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Longitudinal relations between independent walking, body position, and object experiences in home life

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Abstract

How do age and the acquisition of independent walking relate to changes in infants' everyday experiences? We used a novel ecological momentary assessment (EMA) method to gather caregiver reports of infants' restraint, body position, and object holding via text messages sparsely sampled across multiple days of home life at 10, 11, 12, and 13 months of age. Using data from over 4000 EMA samples from $N = 62$ infants recruited from across the United States and sampled longitudinally, we measured changes in the base rates of different activities in daily life. With age, infants spent more time unrestrained. With the onset of walking, infants spent less time sitting and prone and more time upright. Although rates of object holding did not change with age or walking ability, we found that infants who can walk do so more often in an upright position compared with non-walkers. We discuss how accurately measuring changes in lived experiences serves to constrain theories about developmental mechanisms.

Public Significance Statements:

- Our longitudinal study used a multi-day experience sampling survey to characterize everyday experiences with restraint, body position, and objects from 10 to 13 months of age.
- Results indicated the importance of achieving the ability to walk, because walking predicted differences in infants' daily experiences related to cognitive and language development.
- Findings highlighted the importance of measuring the typical range of infants' lived experiences, which varied widely between individuals within a diverse sample of infants across the United States.

Keywords: body position, motor development, everyday experiences, walking, objects

Word count: 8894

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Acquiring new motor skills, such as independent walking, alters how infants interact with objects, places, and people. Some effects unfold in the moment: While walking compared to crawling, infants take more steps and travel farther (Adolph & Tamis-LeMonda, 2014; Adolph et al., 2012; Hoch et al., 2019; Thurman & Corbetta, 2017), can more easily look at caregivers' faces and distant objects (Franchak et al., 2018; Kretch et al., 2014; Luo & Franchak, 2020), stray farther from caregivers (Chen et al., 2022), and engage in new forms of object sharing and communication (Karasik et al., 2011, 2014; West & Iverson, 2021). Consequently, differences in the onset age for new motor skills are implicated in cascading effects on other areas of development (Iverson, 2022; Oudgenoeg-Paz et al., 2016; Smith, 2013; Walle & Campos, 2014). However, there must be measurable differences in the time spent in different motor activities during everyday, lived experiences of walkers compared to non-walkers for the walking milestone to drive these downstream effects. Lived experiences bridge the gap between in-the-moment activity and longer-term development; experiences in the moment accumulate over days, weeks, and months. Here, we argue that shifting from a "milestone lens" (can an infant walk?) to an "experience lens" (how often does an infant walk?) will better reveal how cumulating experiences matter within the "developmental lens" (does walking promote cognitive development?).

Few available measurements bear on whether the acquisition of independent walking predicts differences in infants' everyday motor experiences. As we will review, behavioral video coding is the standard method for scoring motor experiences. However, no video corpora of infants' motor experiences match the full-day observations from wearable audio recorders that measure speech and music input (Casillas & Cristia, 2019; Mendoza & Fausey, 2021; Weisleder & Fernald, 2013). Whereas audio recorders can be worn by infants for a whole day, video observations typically capture 45-120 minutes of behavior (Chen et al., 2022; Herzberg et al., 2021; Karasik et al., 2011), scheduled at a time convenient to the family and the researcher who records the video. Full-day measurements in other developmental domains show that behaviors are distributed in a "bursty" rather than a uniform way (de Barbaro & Fausey, 2022; Warlaumont et al., 2021). For example, the times that infants hear music are clustered in some parts of the day whereas other parts lack music input (Mendoza & Fausey, 2022). Thus, even two continuous hours of video recording may be insufficient to capture the variety of motor experiences that occur across a day.

Intensive longitudinal survey methods, such as ecological momentary assessment (EMA), provide an alternative way of documenting daily experiences. By sending caregivers multiple text message surveys at random intervals throughout the day over several days, Franchak (2019) measured how the frequency of different body positions (i.e., supine, prone, sitting, and upright) differed between 3-, 6-, 9-, and 12-month-old infants. Instead of scoring behaviors from video, caregivers categorized infant behavior as it happened. Unlike video, EMA does not require a researcher to visit the home, easing the risk of participant reactivity (Bergelson et al., 2019; Tamis-LeMonda et al., 2017) and allowing measurements to span from morning to evening, in the house and on the go. Delivering EMA via participants' smartphones also allows broader geographical sampling. In the present study, we employed EMA sampling to test how three different motor experiences (restraint, body position, and object holding) changed in frequency with respect to the emergence of independent walking in a longitudinal study from 10 to 13 months.

Restraint

Being restrained versus unrestrained shapes how infants can explore. Throughout the day, caregivers choose whether to place infants in furniture or specialized seating devices (e.g., high chairs, carseats, strollers), whether to hold infants (e.g., in parents' arms, worn in carriers), or whether to keep infants unrestrained. While restrained in place, infants can only interact with nearby people and objects; while unrestrained, infants can crawl or walk to distant locations and seek out objects of interest. Motor development may be hindered by spending long amounts of time restrained (Abbott & Bartlett, 2001; Fay et al., 2006; Karasik et al., 2023). However, restraint may also facilitate exploratory opportunities that infants could not otherwise achieve. The higher vantage point of being worn in a baby carrier makes it easier for infants to look at faces (Kretch & Adolph, 2015), whereas infants unrestrained on the ground rarely gaze at faces (Franchak et al., 2018). Manual exploration of objects requires postural stability (Bertenthal & von Hofsten, 1998; Soska & Adolph, 2014), which may be aided when sitting in a seating device.

Caregivers might make different decisions about how often to hold infants and/or place infants in seating devices after infants learn to walk independently. However, data about infants' experiences with restraint are sparse. In part, this gap in knowledge about restraint might be a byproduct of researchers' focus on movement during play to the exclusion of other activities (e.g., mealtimes, car trips) that might involve restraint. Infants are rarely held by caregivers in laboratory play sessions (Franchak et al., 2018; Thurman & Corbetta, 2017). Researchers set up the session to observe infants' movement, so seating devices such as high chairs and bouncers are not usually provided. Outside of the lab, surveys of US parents suggest that most families own specialized infant seating devices and use them on a daily basis (Abbott & Bartlett, 2001). In a typical day, non-play activities such as feeding, nursing, comforting, and errands out of the house may increase the likelihood of infants being held or placed in a device. Using retrospective caregiver surveys, Hesketh et al. (2015) found that 20-month-olds who had learned to walk at an earlier age were reported to have significantly greater unrestrained time. However, caregivers might not accurately give numerical estimates of restraint time—which can change from one moment to the next—across an entire day.

Structured interviews and EMA are likely to provide more accurate estimates of restrained versus unrestrained time. Karasik et al. (2022) used structured interviews to estimate the time US and Tajik 12-month-olds spent restrained in a typical day, prompting parents to recount the previous day's activities and placing them in a timeline. They found that infants in both cultures were frequently restrained, but the type of restraint varied according to the kinds of devices that were available in each culture. US infants spent about 34% of their waking day restrained in a device, 14% held by a caregiver, and 42% unrestrained. Similarly, past work using EMA sampling (Franchak, 2019) found that 12-month-olds were held 18% of the time and spent 48% of the time on the ground (and most likely unrestrained). However, because these studies employed cross-sectional designs and did not compare walkers and non-walkers, they could not tease apart how age and walking ability predict restraint experiences.

Body position

Body position—whether supine, prone, sitting, or upright—shapes how infants see the world (Franchak et al., 2018; Kretch et al., 2014; Luo & Franchak, 2020) and influences object exploration (Soska & Adolph, 2014). But despite many such studies that compare in-the-moment differences in exploration between body positions, less work has focused on the question of how much time infants spend in different body positions in daily life. In particular, how does the onset of a new motor skill, such as walking, predict differences in body position? Similar to restraint, most past studies of body position experiences have employed retrospective surveys (Majnemer & Barr, 2005) or coded position from short, video-recorded play sessions (Franchak et al., 2018; Thurman & Corbetta, 2017), with the exception of one previous study that used EMA (Franchak, 2019). Comparing between a short play session and full-day EMA shows the difficulty of generalizing body position experiences from play. Whereas novice walkers spent between 50% and 70% of the time upright in laboratory play sessions (Franchak et al., 2018; Thurman & Corbetta, 2017), estimates from EMA suggest that they spend only 30% of the time upright in a typical day (Franchak, 2019). Most likely, infants spend less time upright during non-play activities, such as errands and meal times.

The cross-sectional data from Franchak (2019) indicate that time spent in body positions changes markedly over the first year of life. When not held by caregivers (which was 50% of the waking day), 3-month-old infants are frequently supine on their backs (18% of the waking day). In contrast, the most frequent position among 12-month-olds is sitting (33% of the waking day), and time spent supine is rare (5%). In addition to differences between age groups, time spent upright differed according to walking ability. Whereas 12-month-old non-walkers were upright 16% of the time, 12-month-old independent walkers were upright 31% of the time. The current study will extend this work by using a longitudinal design to determine how both age and walking ability predict body position experiences across the transition to walking. Although the onset of walking might be associated with immediate changes in daily experiences, acquiring a new skill does not necessitate that the skill is consistently expressed. Indeed, daily surveys about motor skills (not amount of time, but whether infants engaged in the activity at all within a day) revealed that, for most infants, new skills were not expressed each day (Adolph et al., 2008). For example, few infants go from being unable to stand to standing every day. For most infants, they stand on some days but not others after acquiring the ability to stand. Caregiving choices, which may vary between infants and within infants from day-to-day, play a role in the opportunities infants have to express new skills. An infant who can walk can only walk if placed on the ground. Caregivers might provide more opportunities for infants who have begun to walk; however, an alternative or complementary possibility is that that older infants (controlling for walking ability) are given more freedom of movement.

