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Variations in Infants' Physical and Social Environments Shape Spontaneous Locomotion

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Independent locomotion is associated with a range of positive developmental outcomes, but unlike cognitive, linguistic, and social skills, acquiring motor skills requires infants to generate their own input for learning. We tested factors that shape infants' spontaneous locomotion by observing forty 12- to 22-month-olds (19 girls, 21 boys) during free play. Infants were recruited from the New York City area, and caregivers reported that 25 infants were White, six were Asian, four were Black, and five had multiple races; four were Hispanic or Latino. All infants played in four conditions: two environmental conditions (gross-motor toys, fine-motor toys) crossed with two social conditions (alone, together with a caregiver). Infants moved more in the gross-motor toy conditions than in the fine-motor toy conditions. However, the effect of playing with a caregiver differed by toy condition. In the gross-motor toy conditions, playing with a caregiver did not affect how much infants moved, but in the fine-motor toy conditions, playing with a caregiver further depressed infant locomotion. Infants with more walking experience moved more with gross-motor toys but not with fine-motor toys. Differences in the amount of locomotion between conditions were related to how infants used toys and the interactions between infants and caregivers.

Public Significance Statement
Toys like strollers, brooms, grocery carts, and balls, along with a "hands-off" caregiver play style, encourage toddlers to engage in locomotor play. In contrast, toys like pop-ups, xylophones, shape-sorters, and bricks, along with a "hands-on" caregiver play style, encourage more manual, stationary play.

Keywords: infant locomotion, exploration, walking, play, gross-motor play

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Infants learn through exploration. Through spontaneous motor action, they generate information about people, places, and things and about their own bodies and skills (Gibson, 1988; Piaget, 1952). The information that infants can generate depends on what they can do. Accordingly, new motor skills offer infants new opportunities to interact with the environment and new ways to learn (Adolph & Hoch, 2019; Bushnell & Boudreau, 1993).

The onset of independent locomotion (i.e., crawling or walking) is a particularly important milestone in the development of exploratory behavior. Once mobile, infants gain unprecedented access to the

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Justine Hoch served as lead for conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing–original draft, and writing–review and editing. Christina Hospodar served in a supporting role for conceptualization, data curation, investigation, methodology, project administration, validation, visualization, and writing–review and editing. Gabriela Koch da Costa Aguiar Alves served in a supporting role for data curation, funding acquisition, investigation, and writing–review and editing. Karen Adolph served as lead for funding acquisition, resources, and supervision and served in a supporting role for conceptualization, data curation, methodology, validation, visualization, and writing–review and editing.

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larger world and can decide for themselves where to go and what to see and do (Campos et al., 2000; Rheingold & Eckerman, 1969, 1970). As a result, new locomotor skills set in motion cascades of development that ripple through numerous psychological domains: Compared to their stationary peers, crawling infants have better spatial, social, and emotional skills (Bertenthal et al., 1984) and demonstrate more flexible memory retrieval (Herbert et al., 2007). Later, the transition from crawling to walking initiates increased interactions with objects and caregivers (Karasik et al., 2011; Walle, 2016) and rapid growth in infants' communicative abilities (Iverson, 2010; Walle & Campos, 2014; West & Iverson, 2021). Accumulated locomotor practice is associated with improvements in infants' locomotor skills and behavioral flexibility (Adolph & Hoch, 2019; Hospodar et al., 2021). And, increased physical activity in early childhood predicts advances in cognitive development and improved health outcomes (Carson et al., 2016, 2017; Timmons et al., 2012).

Given these clear benefits, caregivers and clinicians may wish to encourage locomotion. But unlike cognitive, linguistic, or social skills, where gaining the requisite experience largely relies on others, the development of motor skills, like walking, requires infants to generate their own input for learning. In other words, infants must move—on their own powers—to learn how to move. Of course, infants actively shape their input for learning in many domains: Infants' babbles shape the way that caregivers speak (Gros-Louis et al., 2006), and infants' facial expressions shape the duration and timing of social interactions (Cohn & Tronick, 1988). But without their caregivers, infants would have little to learn. In contrast, the input for learning motor skills is self-generated. Infants need only their own body and the motivation to move (Atun-Einy et al., 2013). Caregivers and features of the environment may encourage or discourage locomotion, but presumably infants can only learn to crawl or walk by taking steps themselves. So, what factors influence infants' spontaneous locomotion?

Potential Influences on Spontaneous Locomotion

Researchers have yet to precisely quantify how much infants move in a single day, but estimates suggest that infants generate immense amounts of time-distributed, highly varied, spontaneous locomotion. During 1 hr of free play with a caregiver, the average toddler spends 32% of the time in motion, takes 2,400 steps, and travels the distance of 7.7 U.S. football fields (Adolph et al., 2012). These high rates of locomotion are supported by meta-analyses of at-home accelerometry data, which show that toddlers accumulate approximately 4 hr of physical activity per day (Bruijns et al., 2020).

Though impressive, group averages obscure large individual differences in how much infants move. Examining the range of locomotor activity reported in previous studies reveals that some infants take dozens of steps per hour whereas others take several thousand (e.g., Adolph et al., 2012; Hoch et al., 2019). Individual differences in locomotor activity are partially explained by walking experience. New walkers walk less and fall more frequently than more experienced walkers (Adolph et al., 2012; Han & Adolph, 2021; Hospodar et al., 2021), but accumulated measures of locomotion vary widely even among infants who have been walking for similar durations of time. Despite the variation between infants, individual differences in locomotor activity appear to be consistent for infants tested and retested in the same setting with access to the same toys and caregivers: Measures of infants' locomotion at home are highly correlated from 1 hr to the next and between visits spaced a few days apart (Herzberg et al., 2020). Moreover, measures of physical activity are moderately stable across early childhood (Jones et al., 2013).

However, studies of variations in infants' physical and social environments indicate that access to certain toys and caregivers' behavior may influence how much infants move. For example, access to fine- and gross-motor toys and space to move at home predicts improvements in motor development (Hospodar et al., 2021; Saccani et al., 2013), suggesting that these factors may shape infants' real-time locomotor behavior. Likewise, studies show links between caregivers' and young children's physical activity. For example, parental reports of time spent being physically active with their child at 9 months predict children's accelerometer-measured physical activity at 19 months (Hnatiuk et al., 2013), and mothers' and toddlers' physical activity show distinct patterns of correlation that vary throughout the day (Hnatiuk et al., 2017). These correlational data imply that playing with certain toys or interacting with a caregiver may affect infants' spontaneous locomotion, but they do not reveal whether or how these factors influence locomotion in real time.

