other areas of developmental research, descriptions of natural activity have informed understanding about learning mechanisms. For example, in language acquisition, the sheer number of utterances and word tokens in mothers' natural talk to infants when they are 18 months old (estimated from 12 min of mother-infant free play in a laboratory playroom) predicts their rate of vocabulary growth and language processing speed at 24 months of age (Hurtado et al., 2008). In contrast, diversity of language (number of word types) is not predictive. In conceptual development, event type rather than sheer quantity of input affects learning about causal agency: A higher proportion of agentive events compared with self-propulsion events (estimated from 1 hr of video collected with a head camera) during natural activity at 3, 8, and 12 months of age influences generalization about causal agency (in habituation tasks) at 10 to 14 months of age (Cicchino et al., 2011). Similarly, a corpus of natural locomotion allows researchers to investigate possible learning mechanisms by analyzing specific measures of locomotor experience. The current study suggests that quantity, distribution, and variety of experiences are viable candidates as factors affecting learning to walk.

Although most people would assume that infants walk and fall a lot, few would guess that the average toddler takes 2,368 steps, travels 701 m—the length of 7.7 American football fields—and falls 17 times per hour. Hourly rates provide only a tantalizing window into the amounts of practice that likely accumulate over a day. For example, a multiplier of 6 hr (approximately half of infants' waking day) would indicate that infants take 14,000 steps daily, travel the length of 46 football fields, and incur 100 falls. Estimates of natural activity are equally enormous for other skills. Middle-class infants hear 2,150 words per hour, more than 30 million words by 3 years (Hart & Risley, 1995). Eleven- to 13-month-olds spend more than 30 min per hour engaged with objects during everyday activity (Karasik, Tamis-LeMonda, & Adolph, 2011). By 2 months of age, infants have executed more than 2.5 million eye movements (Johnson, Amso, & Slemmer, 2003), and by 3.5 months, they have performed 3 to 6 million.

To put these immense numbers into perspective, consider that concert musicians and professional athletes require approximately 4 hr of practice per day to train and fine-tune their perceptual-motor systems (Ericsson, Krampe, & Tesch-Romer, 1993). The consensus in the literature on expertise is that large amounts of regular practice, accumulated over years of training, promote expert performance (Ericsson & Ward, 2007). The same principle could apply to acquiring expertise in walking.

Natural walking was distributed in time and occurred in variable patterns and contexts. Short bursts of walking were separated by longer stationary periods. Walking bouts were frequently too short—one to three steps—to qualify as periodic gait. Moreover, infants started and stopped at will, traveled in winding paths over varying surfaces, took sideways and backward steps, varied their walking speed, switched from upright to other postures, and misstepped and fell. They visited multiple locations and engaged in different activities therein.

Laboratory studies with older children and adults indicate that time-distributed, variable practice is beneficial for motor learning (Gentile, 2000; Schmidt & Lee, 1999). Time-distributed practice is more effective than massed practice because intermittent rest periods allow learning to be consolidated, relieve fatigue, and renew motivation. Variable practice leads to greater flexibility and broader transfer than blocked practice because executing a variety of movements in a variety of contexts helps learners to identify the relevant parameters and their allowable settings. Recent efforts to teach robots to walk provide additional support for the effectiveness of variable practice. The traditional approach is to train robots to walk as fast as possible in a straight line—essentially, to train robots on periodic gait (Kohl & Stone, 2004). But training robots with omnidirectional gait on variable paths—a regimen similar to infants' natural locomotion—led to more adaptive, functional locomotor skill. After 15,000 runs through an obstacle course, robots had fewer falls, took more steps, traveled greater distances, and moved more quickly than they had prior to training. Moreover, in a test not possible with infants, they exhibited elite performance in robot soccer: With a variable training regimen, the UT Austin Villa team won all 24 games in the 2011 RoboCup 3D simulation competition, scoring 136 goals and conceding none (MacAlpine, Barrett, Urieli, Vu, & Stone, 2012; Urieli, MacAlpine, Kalyanakrishnan, Bentor, & Stone, 2011).

Conclusion

How do infants learn to walk? This corpus of natural locomotion indicates that infants accumulate massive amounts of time-distributed, variable practice. Over days of walking, they take more steps, travel farther distances, and fall less. And they may be motivated to walk in the first place because walking takes them farther faster than crawling without increasing the risk of falling. Traditional studies of infant locomotion during periodic gait could not have revealed these findings.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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