Object holding

Infants' daily experiences with objects facilitate learning about object properties and labels. Data from naturalistic tasks show that infants are more likely to learn labels that correspond to objects that are frequently seen (Clerkin et al., 2017) or acted on (Suarez-Rivera et al., 2022). Moreover, video observations of object interactions in the home suggest that object interactions are vast, amounting to 50-60% of infants' time (Herzberg et al., 2021; Karasik et al., 2011; Swirbul et al., 2022). There are several ways in which developing motor skills, such as sitting and walking, may alter infants' object experiences. Upright and sitting provide better views of distant objects compared with prone (Luo & Franchak, 2020), and sitting facilitates visual-manual object exploration compared with prone and supine positions (Soska & Adolph, 2014). Compared with crawling infants, walking infants more frequently carry objects (Karasik et al., 2012) and are more likely to bring distant objects to share with caregivers (Karasik et al., 2011). Caregivers also provide linguistic and object-directed information differently in the moment based on whether infants are sitting, standing, crawling, or walking (Karasik et al., 2014; Kretch et al., 2022).

How might the onset of walking relate to changes in the frequency of object experiences? On one hand, the advantage of object carrying when comparing crawling to walking infants suggests that walking boosts the rate of object carrying (Karasik et al., 2011). But, walking is only one of many contexts in which infants interact with objects, so walking might have a minimal benefit at the scale of a day. Sitting might be more conducive to object holding compared with standing upright. If so, the increase in upright time associated with learning to walk (Franchak, 2019) may mean that walking infants spend less time sitting, and thus, less time holding objects. Past work that coded object interactions from video observations in the home has mixed findings about the role of walking in object interaction (Herzberg et al., 2021; Karasik et al., 2011). Whereas Karasik et al. (2011) observed similar rates of object holding at 13 months between non-walkers and walkers, Herzberg et al. (2021) found significantly more object holding among 13-month-old non-walkers (63% of the time) compared with 13-month-old walkers (53% of the time). However, the authors of the latter study expressed caution about this difference: Whereas both groups of infants were equivalent in accruing many short (< 60 s) bouts of object holding, the 13-month-old non-walkers had more long bouts, suggesting the group trend arose through the influence of extremely long bouts. The mixed findings in prior work, as well as the limitation of generalizing from single, video-recorded sessions—lead us to use EMA to study object experiences across the full day. Moreover, by measuring the co-occurrence of body position with object holding events across multiple days, the present study has a unique opportunity to examine the motor context of object experiences. Developmental changes in how infants accumulate experiences with objects in different body positions—holding while prone, holding while sitting, holding while upright—may be relevant for perceptual, cognitive, and language outcomes related to object exploration (Iverson, 2022; Smith, 2013; Soska & Adolph, 2014)

Current Study

The acquisition of independent walking facilitates changes to infants' exploratory abilities in the moment, and both retrospective surveys and video observation studies suggest that daily time spent in motor experiences—restraint, body position, and object holding—may differ between non-walkers and walkers. In the current study, we use ecological momentary assessment (EMA) to acquire multi-day estimates of restraint, body position, and object holding experiences in longitudinal sessions at 10, 11, 12, and 13 months. EMA holds several advantages over retrospective surveys and video observation that should result in more accurate and generalizable estimates of daily experiences. Retrospective reports ask too much of caregivers' memory; how could a caregiver accurately estimate how much time infants spend holding objects when there are hundreds of short holding bouts in a single day?

Instead, EMA takes advantage of instantaneous caregiver observations at the moment survey requests are received. We identified behaviors that could be quickly and reliably observed by caregivers to sample 10 times/day for 4 days at each age: *restraint* referred to whether infants were restrained in a device/furniture, restrained by the caregiver (e.g., held), or unrestrained; *body position* referred to whether infants were supine, prone, sitting, or upright; *object holding* referred to whether infants had an object in their hands or not. Although these behaviors can be accurately coded from video observations to produce real-time data, generalizing from a single video-recorded session to measure daily experiences is not straightforward. Whereas home visit sessions must be scheduled for relatively short durations at convenient times of the day in the home, EMA can sample across the entire day's activities. It is important to note that unlike video recorded sessions that directly measure the duration of events, our EMA methods infers the time spent in different activities across the day based on event frequencies. By repeatedly and randomly sampling events throughout the day, we can estimate what percent of events belong to a certain category out of the total number of observations. The percentage of events in a given category (e.g., sitting) will be larger/smaller depending on the duration of that activity in a day (e.g., sitting time). Throughout the paper, we use the term "time" to refer to the estimated time spent in an activity inferred from the percent of observations that an infant was observed in that activity.

We focus on the developmental period from 10 to 13 months to examine how activities change across the transition to walking while controlling for age. At 10 months, most infants cannot walk independently; by 13 months more than half of infants have acquired independent walking (WHO Multicentre Growth Reference Study Group, 2006). We investigated three main questions. First, do infants' everyday experiences with different kinds of restraint, different body positions, and object holding change with respect to infant age and walking ability? Previous findings are mixed, and are difficult to directly compare due to the variety of methods used (retrospective reports, diaries, video observation, and EMA). Moreover, most estimates of the effects of walking on motor experiences in the home derive from age-matched controls at a single time point (Adolph et al., 2012; Franchak, 2019; Herzberg et al., 2021; cf Karasik et al., 2011). By testing across four monthly sessions, we can better disentangle the contributions walking ability while controlling for age as infants acquire the ability to walk. Conversely, controlling for infants' walking ability may reveal that some changes in daily experiences are linked with age, suggesting other unspecified mechanisms of change (e.g., cognitive development, changes in caregiving practices). Finally, EMA sampling across multiple days creates a unique opportunity to examine sources of variability in daily experiences. By testing random effects of participant and testing day (nested within participant), we can determine whether experiences vary more within an infant across days or between different infants.

Unlike a retrospective survey, EMA provides data that describe the co-occurrence of different activities for each response. Each sample indicates how restraint, body position, and object holding were related in the moment that the caregiver looked at their infant's behavior. Thus, our second research question was: Does the rate of object holding differ between different types of restraint or between different types of body positions? Past work indicates that sitting compared with prone/supine is advantageous for object exploration (Soska & Adolph, 2014). We predict that infants would be observed holding objects for a larger share of their sitting time compared with their prone and supine time. To our knowledge, whether object holding differs between unrestrained and restrained time has not been studied. Infants may hold objects more frequently when unrestrained if they are free to locomote and gather objects, whereas when held or restrained in a device, infants must rely on caregivers to provide objects. Alternatively, postural support from a restraint device or a caregiver could make it easier to hold and manipulate objects since infants may be in a sitting position while restrained.

Our third research question was: Does the motor context of object holding change with age and walking onset? If, as hypothesized, walkers spend less time sitting and sitting is the body position that facilitates object holding, we would predict that walkers spend less time holding objects compared with non-walkers (as in Herzberg et al., 2021). Yet, other work suggests that infants immediately incorporate object holding into walking after they first learn to walk, despite the cost to balance (Heiman et al., 2019). Thus, a second possibility is that walkers may hold objects for similar amounts of time to non-walkers, but do so more while upright compared to while sitting. If so, the motor context of object holding may change following walking onset.

Methods

This reproducible manuscript and its analyses and visualizations can be recreated by downloading the data and code from OSF (https://doi.org/10.17605/OSF.IO/YPD95). The current study's design and analysis plan was not pre-registered.

Participants and Design

Seventy-five families were recruited via paid social media advertisements shown across the United States. To be included in the final sample, families were required to have completed at least 2 of the 4 monthly sessions; a completed session was defined as answering at least 15 of the 40 survey notifications. N = 62 families met these criteria and were included in the final sample, contributing M = 3.6 sessions and responding to M = 28.4 samples/session. Of the final sample, families were recruited from 29 different US states. All caregiver respondents identified as female. Table 1 shows the demographic information for families included in the final sample.

The longitudinal study consisted of four monthly EMA sessions that occurred when infants were 10, 11, 12, and 13 months of age. At each session, caregivers received EMA prompts on 4 days (3 weekdays and 1 weekend day) that were required to be ± 1 week of the focal age (10, 11, 12, or 13 months). Caregivers selected days during which they would be with their infant for most of the day, and they indicated a time each morning that they could begin to receive survey prompts based on their infants' wake times. Table 2 shows infants' minimum, mean, and maximum age in months at each of the four sessions and the number of participants contributing data to each monthly session.

Because of the range of variables tested within the current study and lack of prior data for some questions, we could not calculate power for every test of interest. We chose a sample size based on the effect sizes of past studies linking motor ability to motor experiences, which range from medium to large: such as $r = .41$ for the association between walking onset and object carrying (Karasik et al., 2012) and $r = .68$ for the association between walking onset and distance traveled (Adolph et al., 2012). A power analysis indicated that a sample size of $n = 60$ at each age would be sufficient to detect correlations as small as $r = .35$, so we aimed to have at least 60 data points at each monthly session.

Data were collected between March 2020 and May 2022, which coincides with the start of COVID-19 pandemic shut-downs and closures in US states where participants resided. Preliminary testing indicated that behaviors of interest (body position, restraint, object holding) did not vary by test date. Thus, we did not consider date of testing in subsequent analyses.

The procedure was approved by the BLINDED Institutional Review Board. Families received $40 gift certificates as compensation for study participation.

Procedure

Introductory Phone Call. Caregivers completed an introductory phone call during which the experimenter explained the study procedures, referring to an instruction manual (available on the OSF page: https://doi.org/10.17605/OSF.IO/YPD95) and informed consent agreement that were emailed in advance. After consenting, caregivers selected four days to receive survey notifications and provided the start time for each day. During the remainder of the call, the experimenter explained each of the survey questions that caregivers would receive and clarified how different behaviors should be categorized. A comprehension check was conducted by showing 11 photographs of infants' everyday activities and asking caregivers to categorize the behavior displayed in the photograph according to the survey questions.

Scheduling Survey Prompts. Survey sessions were administered using *formr* software (Arslan & Tata, 2021; Arslan et al., 2019). For each of the four survey days at each monthly session, participants received 10 prompts—one per hour—starting at the earliest time that caregivers provided for each day. To prevent survey prompts from being predictable, a random time was selected between the 15th and 45th minute of every hour (this prevented prompts in consecutive hours from being scheduled too close together in time). Survey prompts were sent via SMS through a web service (TextMagic) to the caregiver's mobile phone; a hyperlink opened the *formr* survey page for that participant in the mobile phone browser. Caregivers had 15 minutes to open a prompt before the link expired.