Lab studies with short-term manipulations also suggest that toys and caregivers can affect spontaneous locomotion. For example, in one study, infants who played alone (without their caregiver) with gross-motor toys like balls and strollers were in motion about 50% of the time (Hoch et al., 2019), whereas in a different study, infants who played with fine-motor toys like shape-sorters and xylophones together with their caregivers were in motion only 30% of the time (Adolph et al., 2012). However, because infants in prior work differed in age and locomotor experience, played with different types of toys, and played only with or only without their caregivers, conclusions based on comparisons across studies are limited. Thus, we do not yet know how variations in infants' physical and social environments shape their spontaneous locomotion.

Current Study

Accordingly, we experimentally tested the effects of toy type and caregiver availability on infants' spontaneous locomotion. Although there are likely many features of the physical and social environment that shape how much infants move, we chose to examine toy type and caregiver availability because these factors vary within children's home environments (Cacola et al., 2011; Herzberg et al., 2022), are predictive of later developmental outcomes (Miquelote et al., 2012; Saccani et al., 2013; Valadi & Gabbard, 2020), and can be potentially modified through intervention.

All infants played in four conditions: two toy conditions (gross-motor or fine-motor toys) crossed with two caregiver conditions (infants played alone or together with a caregiver). To test whether the effects of these manipulations differed by locomotor experience, we observed 12- to 22-month-old walking infants because, within this age range, some infants have been walking for a few days whereas others have been walking for several months. We used a repeated measures design to increase statistical power and account for large individual differences in how much infants move. In each condition, we measured infants' time in motion and interactions with toys and their caregiver.

Based on previous research, we hypothesized that variations in infants' physical and social environments shape their spontaneous locomotion. We predicted that infants would move more in the gross-motor toy conditions than in the fine-motor toy conditions because round toys like balls, toys with wheels like a stroller or grocery cart, and toys that are pushed like a broom encourage whole-body actions and are designed to move. In contrast, we predicted that play with fine-motor toys would discourage locomotion because toys with keys, buttons, and small parts like a xylophone, shape sorter, or pop-up toy are designed to elicit manual exploration which occurs less often while walking than while stationary (Heiman et al., 2019). We also predicted that infants would move more when they played alone than when they played together with a caregiver because prior work shows that infants and caregivers coordinate their locomotor activity during free play and that caregivers move less than their infants (Hoch et al., 2021; Thurman & Corbetta, 2017). Despite differences between conditions, we predicted that infants' time in motion would be correlated across conditions, reflecting individual differences in spontaneous locomotor activity. Based on prior work that tested infants with a comparable range of walking experience (Adolph et al., 2012), we predicted that infants with more walking experience would spend more time in motion, regardless of condition.

Although the hypothesis that features of the physical and social environment shape infants' spontaneous locomotion may seem intuitive, no prior study experimentally tested the relative influences of toys and caregivers on how much infants move or the potential interactions between these factors. Albeit unlikely given the available evidence, the alternative hypothesis is also possible—that is, rates of spontaneous locomotion could be stable regardless of the context. If the alternative hypothesis were true, we would expect infants' time in motion to be correlated across conditions but not to differ between conditions. Analyses of infants' interactions with specific toys and infant–caregiver interactions were exploratory.

Method

Transparency and Openness

Videos of each session are shared with authorized investigators (with caregivers' permission) in the Databrary digital library (https://databrary.org/volume/827). Exemplar video clips, the video coding manual, annotated Datavyu coding spreadsheets, scripts for processing the Datavyu spreadsheets, flat file processed data for analyses, and the code for the analyses are publicly available in the Databrary volume. This study was not preregistered. All study procedures were approved by New York University's Institutional Review Board (FY2019-3295). Caregivers of all participants gave their informed consent prior to inclusion in the study.

Participants

We recruited families from the New York City area. Forty 12- to 22-month-old ($M = 16.88$) walking infants (19 girls, 21 boys) participated with their caregivers (34 mothers, four fathers, one grandmother, and one nanny). Caregivers reported that 25 infants were White, six Asian, four Black, and five had multiple races; four were Hispanic or Latino. In a structured interview, caregivers reported infants' walk onset date—the first day caregivers saw infants walk 3 m independently (across a room) without stopping or falling. We verified reports of walk onset from cell phone videos and photos when possible, and an experimenter verified that all infants could walk at least 3 m continuously at the time of testing.

We excluded data from five additional infants because of equipment failure ($n = 1$), infant fussiness ($n = 1$), or caregiver interference in the "alone" conditions ($n = 3$). As souvenirs of participation, caregivers received a magnet with a photo of their infant participating in the study, a tote bag, and a $40 gift card.

Procedure and Playroom

Infants played freely in a large laboratory playroom (4 m × 8 m; Figure 1A). We observed each infant in four conditions: (a) with gross-motor toys, playing alone without their caregiver; (b) with fine-motor toys, playing alone without their caregiver; (c) with gross-motor toys, playing together with their caregiver; and (d) with fine-motor toys, playing together with their caregiver. Caregiver conditions were blocked so that infants either played in both "alone" conditions first or both "together" conditions first. Toy conditions were counterbalanced within caregiver blocks. Between caregiver blocks, we collected measures of standard gait to assess infants' walking skill. Infants were pseudo-randomly assigned to one of eight possible condition orders to balance age, sex, and walking experience.

In every condition, the experimenter sat behind a partition and did not interact with infants or caregivers. In the alone conditions, caregivers sat at the side of the room completing questionnaires (see Figure 1A) and we instructed caregivers to let their infants play on their own. If infants approached caregivers during the alone conditions, we instructed caregivers to encourage infants to "go play" as caregivers would if they were busy with a task at home. In the together conditions, we instructed caregivers to play with their infants as they normally would at home. During the alone conditions, we excluded times when caregivers left their seats or held their infants ($M = 19$ s of alone condition time, range = 0–4.01 min). We aimed to collect 32 min of free play data per infant (8 min per condition). Condition durations were equivalent in all four conditions: gross-motor toys alone ($M = 8.07$ min, $SD = 1.14$); fine-motor toys alone ($M = 8.28$ min, $SD = 1.07$); gross-motor toys together ($M = 8.36$ min, $SD = 0.25$); and fine-motor toys together ($M = 8.36$ min, $SD = 0.24$); $Fs(1, 39) \leq 1.80$, $ps \geq .19$, $\eta_p^2 \leq .04$.