Survey Items. Caregivers answered the same survey questions each time they responded to a prompt. The instruction manual (https://doi.org/10.17605/OSF.IO/YPD95) contain the full text of all six questions that were asked, including extended descriptions and example images used to train and test respondents. Table 3 lists the survey items and possible responses that were analyzed in the current study.

Sampling Waking Moments. Question 1 determined whether the caregiver was available to observe their child's awake behavior. Subsequent questions were only asked if the caregiver responded "child awake"; any response of "child sleeping" or "not with child" ended the survey. Of prompts that caregivers responded to, 68.68% of responses were "child awake", 25.86% of responses were "child sleeping", and 5.47% of responses were "not with child".

Restraint and Body Position. Question 2 established whether the infant was "restrained by device/furniture", "restrained by caregiver", "locomoting", or "neither". As Table 3 shows, branching logic used the response from Question 2 to choose a follow-up question about the type of device/furniture (Question 3a), type of caregiver restraint (Question 3b), or whether infants were "supine", "prone", "sitting", or "upright" during unrestrained times (Question 3c). Questions 2 and 3a-c included exemplar images in the phone survey for caregivers to refer to while responding. Questions 3a-c included write-in options for behaviors that respondents did not think could be categorized. However, such write-in responses were rare, and most could be manually recoded according to the categories listed. Any responses that could not be clearly recoded were eliminated and treated as missing data. Only 4.29% were write-ins for Question 3a, 1.74% were write-ins for Question 3b, and 0.19% were write-ins for Question 3c. The combination of responses to Questions 2 and 3a-c were used to determine the *restraint* and *body position* variables described in the data analysis section.

Object Holding. Question 6 asked about infants' object experiences (Questions 4 and 5 were not analyzed in the current study). Caregivers were asked to observe whether the infant was currently holding an object. The category of object included only carryable items, so caregivers were instructed to exclude things like furniture, large toys, clothing, their own bodies, and other people's bodies that could not be picked up off the ground. Responses to Question 6 determined the *object holding* variable described in the data analysis section.

Follow-Up Phone Calls. Phone calls were made two weeks after each session to schedule the next survey session and to ask about infants' motor milestones. Motor milestone onset dates for independent sitting, crawling, cruising, and walking were obtained using a structured interview (Adolph et al., 2003). Caregivers responded whether infants have performed each milestone skill; for example, whether the infant has walked for 10 feet unaided without stopping or falling. If the infant has displayed a skill, caregivers reported the onset date for that skill. Because the four survey days at each session could be distributed across a two-week period, we categorized infants as walkers if >25% of their samples for a given session occurred on or after the walking onset date. Table 2 indicates the number of infants at each session who were considered non-walkers versus walkers. At 10 months, 57 were non-walkers compared with only 3 infants could walk independently. By 13 months, there were 32 non-walkers compared with 28 walkers.

Data Processing

We used R (Version 4.3.1; R Core Team, 2021) and the R-packages *broom.mixed* (Version 0.2.9.4; Bolker & Robinson, 2021), *lme4* (Version 1.1.34; Bates et al., 2015), *papaja* (Version 0.1.2.9000; Aust & Barth, 2022), *scales* (Version 1.2.1; Wickham & Seidel, 2020), and *tidyverse* (Version 2.0.0; Wickham et al., 2019) for all our analyses and visualizations. Generalized linear mixed-effect models GLMMs with binomial link functions were used to estimate the changing likelihood of behaviors observed over time. These models function as logistic regressions that estimate a binary outcome (e.g., 1 = infant was sitting, 0 = infant was not sitting) according to other predictors (i.e., age, walking status). GLMMs were calculated using the *lme4* package; all fixed effect predictors were mean-centered. Random intercepts and slopes were calculated for testing day nested within participant to account for day-to-day and participant-to-participant variability. For visualizations and descriptive statistics, percentages of samples were calculated by summing the number of 1 responses for a behavior and dividing by the total number of awake responses for a given participant at a given age. Below, we describe how each binary outcome was derived from survey responses.

Calculating Dependent Measures. For all analyses, responses to Question 1 of “child asleep” or “not with child” were removed, so that presence/absence of a behavior was counted out of each child's total awake time. This allows the percentage of samples to represent experience rates as a percent of the waking day.

Three mutually-exclusive *restraint* categories were calculated as binary outcomes based on the responses to survey question 2. "Restrained by device/furniture" was scored as a 1 when infants were in a device or furniture and 0 for all other times. "Restrained by caregiver" was scored as a 1 when infants were held by caregivers and 0 for all other times. "Unrestrained" was scored as a 1 for any response of "locomoting" or "neither", and all other times were scored as 0.

Four mutually-exclusive *body positions* (supine, prone, sitting, upright) were calculated as binary outcomes based on the responses to survey questions 3a and 3c. Supine was scored as a 1 if the response to question 3c was "supine"; all other times were counted as 0. Prone was scored as a 1 if the response to question 3c was "prone"; all other times were counted as 0. Sitting was scored as a 1 if infants were restrained in a seating device (3a responses of "carseat", "stroller", "highchair/booster/other belted seat") or they were sitting unrestrained (3c response of "sitting"); all other times were counted as 0. Upright was scored as a 1 if infants were restrained in an upright device (3a response of "bouncer/jumper/exersaucer") or were upright while unrestrained (3c response of "upright"); all other times were counted as 0. Note, any response to question 2 of "restrained by caregiver" was counted as a 0 for body position because infant's body position is difficult to reliably categorize when they are held in caregiver's arms or in slings/carriers.

Finally, *object holding* was scored as a 1 if caregivers responded "yes" to question 6a ("Is your child holding an object") and scored a 0 otherwise.

Responsivity Statistics. To determine if responses reflected truly in-the-moment observations of behavior (rather than caregivers responding to prompts only when convenient), we calculated the *response time* by subtracting the time the response text message was sent from the time the survey was completed by the participant. Figure 1 shows a histogram of all response times in minutes across participants at every age. The two peaks roughly correspond to surveys that ended after the Question 1 ("child sleeping" and "not with child" responses required answering only Question 1) compared with surveys that required caregivers to answer all 6 questions ("child awake"). The maximum possible response time was 15 minutes, after which the survey would automatically close. The right skew of the histogram indicates that most responses were made quickly, with a *median* of 0.50 min. Thus, caregivers' prompt responses to survey requests suggest that observations captured in-the-moment infant behavior.

Results

Here, we analyze 4534 total observations of infants' in-the-moment behaviors at home, spanning four months of everyday restraint, body position, and object experiences. We organize the results around three main questions. First, do infants' everyday experiences with different kinds of restraint, different body positions, and object holding change with respect to infant age and walking ability? Second, does the rate of object holding differ between different types of restraint or between different types of body positions (e.g., do infants hold objects more while sitting compared to while supine)? Finally, does the context of object holding change with age and walking ability?

Experiential Changes by Age and Walking Ability

We tested whether the frequency of restraint, body position, and object holding were associated with infants' age and/or walking ability. Table 4 shows the results of a generalized linear mixed-effect model testing each dependent measure by fixed effects of age in months and walking status (0 = non-walker, 1 = walker) with random effects by participant and testing day nested within participant. Each binary outcome indicated the presence or absence of a behavior among awake responses for each participant. Age and walking status were centered in all models. In an initial testing step, we calculated models with fixed effects of age, walking status, and the age*walking status interaction. The interaction term was non-significant in all models, so here we report parsimonious models omitting age*walking status interactions.

Restraint. Restraint provides different opportunities for exploration: Seating devices provide postural support, restraint by caregivers provides social contact, and unrestrained time allows infants to crawl or walk to explore distant locations and objects. Here, we show that everyday experiences in different restraint types vary according to age and walking status. Table 5 and Figure 2 show the percent of time (out of awake samples) in each type of restraint, and results of separate GLMM models for each of the three restraint categories are shown in Table 4. Overall, infants spent 26.90% of their awake time restrained in furniture or a device, which did not significantly vary according to age or walking status. In contrast, time spent restrained by caregiver significantly decreased with age, but was not related to infants' walking ability. Across walkers and non-walkers, infants were restrained by caregivers 19.66% of the time at 10 months compared to 13.91% at 13 months. Unrestrained time increased both according to age and walking ability (Figure 2). Across walking status, infants were unrestrained 51.29% of the time at 10 months, which increased to 60.58% at 13 months. Across ages, non-walkers were unrestrained 52.54% of their awake time compared with 63.99% for walkers. The model results in Table 4 confirm the effects of age and walking for unrestrained time.

The multi-day testing scheme provides a unique opportunity to compare variability between individuals compared to variability across testing days. In all three models, random effect coefficients by subject were greater compared with random effects of testing day nested within subject, showing that inter-individual differences in restraint exceeded intra-individual differences in day-to-day restraint.

Body Position. Prone, sitting, and upright body positions were each related to age and walking ability in a different way (Figure 3). Neither age nor walking ability predicted time spent supine, which was rare among infants across the age range studied

(3.55% of the waking day) and will not be discussed further. The key findings were: 1) Time spent prone decreased both as a function of age and walking onset, 2) Walkers spent less time sitting compared with non-walkers, but no effect of age was detected, 3) Time spent upright increased both with age and with walking ability. Descriptive statistics for all body positions by age and walking ability are reported in Table 6 and full model results are reported in Table 4.

Time spent prone was relatively rare (8.74% of the waking day) and decreased with age and after the onset of walking. Across walkers and non-walkers, infants spent 11.08% of the time prone at 10 months compared with 6.96% at 13 months. Across age, non-walkers spent 9.72% prone compared with only 4.76% of the time for walkers. Sitting was the most frequently observed body position (44.51% of the waking day), but significantly decreased following the onset of walking. Across age, non-walkers spent 46.63% of the time sitting compared to only 39.19% for walkers. No significant effect of age was detected. Time spent upright significantly increased with age and with walking ability. Across walking ability, infants spent 16.67% of the time upright at 10 months, which increased to 29.56% at 13 months. Across age, non-walkers were upright 19.05% of the waking day compared to 38.41%.