Toys

For each toy condition, we positioned five toys at set locations around the room (Figure 1A). The gross-motor toys were designed by the manufacturer to elicit whole-body actions, including locomotion: a toy grocery cart filled with round plastic food (e.g., orange, tomato), a big clear ball, a toy broom, a baby-doll stroller, and a round bucket filled with small balls (Figure 1B). The fine-motor toys were designed to elicit manual actions: a toy xylophone with keys, a pop-up toy with buttons, toy bricks, a plush pig, and a shape sorter with three shapes (Figure 1C). Infants were not familiarized with the function of the toys prior to the session.

Video Recordings

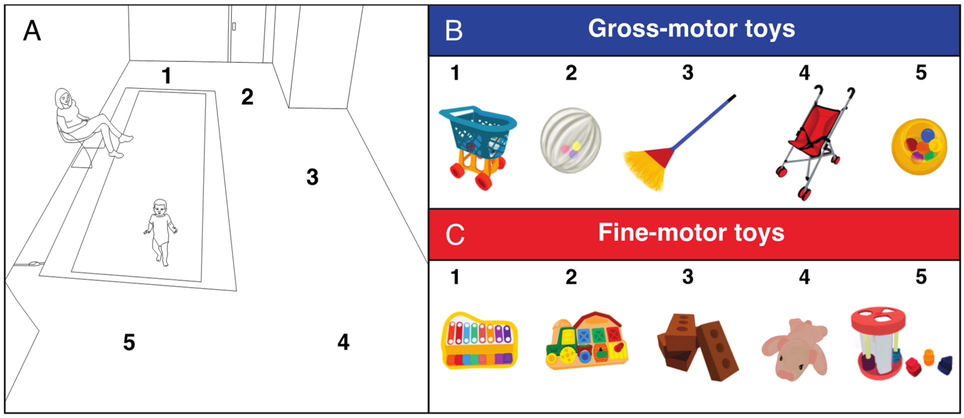
Four fixed camera views recorded infants' and caregivers' behavior from each wall; views were synced onto one video frame for later coding using vMix software (https://vimix.com). An additional fixed overhead view captured the entire playroom.

Validation of Walking Experience

Infants' walking experience (months between walk onset and test date) ranged from 0.33 to 10 months ($M = 3.8$); test age and

Figure 1

Study Design



Note. Panel A: Playroom and pressure-sensitive mat (large rectangle). Illustration shows the alone condition with the caregiver seated. In the together condition, the infant and caregiver played together. Panel B: Gross-motor toys: (1) grocery cart with food, (2) big ball, (3) broom, (4) stroller, and (5) bucket filled with small balls. Panel C: Fine-motor toys: (1) xylophone, (2) pop-up toy, (3) bricks, (4) pig, and (5) shape sorter and shapes. Toys were placed in the corresponding locations shown in Panel A. Toy illustrations by Ramya Manikkan are published with permission. See the online article for the color version of this figure.

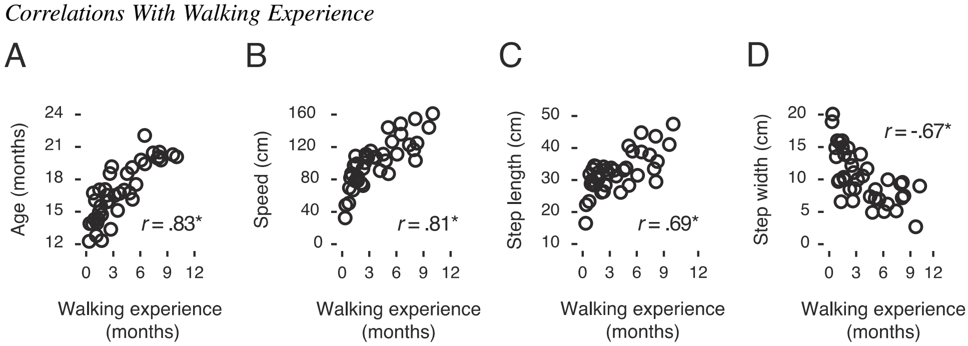
walking experience were highly correlated, $r(38) = .83$, $p \leq .001$ (Figure 2A). To ensure the reliability of caregiver reports of infants' walk onset date, we collected standard measures of infant gait: Infants with more walking experience display more mature gait patterns (for review, see Adolph & Hoch, 2019). Following the first two free-play conditions, an experimenter placed infants at one end of a pressure-sensitive mat (1.2 m × 4.9 m, 120 Hz, 4 sensors/in^2, protokinetics.com; large rectangle in Figure 1A) and caregivers encouraged infants to walk toward them using toys and snacks as incentives. We collected six walking trials per infant. The two fastest trials in each condition were analyzed for standard gait measures (Lee et al., 2018). For each pair of steps, we measured step length (front-to-back distance between consecutive steps) and step width (side-to-side distance between heels). The speed of each walking trial was calculated as the distance between the first and last step divided by the duration of the trial (cm/s). As expected, infants with more walking experience took faster, $r(38) = .81$, $p < .001$; longer, $r(38) = .69$, $p < .001$; and narrower, $r(38) = -.67$, $p < .001$, walking steps, corroborating caregivers' reports of infants' walk onsets (Figure 2B–2D).

Data Coding

A primary coder annotated the videos using Datavyu—video-coding software that provides fingertip control over video playback with frame-accurate precision and time locks user-defined events to their location in the video (https://datavyu.org). A second coder independently annotated 25% of each condition in each session. For categorical variables (infant and caregiver locomotor posture, caregiver toy touches), coders agreed on ≥91% of bouts, all

Figure 2

Correlations With Walking Experience



Note. Correlations between (Panel A) walking experience and infant age and (Panel B to Panel D) walking experience and walking skill. Infants with more walking experience had (Panel B) faster walking speeds, (Panel C) longer step lengths, and (Panel D) narrower step widths.

* $p \leq .001$.