In all three models (prone, sitting, upright), beta coefficients for walking ability were considerably stronger compared with beta coefficients for age, suggesting that learning to walk has stronger explanatory value for understanding body position experiences compared with chronological age. Moreover, random effect coefficients by subject were stronger compared with random effects of testing day nested within subject across the three models. This indicates that inter-individual differences in body position experiences surpassed intra-individual differences in day-to-day body position.

Object Holding. Infants held objects frequently, M = 40.10% (SD = 16.70) of their waking day, across age and walking ability. However, as the model results show in

Table 4, neither age nor walking ability was significantly related to object holding time.

Summary of Infant Daily Experiences. Age and walking ability had differential effects across the three kinds of motor experiences we measured (restraint, body position, and object holding). To help illustrate the scope of these results, we provide estimates of experiences in hours per day by multiplying the percentage of awake samples by 11.1 hours, the estimated waking day of infants in this age range (Galland et al., 2012). The secondary y-axes on Figures 2 and 3 illustrates estimated hours/day. Some experiences were unrelated to both age and walking experience: Infants spend an average of 2.99 hours restrained in furniture, 0.39 hours supine, and 4.45 hours holding objects. Some experiences differed according to either age or walking ability (but not both). From 10 to 13 months, the total amount of restraint by caregivers in a typical day decreased by 0.64 hours. In contrast, non-walkers spent more time sitting (5.18 hours) compared with walkers (4.35 hours) regardless of age.

Effects of both age and walking ability were observed for infants' time spent unrestrained, prone, and upright. Over the four month testing period, daily unrestrained time increased by 1.03 hours, daily prone time decreased by 0.46 hours, and daily upright time increased by 1.43 hours. However, differences according to walking ability were larger compared with age differences. Walking was associated with a 1.27 hour increase in daily unrestrained time, a 0.55 hour decrease in daily prone time, and a 2.15 hour increase in daily upright time.

Even the more modest changes accumulate to sizeable differences in experience. When extrapolated to a month, non-walkers spend 16 more hours prone—incurring limitations for visually exploring faces and objects—compared with walkers of the same age. The largest differences are staggering when considered in aggregate. Walkers spent 2.15 more hours per day upright and 1.27 more hours per day unrestrained compared with non-walkers, suggesting that each month spent as walker means accruing 65 more hours per month on one's feet and 38 more hours per month with freedom of movement. Considering that the typical range of walking onset is between 9 and 18 months (WHO Multicentre Growth Reference Study Group, 2006), these estimates suggest that the timing of walking onset predicts tremendous differences in opportunities for exploration.

Object Holding Varies by Restraint and by Body Position

The previous section indicated that infants held objects frequently—4.45 hours/day—but that the overall amount of object holding time did not significantly vary according to age or walking status. However, previous laboratory observation suggests that object exploration varies in the moment depending on body position; in particular, sitting facilitates visual-manual exploration of objects compared with supine and prone (Soska & Adolph, 2014). Here, we test whether in-the-moment object holding relates to restraint and body position in everyday home life by calculating object holding rates conditioned on each restraint/position category. For example, we can estimate the rate of object holding while sitting by calculating the number of samples where the infant was simultaneously sitting and holding an object divided by the total number of sitting samples at each age. Repeating this calculation for each restraint and body position category produced Figure 4, which indicates restraint and body position categories are associated with different rates of object holding. The moderating effects of restraint and body position on object holding were not influenced by age or by walking ability (tested in preliminary models), so results in this section will describe effects across age and walking ability.

Restraint Type Moderated Object Holding. Object holding may be facilitated by the postural support afforded by infant furniture or a caregiver, or restraint may hinder object holding if it prevents infants from independently acquiring objects. However, differences in object holding have not been tested according to restraint type. We found that infants held objects most frequently while unrestrained (M = 46.90%, SD = 22.20), slightly less often while restrained in furniture (M = 44.40%, SD = 29.40), and far less often while restrained by a caregiver (M = 22%, SD = 29.70). A GLMM was calculated to predict holding (holding an object = 1, not holding an object = 0) from the three restraint categories (reference category = Device/Furniture) with random intercepts according to test day nested within participant. Statistically-significant parameters for unrestrained ($\hat{\beta} = 0.16$, 95% CI $[0.01, 0.30]$) and restrained by caregiver ($\hat{\beta} = -1.15$, 95% CI $[-1.36, -0.94]$) indicate that they differed from the reference category of restraint by device/furniture. Follow-up pairwise comparisons were all statistically significant: restraint by caregiver versus restraint by device/furniture ($z = 10.77$, $p_{\text{Holm(3)}} < .001$), restraint by caregiver versus unrestrained ($z = -13.45$, $p_{\text{Holm(3)}} < .001$), and restraint by device/furniture versus unrestrained ($z = -2.09$, $p_{\text{Holm(3)}} = .037$).

Body Position Moderated Object Holding. Consistent with previous work showing a sitting advantage for object exploration (Soska & Adolph, 2014), we found that infants held objects most frequently while sitting (M = 51.60%, SD = 23.70) compared with the other three body positions. Object holding was less frequent when supine (M = 35.80%, SD = 43), prone (M = 31.40%, SD = 36.60), and upright (M = 39%, SD = 31.70). A GLMM was calculated to predict holding (holding an object = 1, not holding an object = 0) from the four body position categories (reference category = sitting) with random intercepts according to test day nested within participant. Statistically-significant parameters for supine ($\hat{\beta} = -0.67$, 95% CI $[-1.00, -0.34]$), prone ($\hat{\beta} = -0.74$, 95% CI $[-0.98, -0.50]$) and upright ($\hat{\beta} = -0.54$, 95% CI $[-0.70, -0.38]$) indicate that they differed from the reference category of sitting. Follow-up pairwise comparisons confirmed that holding while sitting was significantly greater compared with each of the other body positions: supine ($z = 3.93$, $p_{\text{Holm(6)}} < .001$), prone ($z = 6.02$, $p_{\text{Holm(6)}} < .001$), and upright ($z = 6.50$, $p_{\text{Holm(6)}} < .001$). However, no significant differences were found between holding rates among supine, prone, and upright positions (ps $> .398$).

Changing Context of Object Holding With Age and Walking Ability

Here, we reconcile the two previous sets of findings. For restraint, we found that time spent restrained by caregivers decreases with age and that object holding is least likely to occur while held by a caregiver; yet, object holding did not change with respect to age. For body position, we found that non-walkers spend more time sitting and that object holding occurs more frequently in a sitting position; however, no difference was found in overall object holding time when comparing non-walkers to walkers. An alternative possibility is that the context of object holding adapts to changes in the time spent in different kinds of restraint and body positions, such that infants incorporate object holding into the activities they spend the most time doing (i.e., Heiman et al., 2019).

Object Holding Adapts to Changes in Restraint. To test this, we took every sample of object holding (n = 1827) and calculated the percentage of holding samples that were observed in each type of restraint (in device, by caregiver, and unrestrained). The only significant finding to emerge was that a smaller share of non-walkers' object holding was spent unrestrained (M = 59.90%), whereas a larger share of walkers' object holding occurred while unrestrained (M = 70.93%). This was confirmed by a GLMM testing the likelihood of being unrestrained while holding an object based on age and walking with random intercepts according to participant and testing day nested within participant (random slope models failed to converge), which revealed a significant positive effect of walking ($\hat{\beta} = 0.31$, 95% CI $[0.01, 0.62]$) but no significant effect of age ($\hat{\beta} = 0.07$, 95% CI $[-0.02, 0.17]$). Similar models were tested to determine if the share of object holding varied by age/walking for restraint by device/furniture and by caregiver, but no significant effects were found. Thus, more of walkers' object holding time occurs in an unrestrained context, presumably because walkers spend more overall time unrestrained.

Object Holding Adapts to Changes in Body Position. Next, we took every sample of object holding and calculated the percentage of holding samples that were observed in each of the four body positions at each age. Figure 5 shows the share of infants' overall holding time that took place when supine, prone, sitting, and upright and how it differed between non-walkers and walkers. Across ages and walking ability, supine accounted for a small share of holding experiences (M = 3.51%), and a GLMM testing the likelihood of being supine while holding an object decreased with age ($\hat{\beta} = -0.29$, 95% CI $[-0.54, -0.04]$) but not walking ability ($\hat{\beta} = 0.28$, 95% CI $[-0.61, 1.18]$). Prone also accounted for a small share of holding experiences overall (M = 7.83%). The likelihood of being prone while holding objects significantly decreased for walkers ($\hat{\beta} = -1.81$, 95% CI $[-2.79, -0.83]$) but did not vary according to age ($\hat{\beta} = -0.01$, 95% CI $[-0.18, 0.17]$).

The largest changes in the context of object holding were observed when comparing sitting and upright holding time among walkers and non-walkers. The share of holding that occurred while sitting was significantly more for non-walkers (M = 69.27%) compared with walkers (M = 47.45%), as indicated by a significant coefficient for walking ($\hat{\beta} = -0.77$, 95% CI $[-1.10, -0.44]$). The share of object holding while sitting was not significantly related to age ($\hat{\beta} = -0.03$, 95% CI $[-0.13, 0.08]$). In contrast, holding-while-upright accounted for less of non-walkers' time (M = 17.12%), whereas walkers spent a greater share of their object holding time in an upright position (M = 48.21%). Holding-while-upright significantly increased as a function of walking ability ($\hat{\beta} = 1.16$, 95% CI $[0.82, 1.51]$), and did not significantly change with age ($\hat{\beta} = 0.09$, 95% CI $[-0.03, 0.21]$).