Cohen's κ coefficients $\geq .88$, $ps < .001$. For continuous measures (infant and caregiver locomotor bouts, locomotor bout durations, and total time moving; toy bouts, toy bout durations, total time with toys), correlations between coders' scores were high, $rs \geq .92$, all $ps < .001$. To avoid coder drift, coders reviewed disagreements after every few sessions were annotated. Although rare, typos and careless errors were corrected to avoid propagating known errors into the final data set. For true disagreements (e.g., one coder thought the caregiver was touching a toy and the other did not), the primary coder's data were retained in the final data set.

Infant and Caregiver Locomotion

Coders distinguished bouts of locomotion—taking one or more steps—from stationary periods for both infants and mothers. A bout of locomotion began on the first video frame the foot, knee, or buttocks lifted off the ground or changed location; locomotion ended on the first video frame when both feet, knees, or buttocks were on the ground for at least 0.5 s (Lee et al., 2018). Infants mostly walked ($M = 93\%$ of bouts, $SD = 10\%$) and occasionally crawled ($M = 7\%$ of bouts, $SD = 10\%$). Caregivers also mostly walked ($M = 55\%$ of bouts, $SD = 32\%$) and occasionally crawled ($M = 14\%$ of bouts, $SD = 14\%$) but also produced other forms of locomotion, including bum-shuffling (moving across the floor on hands and buttocks; $M = 16\%$ of bouts, $SD = 24\%$), knee-walking (moving on knees with hands off the ground; $M = 14\%$ of bouts, $SD = 16\%$), and belly-crawling (sliding with the abdomen in contact with the ground; $M = 1\%$ of bouts, $SD = 8\%$). For analyses, we collapsed across all forms of locomotor posture. To account for small differences in recording times between conditions, we calculated time in motion as a percentage (% time in motion = sum of bout durations/condition duration).

Interactions With Toys

Bouts of toy interaction began on the first frame infants manually contacted a toy and ended when the infant stopped touching the toy for at least 1 s. If an infant deliberately kicked a toy or used one toy to deliberately contact another (e.g., pushed the big ball with the grocery cart), the bout of toy interaction was identified according to contact with the foot or toy instead of the hands. For toys with multiple parts (shape sorter/shapes, bucket/small balls, grocery cart/food), contact with each set of parts was annotated separately. To capture how much infants played with toys, we calculated % time with toys (time with toys/condition duration). We used the overlap between infants' time in motion and time with toys to calculate % of time moving with toys (time moving with toys/time moving). To capture how infants used toys, regardless of how much they played with each toy, we also calculated the % time with toys spent moving (time moving with toys/time with toys).

In the two "together" conditions, coders annotated whether caregivers and infants simultaneously touched toys based on two criteria: (a) if caregivers and infants touched the same toy for at least one video frame, or (b) if caregivers were within arms' reach of the infant and both simultaneously touched parts of a toy with multiple parts for at least one video frame (e.g., caregiver held bucket while infant inserted small balls, caregiver and infant stacked bricks next to each other but did not touch the same brick). To compare caregiver interactions across conditions and toys that had different numbers of toy bouts, we calculated % toy bouts with caregiver touch (# caregiver touch bouts/# toy bouts).

Analyses

All analyses were conducted using IBM SPSS Version 25. Infants' age and walking experience were highly correlated (Figure 2A) and did not hold a unique statistical value. As such, we chose to include walking experience as a predictor variable because it was more conceptually relevant to our primary research questions. For condition comparisons that included walking experience as a predictor, we used multilevel modeling (MLM) to account for the repeated measures nested within infants. MLMs 1–4 included toy condition, caregiver condition, walking experience (centered at the group average), and their interactions as fixed effects, and a random intercept for subjects. MLM 5 included toy condition and person (infant, caregiver) and their interaction as fixed effects and a random intercept for dyads. Sample sizes varied for individual toy comparisons because analyses were limited to the number of infants who played with that toy in both the alone and together conditions and thus precluded comparisons across individual toys. Preliminary analyses showed no effects of infant sex or condition order, so these variables were not included in subsequent analyses.

Results

Differences in Spontaneous Locomotion

Toy and Caregiver Conditions

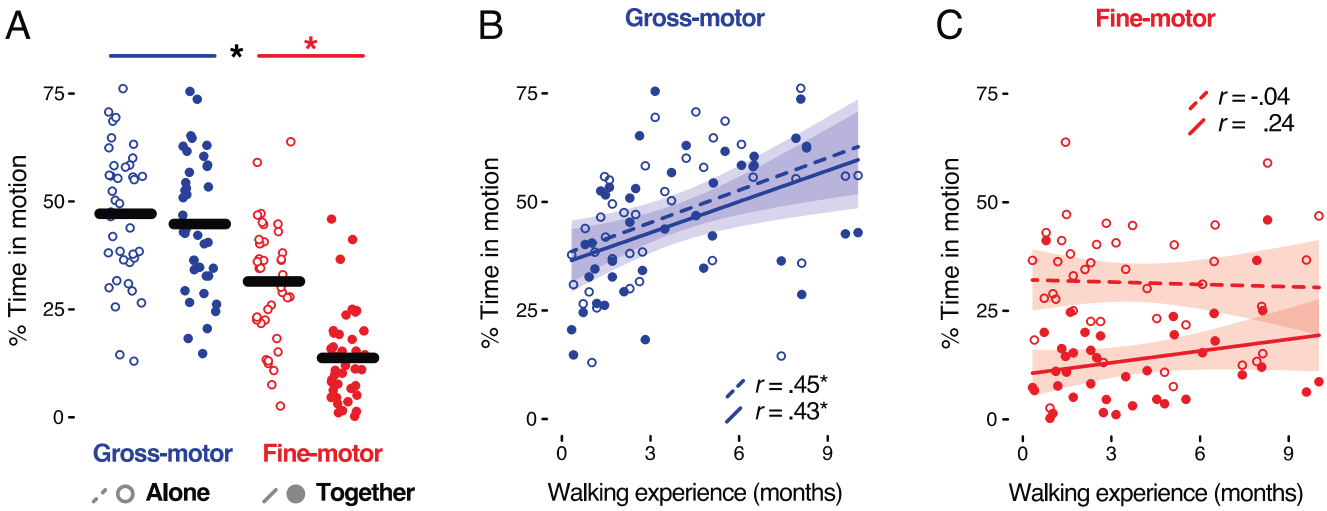
As predicted, features of both the physical and social environment affected infants' spontaneous locomotion. Infants spent more time in motion in the gross-motor toy conditions than in the fine-motor toy conditions (Figure 3A). However, the effect of playing with a caregiver differed by toy condition, $F(1, 120) = 19.19$, $p < .001$ (see Table 1 in the online supplemental materials for parameter estimates). In the gross-motor toy conditions, infants spent the same percentage of time in motion regardless of whether they played alone ($M = 47\%$, $SD = 15\%$), or together with their caregiver ($M = 45\%$, $SD = 15\%$; $b = -0.02$, $SE = 0.02$, $p = .32$). But in the fine-motor toy conditions, infants spent twice as much time in motion when they played alone ($M = 31\%$, $SD = 14\%$) compared to when they played together with a caregiver ($M = 14\%$, $SD = 11\%$; $b = -0.18$, $SE = 0.02$, $p < .001$). Walking experience was correlated with time in motion in the gross-motor toy conditions, $rs(38) \geq .43$, $ps \leq .01$ (Figure 3B), but not in the fine-motor toy conditions, $rs(38) \leq .24$, $ps \geq .14$ (Figure 3C). The MLM confirmed an interaction between walking experience and toy condition, $F(1, 120) = 10.44$, $p = .002$. Each additional month of walking beyond the average was associated with a 2% increase in the percentage of time in motion in the gross-motor toy conditions ($b = 0.02$, $SE = 0.01$, $p = .002$) but not the fine-motor toy conditions ($b = -0.002$, $SE = 0.01$, $p = .80$).