Discussion

Caregiver reports of infants' restraint, body position, and object holding revealed changes in infants' everyday experiences related to both age and walking ability from 10 to 13 months. EMA sampling within the day and across multiple days ensured that we captured variability in activities, and allowed us to sample more broadly across the US population. Longitudinal sampling allowed us to tease apart the contributions of age and motor development as infants learned to walk at different ages throughout the study. Controlling for walking ability, older infants spend more time unrestrained, less time prone, and more time upright compared with younger infants. Controlling for age, infants who could walk spent more time unrestrained, less time prone and sitting, and more time upright. Regardless of age and walking ability, all infants held objects frequently—about 40% of their awake time and totaling more than 4 hours/day—and the likelihood of object holding changed in the moment depending on restraint and body position. Infants were more likely to hold an object while sitting and least likely to hold an object while held by a caregiver. Developmental changes in motor ability were associated with changes in how infants held objects: Walkers spent more time each day holding objects in an upright position, and non-walkers spent more time each day holding objects while sitting.

Viewing Developmental Cascades through an "Experience Lens"

The present results provide important context for disentangling the cascading effects linked to the acquisition of walking (Iverson, 2022; Oudgenoeg-Paz et al., 2016; Smith, 2013; Walle & Campos, 2014). Taking an "experience lens"—knowing what experiences change and how much they change for walkers compared to non-walkers—helps to narrow down the set of hypothetical mechanisms that could mediate cascading effects. By documenting base rates about infant daily experiences, we hope to constrain theories about developmental mechanisms.

For example, learning to walk is linked with increases in infants' vocabulary size (Oudgenoeg-Paz et al., 2016; Walle & Campos, 2014). One potential reason is that walking facilitates infants' engagement with objects; mobile infants can explore more places (Adolph & Tamis-LeMonda, 2014; Adolph et al., 2012), and walking facilitates object carrying (Karasik et al., 2012). However, the present results rule out a change in the overall frequency of object experiences, because walking and non-walking infants spend similar times throughout the day holding objects. Our data reveal that other aspects of walkers' experiences did differ. Increased time unrestrained might allow walkers more freedom to navigate towards objects of interest and more frequently share those objects with caregiver (Karasik et al., 2011; West & Iverson, 2021). Indeed, we showed that walkers spent more time holding objects in an upright position, whereas non-walkers spent more time holding objects while sitting (and thus while stationary). Since parents give differential verbal responses in infants' object sharing bids based on infants' body position (Karasik et al., 2014), walkers are likely to accrue more directed information about the objects they encounter. Our results also highlight the relative influence of walking within broader age-related changes. For example, infants' unrestrained time increased with respect to walking, but also more modestly with respect to age. Thus, infants gain more freedom of movement with age, but even more so when they begin to walk. This might allow walkers to encounter a greater variety of objects compared with non-walkers, even if the total amount of time spent holding objects does not change. More work is needed to understand the mechanisms behind age differences in unrestrained time because age alone does not offer an explanation for the source of the change (e.g., changes in infants' responses to being restrained versus changes in daily routines).

Learning to walk is also theorized to change affective and social encounters between infants and their caregivers (Biringen et al., 1995). Increased independence from walking is thought to increase infants' interest in their surroundings (Gibson, 1988), which in turn increases caregivers' prohibitions when trying to keep infants out of danger as they go off on their own (Biringen et al., 1995). Indeed, infants who can walk stray further from caregivers in everyday play compared to infants who can only crawl (Chen et al., 2022); infants who can walk spend less time near caregivers when objects are around to explore (Hoch et al., 2019). But why might *walking* spur such changes, when most non-walkers already have the means to locomote by crawling? Our findings suggest that learning to walk has larger effects on how infants spend their time because of differences in the base rate of prone and upright time. Even among non-walkers, prone time (which sets the upper limits on how much time infants can crawl) is relatively brief (~10% of the day), suggesting that crawlers' opportunities to "test boundaries" are limited. Those same non-walking infants spend far more time upright (20% of the day) even though they cannot walk when on two feet. Walkers, however, spend nearly double the amount of time upright (38% of the day). Although we cannot say how much of that upright time is spent walking, lab and home video observations suggest that walkers walk far more than crawlers crawl (Adolph et al., 2012). Our data add that across a day, walkers accrue more *potential walking time* whereas crawlers accrue little *potential crawling time.* One might expect that parents of walkers might (for safety and/or convenience) limit infants' time unrestrained. Yet, the opposite pattern was found: Walkers were unrestrained 64% of the time whereas non-walkers were unrestrained 52% of the time. This hints that parents of walkers might be the losing side in the "testing of wills" if their newly-walking babies are unhappy to be restrained in devices, but more work would be needed to determine the causal direction. It is also possible that unrestrained infants have more opportunity to move and develop strength and balance, thus learning to walk sooner.

Bridging the Gap Between Real-Time and Developmental Time

More generally, the present results illustrate the difficulty in generalizing from what infants *are able to do in the moment* to developmental changes in what *actually do in daily life* without understanding the base rates of different behaviors. Consistent with past lab work about object exploration (Soska & Adolph, 2014), we found that sitting facilitates object holding. Infants held objects for a greater share of their sitting time than any other body position. The logical extension of this difference is that object holding experiences should decrease if sitting time decreases. Yet, object holding did not change over the transition to walking. Though moment-to-moment changes in body position do facilitate object holding, infants are flexible. The motor context of object holding adapts to what infants spend their time doing. Walkers spend more time holding objects while upright on two feet, compensating for the lack of time spent holding objects while sitting. This replicates past work showing that even newly-walking infants hold objects while standing and walking, even though holding objects disrupts infants' gait movements (Heiman et al., 2019).

Similar compensatory effects have been found when examining differences between crawling and walkers viewing faces (Franchak et al., 2018). Although infants are less likely to look at caregivers' faces while prone compared to while upright or sitting, infants who could only crawl did not accrue less overall time looking at caregivers' faces compared with walkers. Crawling infants do not spend all their time prone, and when they choose to sit they can gaze at faces more easily. Moreover, caregivers of crawlers spend more time crouched on the floor rather than standing upright, making their own faces easier to view. Thus, differences in the base rates of infant and caregiver body position compensate for crawling infants' disadvantaged view.

Both examples speak to the need to collect data about infants' experiences at a longer timescale than what brief laboratory observations or video-recorded home visits can offer. Although we found greater intra-individual consistency compared with inter-individual consistency in motor behavior frequencies, activities within a day are still heterogenous. Infants and caregivers co-determine how to spend their time based on a variety of factors—an active morning playing outside might be followed by a quiet afternoon reading books and watching TV. A fussy infant at breakfast might prompt an errand in the car or a walk in the stroller. Sampling only portions of a day may miss how earlier activities are balanced out or compensated for by later ones. How macro-level activities (e.g., play, errands, mealtimes) moderate infant activity—and how those daily activities are selected—are important avenues for future work. Questions about the consistency of sources of variability can be answered through longitudinal examinations of infants' activity. Are intra- and inter-individual differences in daily routines maintained over months of development, or are those sources of variability also changing?

Experiential variability is also relevant when considering the "milestone lens" that is often used when comparing differences in infants' ability. Even though we (and others) may use categorical terms, such as "non-walker" and "walker", to describe transitions in motor ability, what is happening developmentally is more continuous and messy. As daily diaries show, new skills are expressed inconsistently on a day-to-day basis (Karasik et al., 2011). The fact that different researchers use different thresholds classify what it means to be able to walk—3 independent steps versus 7 independent steps versus 10 independent steps—demonstrates another way in which the milestone lens fails to capture variability (Karasik et al., 2011; Thurman & Corbetta, 2017; West & Iverson, 2021). We used 10 steps as a threshold to categorize walkers from non-walkers, and the results may have differed had we used a 3- or 7-step definition. However, our goal was not to reify one particular definition of a walker, but rather to show that walking is one factor that predicts inter-individual differences in some daily experiences. No matter what definition we might choose for walking, intra- and inter-individual differences in daily experiences will be abundant. Measuring those experiences directly can capture that variability, but inferring experiences based on milestones will overlook it.

Methodological Advantages and Disadvantages of EMA

Deciding how to sample daily motor experiences means navigating a trade-off. Video data are rich and real-time, but cannot capture a full day or multiple days. EMA data provide sparse samples of individual behaviors, but can be distributed across the day and over multiple days of varying activity. We would not argue that EMA is a replacement for video measures, but suggest that converging evidence from both approaches are necessary to understand infants' daily experiences. Finding correspondence between both types of data increases our confidence about how in-lab or in-home video generalize to daily life. For example, prior video observations suggest that infants who walk spend more time walking than non-walkers spend time crawling (Adolph & Tamis-LeMonda, 2014; Adolph et al., 2012). Our results confirm that infants who can walk have more opportunity to walk (they spend more time upright) than crawling infants have opportunities to crawl (they spend little time prone). Karasik et al. (2012) found that carrying is more frequent while walking than while crawling; likewise, we found that holding-while-upright far surpasses time spent holding-while-prone. Heiman et al. (2019) reported that infants held objects for ~34% of standing and walking bouts; we found that infants held objects for 39% of their upright time. EMA can also provide converging evidence with other survey/interview approaches. Our finding about the relative frequency of restraint types—unrestrained was most frequent, followed by restraint in device/furniture, followed by restraint by caregiver—mirrors the ranking found in an interview-based study (Karasik et al., 2022).

Although EMA data in aggregate can help estimate the relative frequency of behaviors, and EMA samples can reveal the co-occurrence of different behaviors in the moment, there are limits to what sparse samples can reveal about the temporal sequence of daily behavior. Continuous data, such as video recording, can identify transitions between behaviors—how frequently do infants switch between positions, how long is a bout of object holding, or do changes in restraint increase the likelihood of picking up an object. Continuous data are needed to identify clustering or burstiness of behavior; sparse EMA samples cannot capture the local structure of successive events. Researchers of infants' language do not have to choose between short samples of continuous behavior and sparse samples of momentary behavior, since wearable audio recorders can gather real-time data about infants' auditory environment across the entire day for multiple days (Casillas & Cristia, 2019; Mendoza & Fausey, 2021; Weisleder & Fernald, 2013). In the future, characterizing infant motor behavior from wearable sensors may be a promising alternative. Recent examples include automatically classifying whether infants are held (Yao et al., 2019), locomoting (Airaksinen et al., 2020), and in different body positions (Franchak et al., in press; Franchak et al., 2021). However, other types of behaviors—such as whether infants are grasping objects—and other aspects of interactions—what kind of object during what type of activity or social situation—may be impossible to decipher from motion alone. Thus, even with future advances in movement classification, we believe that video, EMA, and sensing will play complementary roles in measuring daily experiences.

Conclusions

How best can we characterize infants' everyday motor experiences? We offer EMA as an important tool for taking an "experience lens" because it can capture behavior within the day and across multiple days, in and out of the house. Our results show that infants' daily experiences with restraint, in different body positions, and holding objects relate to age and to the development of walking. Effects of age and walking ability had differential effects depending on the specific type of experience, pointing to the need to measure base rates of infants' experiences from actual behavior in daily life. In measuring base rates—and how they change over development—we can better constrain theories about developmental mechanisms and cascades.

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Table 1

Demographics of participating families

		n	%
Infant's Sex Assigned at Birth	Female	34	54.8
	Male	28	45.2
Infant's Ethnicity	Hispanic or Latino	11	17.7
	Not Hispanic or Latino	51	82.3
Infant's Race	Asian	1	1.6
	Black Or African American	1	1.6
	More Than One Race	10	16.1
	Other Race Not Listed	5	8.1
	White	45	72.6
Community Type	Rural Area	5	8.1
	Town Or Village	11	17.7
	Suburbs Of A Large City	17	27.4
	Small City	14	22.6
	Large City	15	24.2
Annual Income	<$25,000	5	8.1
	$25,000-$50,000	15	24.2
	$50,000-$75,000	10	16.1
	$75,000-$100,000	7	11.3
	$100,000-$125,000	11	17.7
	$125,000-$150,000	1	1.6
	$150,000-$175,000	2	3.2
	$175,000-$200,000	4	6.5
	>$200,000	1	1.6
	Prefer Not To Disclose	6	9.7
Mother's Education	Partial High School	2	3.2
	High School Graduate/GED	5	8.1
	Partial College	17	27.4
	Standard College Graduation	21	33.9
	Graduate/Professional Training	17	27.4

Table 2

Number of infants, infant age (in months), and number of non-walkers and walkers at each session

Session	n	Min_{age}	M_{age}	Max_{age}	$n_{\text{Non-Walkers}}$	n_{Walkers}
10	60	9.71	9.98	10.31	57	3
11	62	10.76	11.01	11.34	54	8
12	61	11.78	12.00	12.32	43	18
13	60	12.70	13.00	13.34	32	28

Table 3

Survey items analyzed in current study.

Item
Question 1. Are you with your child? Is your child awake?
- Child awake [Continues survey]
- Child sleeping [Ends survey]
- Not with child [Ends survey]
Question 2. Is your child...
- Restrained by device/furniture [Branches to 3a]
- Restrained by caregiver [Branches to 3b]
- Locomoting [Branches to 3c]
- Neither [Branches to 3c]
Question 3a. In what device/furniture is your child restrained?
- Carseat
- Stroller
- Highchair/booster/other belted seat
- Bouncer/jumper/exersaucer
- Other: Write in
Question 3b. In what way is your child restrained by caregiver?
- Baby carrier in front
- Baby carrier on back
- Held on lap
- Held in arms
- Other: Write in
Question 3c. In what position is your child?
- Upright
- Sitting
- Supine
- Prone
- Other: Write in
Question 6. Is your child holding an object?
- Yes
- No

Table 4

Results of GLMM models predicting the likelihood of observing each type of experience from age and walking ability. Reported coefficients are log(odds). Each model tested fixed effects of centered age in months and centered walking ability (0 = non-walker, 1 = walker) without an interaction term. Random effects are reported for subject and for testing day nested within subject, with random intercepts and random slopes according to age and walking ability.

	Fixed Effects				Random Effects (SD)	
Predictor	$\hat{\beta}$	*SE*	*z*	*p*	Subject	Day:Subject
Restrained by Device/Furniture						
Intercept	1.00	0.063	-16.55	<0.001	0.3725	0.0770
Age	-0.03	0.036	-0.92	0.36	0.0429	0.0475
Walking Ability	-0.33	0.173	-1.92	0.055	0.6440	0.0351
Restrained by Caregiver						
Intercept	1.00	0.067	-22.53	<0.001	0.4081	0.0000
Age	-0.12	0.040	-2.96	0.003	0.0814	0.0001
Walking Ability	-0.05	0.129	-0.36	0.72	0.3517	0.0017
Unrestrained						
Intercept	0.18	0.056	3.21	0.001	0.3585	0.0000
Age	0.09	0.031	2.72	0.006	0.0280	0.0000
Walking Ability	0.25	0.119	2.09	0.037	0.2840	0.0005
Supine						
Intercept	1.00	0.123	-26.00	<0.001	0.6506	0.1969
Age	-0.17	0.099	-1.73	0.083	0.3991	0.0387
Walking Ability	-0.24	0.306	-0.77	0.44	0.0657	0.8055
Prone						
Intercept	1.00	0.123	-20.01	<0.001	0.6614	0.0000
Age	-0.24	0.068	-3.52	<0.001	0.2301	0.0000
Walking Ability	-0.91	0.343	-2.64	0.008	1.7940	0.0001
Sitting						
Intercept	0.26	0.063	4.08	<0.001	0.3789	0.0000
Age	0.04	0.038	1.04	0.30	0.0957	0.0000
Walking Ability	-0.59	0.145	-4.09	<0.001	0.5762	0.0001
Upright						
Intercept	1.00	0.074	-13.82	<0.001	0.4453	0.0000
Age	0.12	0.045	2.70	0.007	0.1499	0.0000
Walking Ability	0.89	0.157	5.66	<0.001	0.6724	0.0000
Holding Object						
Intercept	-0.37	0.068	-5.47	<0.001	0.4684	0.0000
Age	-0.04	0.036	-1.00	0.32	0.1180	0.0637
Walking Ability	-0.08	0.127	-0.66	0.51	0.2678	0.1706

Table 5

Means and standard deviations for percent of awake samples infants were reported to be restrained by age. Statistics are shown overall (across all infants) and split by non-walkers versus walkers. Note that statistics for walkers at 10 months and 11 months are based on n = 3 and n = 8 infants.

	Age	Overall	Non-Walkers	Walkers
Restrained by Device/Furniture	10	29.05 (12.89)	29.58 (12.92)	19.08 (8.36)
	11	26.41 (13.18)	28.03 (12.90)	15.23 (8.45)
	12	25.82 (14.54)	27.50 (13.38)	21.62 (17.11)
	13	25.51 (14.33)	27.49 (13.07)	23.15 (15.35)
	Across Ages	26.90 (9.99)	27.97 (9.29)	22.24 (13.84)
Restrained by Caregiver	10	19.66 (12.09)	20.12 (12.10)	10.89 (9.82)
	11	20.23 (13.86)	19.67 (14.43)	24.14 (6.99)
	12	19.15 (11.63)	19.92 (12.27)	17.74 (10.36)
	13	13.91 (9.29)	14.73 (9.38)	12.44 (9.41)
	Across Ages	18.79 (7.79)	19.48 (8.84)	13.77 (8.16)
Unrestrained	10	51.29 (14.99)	50.30 (14.69)	70.02 (5.81)
	11	53.36 (16.46)	52.30 (16.80)	60.63 (10.75)
	12	55.03 (16.30)	52.58 (15.55)	60.64 (18.67)
	13	60.58 (16.71)	57.78 (16.17)	64.40 (16.83)
	Across Ages	54.31 (11.23)	52.54 (10.61)	63.99 (14.69)

Table 6

Means and standard deviations for percent of awake samples infants were reported to be in different body positions by age. Statistics are shown overall (across all infants) and split by non-walkers versus walkers. Note that statistics for walkers at 10 months and 11 months are based on n = 3 and n = 8 infants.

	Age	Overall	Non-Walkers	Walkers
Supine	10	5.11 (7.14)	5.38 (7.22)	0.00 (0.00)
	11	3.84 (5.35)	3.82 (5.48)	3.49 (4.48)
	12	2.68 (4.13)	3.33 (6.03)	2.30 (4.51)
	13	2.91 (4.55)	2.85 (4.36)	2.88 (4.80)
	Across Ages	3.55 (3.07)	3.40 (3.11)	2.45 (3.94)
Prone	10	11.08 (10.56)	11.29 (10.73)	7.10 (6.25)
	11	10.97 (12.36)	11.37 (12.05)	8.20 (14.17)
	12	6.24 (8.54)	7.66 (9.49)	2.62 (3.80)
	13	6.96 (11.12)	10.46 (13.37)	3.78 (10.00)
	Across Ages	8.74 (7.52)	9.72 (8.12)	4.76 (9.94)
Sitting	10	45.87 (15.33)	45.97 (15.16)	44.10 (22.14)
	11	44.26 (17.64)	45.87 (17.74)	30.87 (10.45)
	12	44.47 (17.81)	48.62 (12.97)	33.19 (23.75)
	13	45.29 (16.42)	49.43 (15.06)	40.58 (16.66)
	Across Ages	44.51 (10.80)	46.63 (11.57)	39.19 (14.61)
Upright	10	16.67 (12.93)	15.90 (12.24)	31.28 (20.07)
	11	18.85 (14.44)	17.17 (13.40)	33.31 (15.89)
	12	25.08 (17.15)	17.71 (10.54)	42.83 (20.37)
	13	29.56 (17.64)	21.36 (12.81)	38.75 (19.06)
	Across Ages	22.60 (11.84)	19.05 (8.59)	38.41 (17.93)