Stability of Individual Differences

Individual differences in infants' time in motion were stable when infants played with gross-motor toys and when infants played alone. Time in motion was correlated between gross-motor toy conditions, $r(38) = .54$, $p < .001$, but not between fine-motor toy conditions, $r(38) = .20$, $p = .22$. Moreover, time in motion was correlated

Figure 3

Differences in Infant Spontaneous Locomotion



Note. Panel A: Infants spent more time in motion with gross-motor toys compared to fine-motor toys, and playing with caregivers further depressed infants' time in motion with fine-motor toys. Panel B: Walking experience predicted time in motion in the gross-motor toy conditions. Panel C: Walking experience was not related to time in motion in the fine-motor toy conditions. See the online article for the color version of this figure.
* $p \leq .01$.

between alone conditions, $r(38) = .34$, $p = .03$, but not between together conditions, $r(38) = .15$, $p = .37$.

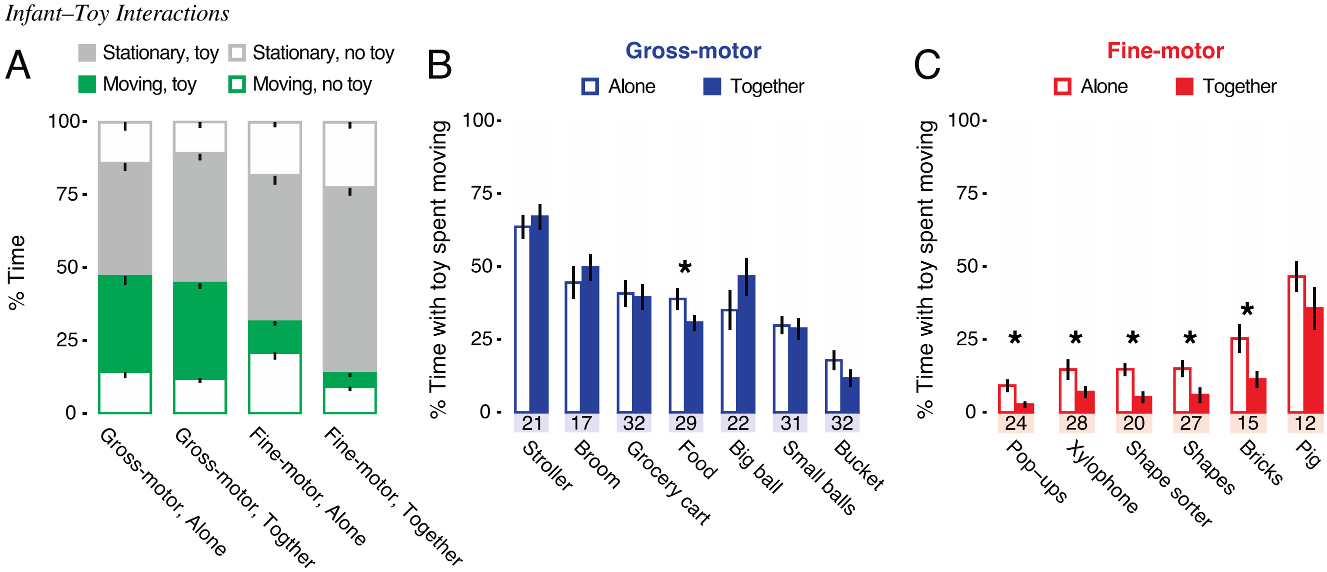
Factors That Influence Spontaneous Locomotion

Infant–Toy Interactions

Infants spent more time playing with gross-motor toys than with fine-motor toys (see filled portions of bars in Figure 4A), and playing together with a caregiver increased the amount of time spent playing with both types of toys, $Fs(1, 120) \geq 5.70$, $ps \leq .02$ (see Table 2 in the online supplemental materials for parameter estimates). In the gross-motor toy condition, playing with a caregiver increased time spent with toys from $M = 72\%$ ($SD = 25\%$) to $M = 77\%$ ($SD = 13\%$), and in the fine-motor toy condition, playing with a caregiver increased time spent with toys from $M = 61\%$ ($SD = 22\%$) to $M = 68\%$ ($SD = 17\%$). Walking experience was

Figure 4

Infant–Toy Interactions



Note. Panel A: Stacked bars show the percentage of time spent moving and stationary with and without toys. Panel B and Panel C: Percentage of time with each toy spent moving. Toys are arranged in descending order in the gross-motor toy condition and ascending order in the fine-motor toy condition. *N*s below bars denote the number of infants who played with the toy in both caregiver conditions. Error bars denote ±1 *SE*. See the online article for the color version of this figure.
* $p \leq .05$.

not correlated with time with toys in any condition, *r*s(38) ≤ .23, *p*s ≥ .15.