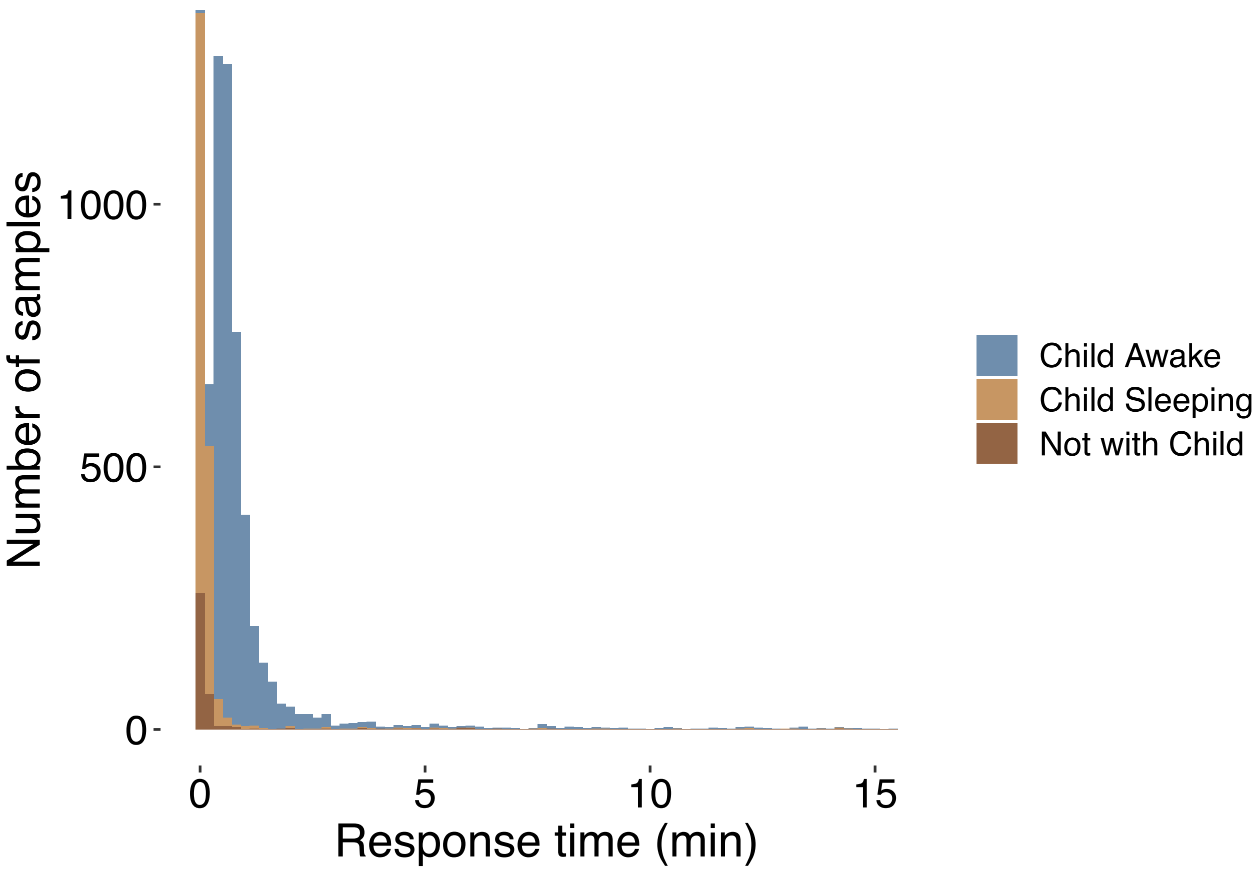

Figure 1. Distribution of response time (elapsed time in minutes between receiving the prompt and completing the survey) showing that responses captured infants' behavior at the moment caregivers received survey requests (median response time = 0.5 minutes). For most responses, children were awake with caregivers present to report their behavior (blue bars). Subsequent analyses report experiences as percent of awake samples, excluding times that infants were sleeping or caregivers were not with their child (brown bars).

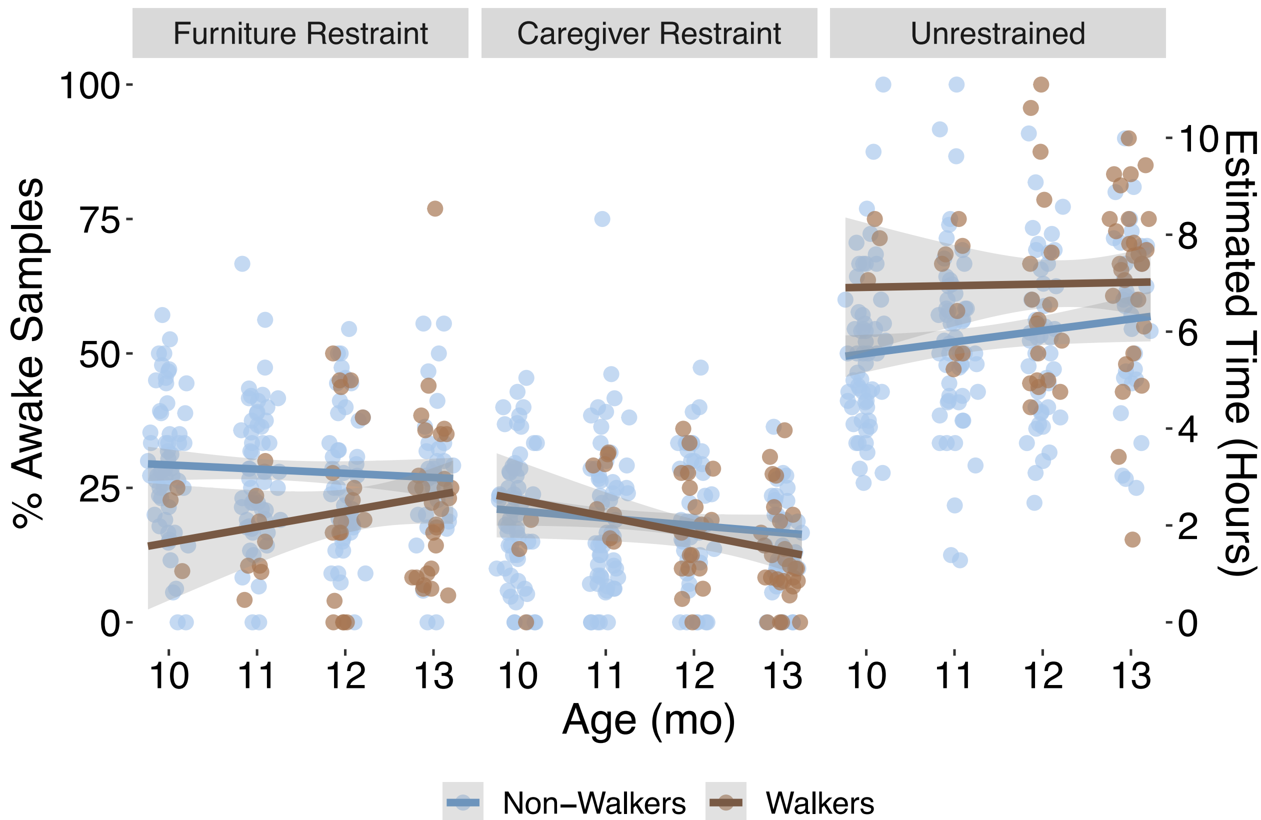

Figure 2. Percent of time infants were restrained by age (x-axis) and walking status (blue = non-walkers, brown = walkers). Furniture restraint (left) was not significantly related to age or walking status, caregiver restraint significantly decreased with age (center), and unrestrained time significantly increased with age and for walkers (right). Each individual point shows one infant's restraint percentage for each age; smoothed lines indicate linear age-related change within walkers and non-walkers. Secondary y-axis indicates estimated daily experience in hours based on an average waking day of 11.1 hours.