In the gross-motor toy conditions, infants mostly moved with a toy, whereas in the fine-motor toy conditions, infants mostly moved without a toy (see Figure 4A). Of the total time spent moving in the gross-motor toy conditions, infants spent *M* = 68% (*SD* = 28%) of the time with a toy when playing alone and *M* = 73% (*SD* = 17%) of the time with a toy when playing with a caregiver. Of the total time spent moving in the fine-motor toy conditions, infants spent *M* = 35% (*SD* = 23%) of the time with a toy when playing alone and *M* = 35% (*SD* = 27%) of the time with a toy when playing with a caregiver. The MLM confirmed that infants spent a greater percentage of their time in motion with toys in the gross-motor toy conditions compared to fine-motor toy conditions, *F*(1, 120) = 97.78, *p* ≤ .001 (see Table 3 in the online supplemental materials for parameter estimates). Playing with a caregiver did not affect the percentage of time in motion with either type of toy, *F*(1, 120) = 0.35, *p* = .56. Walking experience was not correlated with time in motion with toys in any condition, *r*s(38) ≤ .19, *p*s ≥ .25.

We also investigated how infants used toys. Infants used gross-motor toys for locomotor play more often than they used fine-motor toys for locomotor play (see Figure 4A). However, the effect of playing with a caregiver differed by condition, *F*(1, 120) = 7.69, *p* = .006 (see Table 4 in the online supplemental materials for parameter estimates). Playing with a caregiver did not affect how infants used gross-motor toys: Of the time that infants played with gross-motor toys, they moved just as much when they played alone (*M* = 43% of toy time, *SD* = 19%) and played together with a caregiver (*M* = 42% of toy time, *SD* = 16%; *b* = −0.002, *SE* = 0.03, *p* = .95). But, playing with a caregiver changed how infants used fine-motor toys: Of the time that infants played with fine-motor toys, infants moved more when they played alone (*M* = 18% of toy time, *SD* = 12%) compared to when they played together with a caregiver (*M* = 7% of toy time, *SD* = 7%; *b* = −0.11, *SE* = 0.02, *p* ≤ .001). Walking experience was correlated with the percentage of time with gross-motor toys spent moving, *r*s(38) ≥ .35, *p*s ≤ .03, but not the percentage of time with fine-motor toys spent moving, *r*s(38) ≤ .25 *p*s ≥ .13. The MLM confirmed an interaction between toy condition and walking experience, *F*(1, 120) = 9.23, *p* = .002. Walking experience was associated with an increase in the percentage of time with gross-motor toys spent moving (*b* = 0.03, *SE* = 0.01, *p* = .002) but not the percentage of time with fine-motor toys spent moving (*b* = 0.0003, *SE* = 0.01, *p* = .95).

The way that infants played with individual toys followed the general pattern of results and largely validated our initial categorization of "gross-" and "fine-motor" toys. Although analyses are limited because not all infants played with all toys, visual inspection suggests that, apart from the bucket and the pig, infants moved more while playing with each gross-motor toy than while playing with each fine-motor toy (Figure 4B and 4C). In the gross-motor toy conditions, caregivers only reduced how much infants moved when playing with food, *t*(28) = 2.14, *p* = .04 (Figure 4B). In contrast, in the fine-motor toy conditions, caregivers reduced how much infants moved with every toy (*t*s ≥ 2.07, *p*s ≤ .05), except the pig, *t*(11) = 1.38, *p* = .19 (Figure 4C).

Infant–Caregiver Interactions

As expected, caregivers moved less than infants, and like infants, caregivers spent more time in motion in the gross-motor toy condition (*M* = 13%, *SD* = 8%) than in the fine-motor toy condition (*M* = 5%, *SD* = 6%). An MLM confirmed effects of person (infant, caregiver) and toy condition (gross-motor, fine-motor) qualified by a person by toy condition interaction, *F*s(1, 80) ≥ 78.56, *p*s ≤ .001 (see Table 5 in the online supplemental materials for parameter estimates). The interaction showed that the difference between gross-motor and fine-motor conditions was larger for infants (*b* = −0.31, *SE* = 0.03, *p* ≤ .001) than for caregivers (*b* = −0.07, *SE* = 0.02, *p* ≤ .001). Moreover, infant and caregiver time in motion were not correlated in the gross-motor condition, *r*(38) = .28, *p* = .08, but were correlated in the fine-motor toy condition, *r*(38) = .70, *p* ≤ .001, suggesting that infants and caregivers engaged in more coordinated locomotion when playing with fine-motor toys.

In addition to differences in locomotor coordination, dyads played differently with each set of toys. A paired *t* test revealed that infants and caregivers simultaneously touched toys less often in the gross-motor toy condition (*M* = 38% of toy bouts, *SD* = 22) compared to the fine-motor toy condition, 62% of toy bouts, *SD* = 21; *t*(39) = 5.73, *p* ≤ .001 (see Figure 5A). Infant walking experience was not correlated with simultaneous toy touching in the gross-motor toy condition, *r*(38) = −.23, *p* = .15. But in the fine-motor toy condition, simultaneous toy touching decreased with walking experience, *r*(38) = −.34, *p* = .03. Moreover, in both toy conditions, the more caregivers and infants simultaneously touched toys, the less infants moved, *r*s(38) ≥ −.32, *p*s ≤ .05 (Figure 5B and 5C).