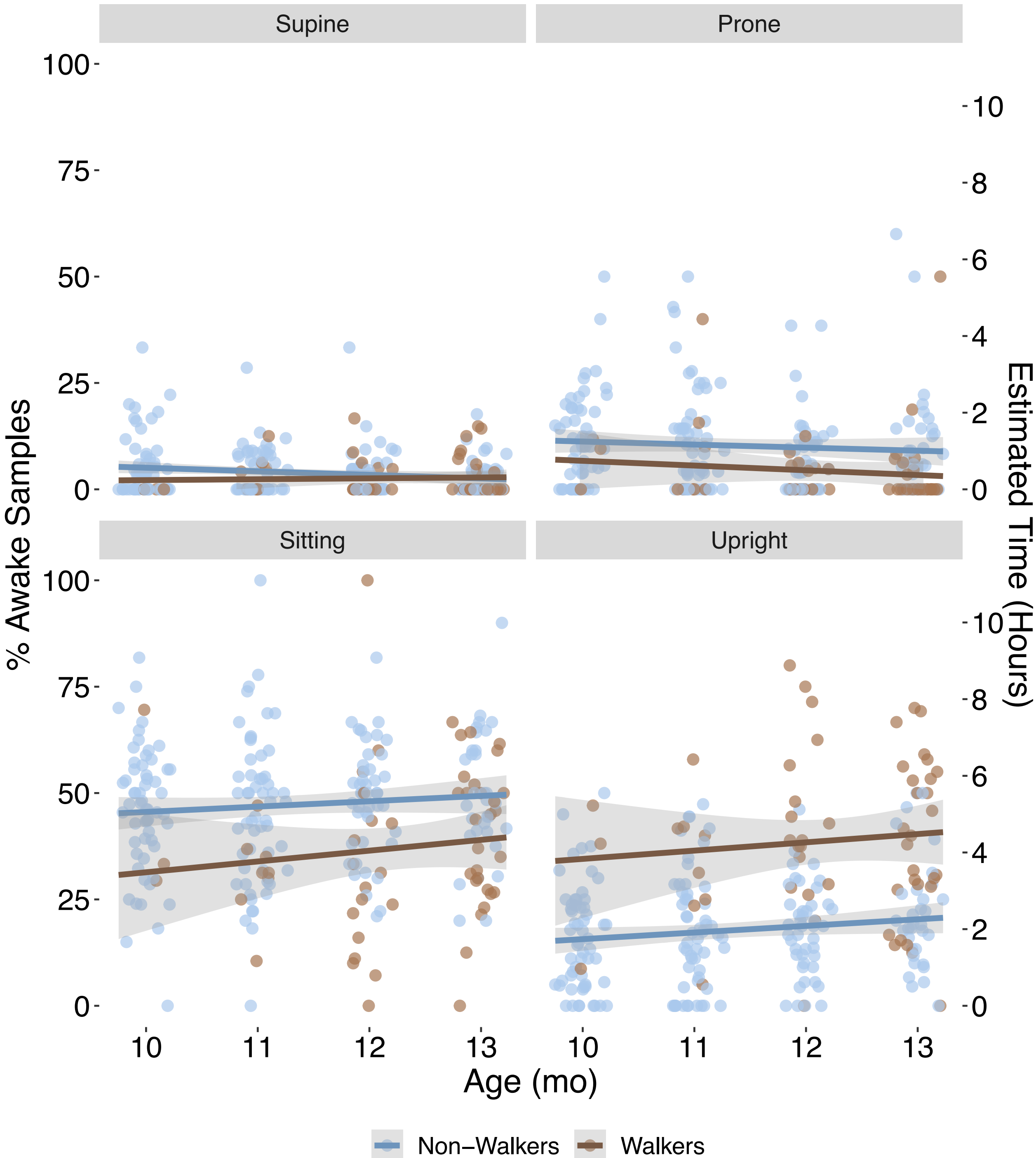

Figure 3. Percent of time infants were in each body position (shown in separate plots) by age (x-axis) and walking status (blue = non-walkers, brown = walkers). Supine was not significantly related to age/walking, prone time decreased as a function of both age/walking, sitting time decreased for walkers, and upright time increased both with ag/walking. Each individual point shows one infant's percent of time in each body position for each age; smoothed lines indicate linear age-related change within walkers and non-walkers. Secondary y-axis indicates estimated daily experience in hours based on an average waking day.

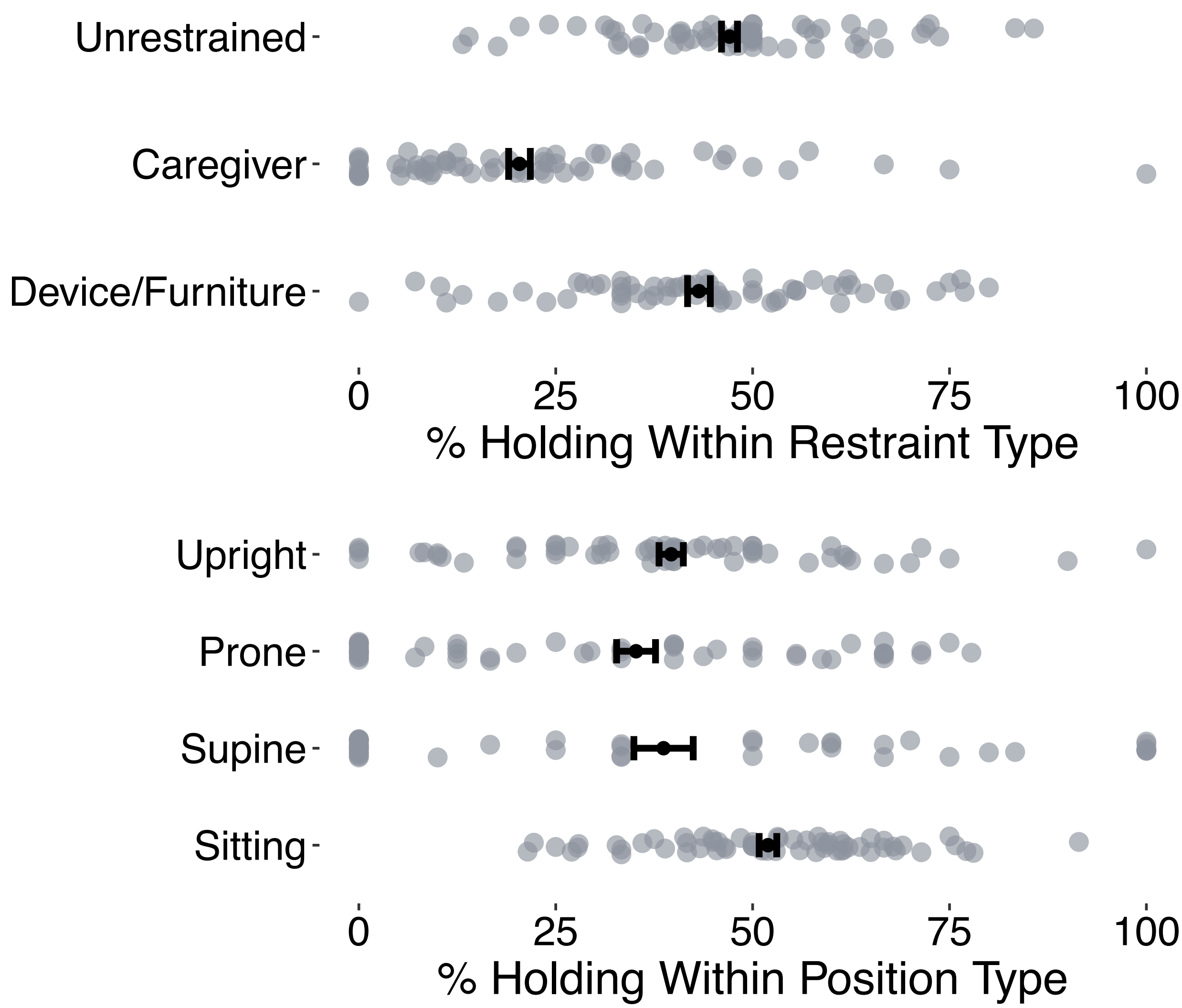

Figure 4. Percent of time within each restraint category (top panel) and body position (bottom panel) that infants spent holding objects. Significantly less holding was observed during caregiver restraint compared with furniture restraint and unrestrained activity (top). Significantly more hold was observed while infants sat compared with the other three body positions (bototm). Each point is one infant's holding percentage at each session. Black points show means across ages with error bars indicating 1 SE.

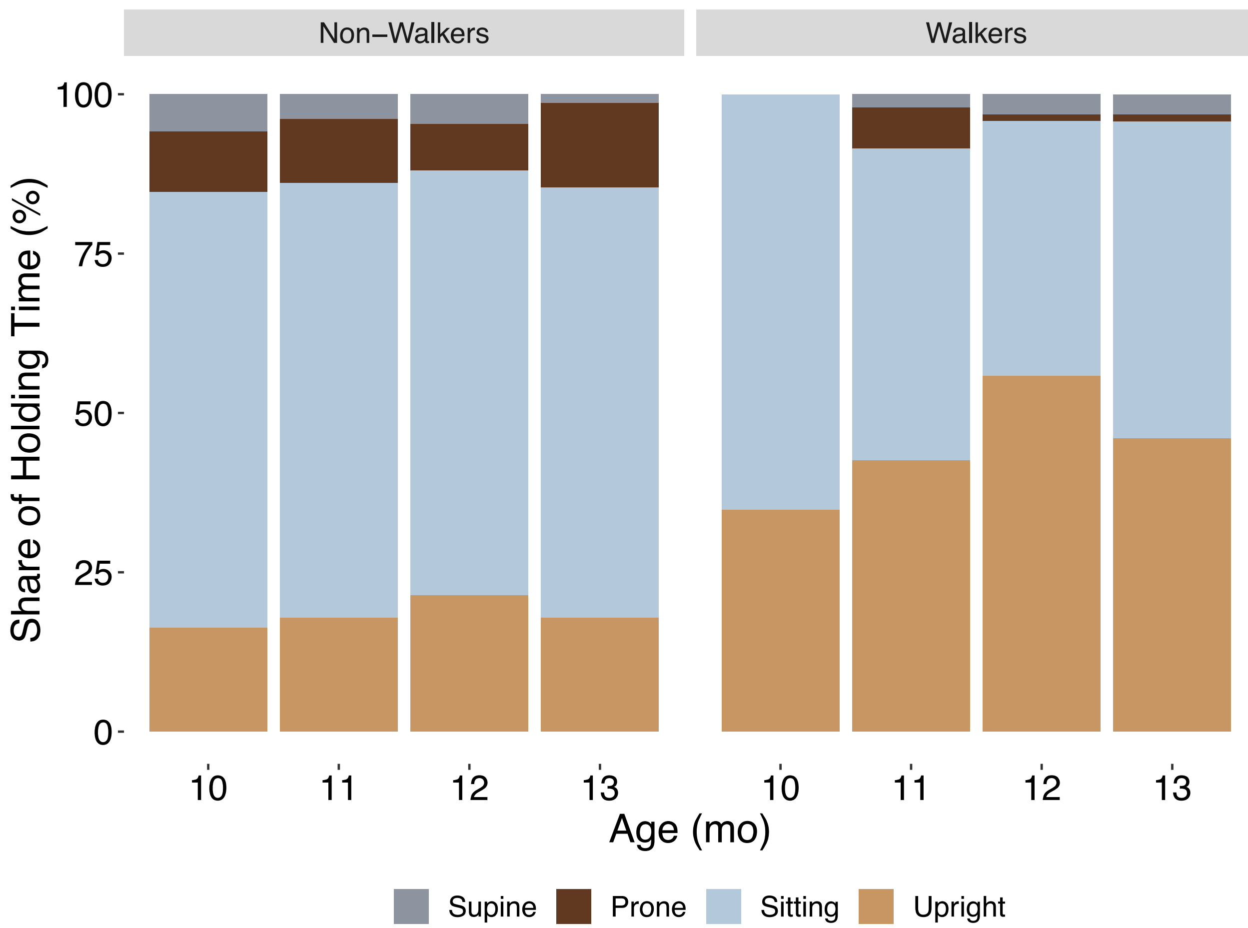

Figure 5. Non-walkers (left) spend a smaller share of their object holding time in an upright position (orange bars) compared with walkers (right). Each bar shows the percent of infants' object holding time that occurred in each of the four body positions at each age.