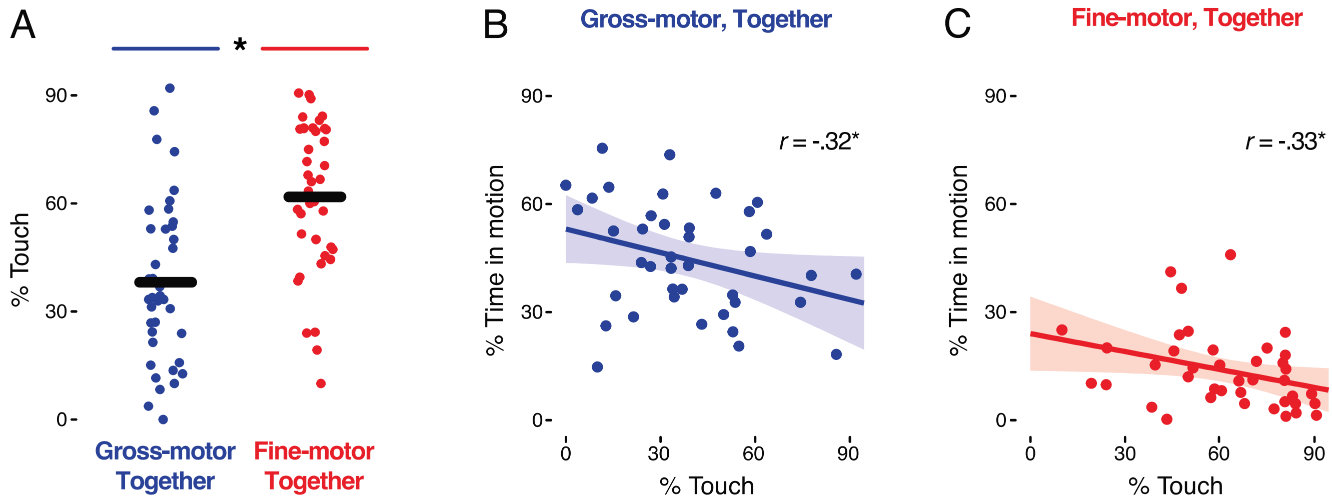
Discussion

Here, we provide foundational, empirical evidence for the hypothesis that variations in infants' physical and social environments influence their spontaneous locomotion. By systematically manipulating the properties of toys and whether caregivers were available for play, we found that gross-motor toys encourage locomotion whereas fine-motor toys discourage locomotion. Moreover, we show that features of the physical and social environment interact: Playing with a caregiver did not affect how much infants moved in the gross-motor toy conditions, but playing with a caregiver further depressed infant locomotion in the fine-motor toy conditions. Below, we discuss how infants' interactions with toys and caregivers shaped their spontaneous locomotion and propose implications for learning and development.

Individual Differences and the Role of Walking Experience

Our findings provide an important experimental replication and extension of prior correlational work (e.g., Herzberg et al., 2020; Jones et al., 2013) by showing that individual differences in spontaneous locomotion are stable across contexts when infants play independently. Despite dramatic differences in spontaneous locomotion between toy conditions, infants who were more active when playing with gross-motor toys alone were also more active when playing with fine-motor toys alone. Likewise, infants who were more active when playing with gross-motor toys alone were also more active when playing with gross-motor toys together with their caregiver. We suspect that infants' time in motion was correlated between "alone" and "together" gross-motor toy conditions because, even in the "together" condition, infants mostly played with gross-motor toys on their own. This sent of findings suggests that when infants played independently, their

Figure 5
Infant–Caregiver Interactions



Note. Panel A: Infants and caregivers simultaneously touched toys less often in the gross-motor toy condition than in the fine-motor toy condition. Panel B and Panel C: In both toy conditions, simultaneous toy touching was negatively correlated with time in motion. See the online article for the color version of this figure. * $p \leq .05$.

spontaneous locomotion reflected consistent individual differences in their tendency to move. In contrast, when infants and caregivers played together with fine-motor toys, infants' time in motion was not correlated with how much they moved in any other condition. Because caregivers were especially engaged with infants' play in the fine-motor toy condition, we suggest that interacting with a caregiver masks consistent individual differences in spontaneous locomotion.

We also replicated prior work showing that walking experience predicts time in motion (Adolph et al., 2012; Hospodar et al., 2021). But importantly, our data further suggest that this relation is context specific. Although we predicted that walking experience would be positively associated with time in motion in all conditions, more experienced walkers only moved more in the gross-motor toy conditions. Our data show that the least experienced walkers were not sensitive to the affordances of gross- and fine-motor toys—they spent the same amount of time in motion in both toy conditions when playing alone (compare the least experienced infants in Figure 3B and 3C). However, differences between toy conditions quickly emerged as infants gained walking experience and were better able to exploit the affordances of gross-motor toys (compare the more experienced infants in Figure 3B and 3C). Thus, toys that are designed to be pushed or rolled are especially effective for encouraging movement after infants have mastered the basics of upright locomotion.

Interactions With Toys

Analyses of infants' interactions with toys revealed that they moved more in the gross-motor toy conditions than in the fine-motor toy conditions because they used gross-motor toys for locomotor play and fine-motor toys for stationary play. Although this finding may seem obvious with data in hand, differences in locomotion could have resulted from moving without a toy. For example, the sight of gross-motor toys could have been particularly arousing and thereby encouraged locomotion, or infants could have locomoted between (but not with) gross-motor toys. However, this was not the case: In the gross-motor toy conditions, when infants moved, they primarily moved with a toy in hand, suggesting that interacting with gross-motor toys encouraged locomotion. In contrast, in the fine-motor toy conditions, infants primarily moved without a toy in hand. Thus, interacting with fine-motor toys did not encourage locomotion. Anecdotally, in the fine-motor toy conditions, when infants walked, they typically moved from toy to toy or to their seated caregiver.

Moreover, although the data supported our prediction that infants would move more in the gross-motor toy conditions than in the fine-motor toy conditions, before conducting this study, we did not know how infants would use the toys. Our initial categorization of "gross-motor" and "fine-motor" toys was based on surveys designed to collect information about affordances for motor development in the home (Cacola et al., 2011) and toys used in previous studies that investigated spontaneous locomotion (e.g., Adolph et al., 2012; Hoch et al., 2019). But, prior work shows that infants often ignore the designed actions of objects by carrying fine-motor toys like blocks around the playroom (Heiman et al., 2019) and play with household objects just as often as they play with toys (Herzberg et al., 2022). Indeed, although infants' actions generally aligned with our categorization of "gross-motor" and "fine-motor" toys, infants did not use toys for only one type of play. Indeed, with a gross-motor toy in hand, infants spent less than half of the time in motion, suggesting that these toys also frequently elicited stationary play (e.g., examining food in the grocery cart). Likewise, although the fine-motor toys were mostly used while stationary, infants occasionally played with these toys while in motion (e.g., carrying shape sorter blocks around the room).

Nonetheless, infants were more likely to move while playing with round toys like balls, toys with wheels like the stroller and grocery cart, and toys that are designed to be pushed like the broom, and infants were less likely to move while playing with toys with keys, buttons, and small parts like the xylophone, shape sorter, and pop-up toy that require more precise manual actions. In fact, infants moved more while playing with any individual gross-motor toy than while playing with any individual fine-motor toy, with only two exceptions: Infants moved with the bucket as much as they moved with most fine-motor toys, and infants moved with the pig as much as they moved with most gross-motor toys. The round bucket, which was presented with small balls inside, rolled when placed on the ground, so we assumed this toy would encourage infants to move. However, infants often stood or sat while taking balls in and out of the bucket. Although the opening to the bucket was relatively large, this action may have been difficult to execute while moving (Heiman et al., 2019). In contrast, we assumed the plush pig would encourage manual actions (e.g., petting, hugging, manipulation). However, these actions may have required infants to engage in symbolic play, which typically develops between 18 and 24 months of age (Ungerer et al., 1981). Thus, many of the infants in our study may have been too young to consistently produce these actions. Instead, infants mostly played with the pig by carrying it around the playroom. Accordingly, these exceptions are consistent with the notion that rounded or easily transported toys encourage locomotion, whereas toys that require precise manual action discourage locomotion.

Interactions With Caregivers

We predicted that playing with a caregiver would depress infant locomotion in both toy conditions, but playing with a caregiver only affected how much infants moved in the fine-motor toy condition. This difference likely stemmed from how infants and caregivers played with each set of toys: In the gross-motor toy condition, caregivers and infants rarely simultaneously touched toys, and infant and caregiver time in motion were not correlated, suggesting that dyads moved independently. Thus, the presence of a caregiver likely had little effect on infants' behavior because infants mostly played with gross-motor toys on their own. Although we can only speculate about why caregivers were rarely involved in infant's gross-motor toy play, it is possible that gross-motor toys may not be easily used for dyadic play (i.e., pushing a toy stroller is a one-person job) or that gross-motor toys may be less appealing to caregivers who typically move less than infants (Hoch et al., 2021; Thurman & Corbetta, 2017).

In contrast, in the fine-motor toy condition, caregivers provided frequent hands-on support while infants interacted with toys, and infant and caregiver time in motion were highly correlated, suggesting that dyads moved and played together. Increased caregiver engagement was associated with lower rates of spontaneous locomotion in both toy conditions, likely because it is difficult for infants and caregivers to interact with the same toy while infants are moving. In addition, prior work shows that when caregivers engage with infants during play by touching and talking about objects, infants produce longer, more complex interactions (i.e., functional or symbolic actions) than when infants play on their own (Schatz et al., 2022). Thus, high-caregiver engagement in the fine-motor toy condition may have encouraged manual action and thereby further depressed spontaneous locomotion.

The current data cannot speak to caregivers' goals; however, we suspect that caregiver involvement differed between the two toy conditions because caregivers perceived unique opportunities for learning with each set of toys. Although caregivers could have used fine-motor toys as an opportunity to promote gross-motor development (e.g., by using fine-motor toys as a lure to encourage locomotion, as is common in lab-based settings), they did not. Instead, when infants and caregivers played together with fine-motor toys, infants moved less than in any other condition. This was true even for novice walkers, who might have benefited from the practice, suggesting that caregivers may view fine-motor toys as an opportunity to enrich other skills like infants' language, social, and cognitive development. Indeed, prior work shows that as infants manipulate objects, caregivers name the objects in hand, which, in turn, facilitates noun learning (Custode & Tamis-LeMonda, 2020; Pereira et al., 2014; Tamis-LeMonda et al., 2013; West & Iverson, 2017; Yu & Smith, 2012). Moreover, caregivers seem especially interested in talking about young children's manual actions: Although caregivers produce both whole-body and manual verbs in response to infants' real-time behavior, caregivers use a wider variety of manual verbs compared to whole-body verbs, and caregivers increase their production of manual, but not whole-body, verbs from 13 to 18 months (West et al., 2022).

Implications for Learning and Development

For infants with typical development, both stationary and locomotor play with objects offer opportunities for learning and skill acquisition (Babik et al., 2022; Miquelote et al., 2012). However, our data suggest that toys that easily move (balls that roll, strollers with wheels, etc.) are especially useful for eliciting spontaneous locomotion and may thereby advance infants' locomotor skills and foster subsequent cascades of developmental achievements. Moreover, such toys introduce variability into infants' locomotor practice regimen as they chase after balls, follow the veering path of a toy stroller, and adjust their trajectory after pushing a cart into an obstacle (Hoch et al., 2019). More variable locomotor practice, in turn, may be linked to the development of functional walking skill (Ossmy et al., 2018). Accordingly, our findings can be used to inform interventions that manipulate the physical and social environment to encourage spontaneous locomotion in infants with developmental delays or impairments. For example, our data suggest that children may benefit from the use of gross-motor (rather than fine-motor) toys to encourage locomotion in clinical settings and that providing families with gross-motor toys may increase spontaneous locomotion at home. However, because the effects of playing with gross-motor toys were greatest for infants who had already mastered the basics of walking, caregivers and clinicians may need to scaffold infants' use of gross-motor toys and offer toys that suit infants' abilities.

Limitations and Future Directions

In the current study, we manipulated toy type and caregiver availability to investigate the effects of variations in the physical and social environment on infants' locomotor practice. However, we cannot know the extent to which infants' spontaneous exploration of objects and the larger layout were because of the novelty of the laboratory environment and toys. Because we did not collect measures of caregivers' goals or perceptions of the learning opportunities afforded by different toys, we can only speculate about why caregivers' behaviors differed when playing with gross- and fine-motor toys. Moreover, during everyday activity, infants encounter numerous changes in the environment and interact with a variety of social partners (see de Barbaro & Fausey, 2022; Evans, 2006), any of which have the potential to encourage or discourage locomotion. Future studies might consider additional features of the physical and social environment such as the effects of layout (for review of potentially relevant layout properties, see van Liempd et al., 2018), surface properties (e.g., slippery, high traction, deformable, rigid), space to move (e.g., Hospodar et al., 2021), caregivers' gender, and the presence of siblings or peers. Finally, because age and walking experience were highly correlated in our sample, further research might test same-aged infants with a range of walk onset ages to distinguish the effects of age and walking experience.

Conclusion

Despite individual differences in infants' spontaneous locomotion, we show that toys and caregivers shape how much infants move. These findings suggest that the natural variations observed in infants' homes likely influence their real-time locomotor behavior and, in turn, the input they generate for learning locomotor skills. Moreover, because spontaneous locomotion is associated with advances in a range of cognitive, linguistic, and social skills, our findings suggest promising potential avenues for creating interventions that support healthy development.

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