Real-time teaching and learning: Caregivers teaching infants to descend stairs

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Author Note

We have no conflicts of interest to disclose.

The data and study materials used are available on request.

This study was not preregistered.

This work was supported by the National Science Foundation, Division of Behavioral and Cognitive Science (1941122) to S.E.B.

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Abstract

Learning to descend stairs requires motor and cognitive capacities on the part of infants and opportunities for practice and assurance of safety offered by caregivers. The AAP prescribes the age strategy to teach toddlers to safely descend stairs but without much consideration for individual differences in infants' skills or caregivers' techniques. The purpose of this study was to observe the natural ways in which caregivers teach infants to descend stairs at home and the extent to which infants abide. Of particular interest was to examine the dynamic nature of caregivers' teaching and infants' learning over the session with attention to individual differences. Dyads (*N* = 59) were videorecorded on Zoom for 10 minutes interacting on stairs at home in the U.S., Brazil, Canada, Italy, and Spain. Infants (*n* = 30 girls, 29 boys; 13-month-olds ± 1 week) were novice walkers (*M* = 2.04 months walking experience). Caregivers used a variety of teaching strategies and focused on "backing" and "scooting." Infants were more likely to heed caregivers' guidance when caregivers provided hands-on support and verbal encouragement suggesting infants were engaged and responsive to caregivers' overtures. Infants' walking experience predicted change in descent strategy over the session. Although infants did not show evidence of learning over the session, consistent caregiver instruction suggested caregivers were persistent, if not effective, teachers. Teaching and learning motor skills in a potentially risky task creates a unique opportunity for interaction allowing infants and caregivers to learn from one another.

Keywords: infancy, motor development, stairs, naturalistic, caregiver interaction, remote study

Author Contributions

https://credit.niso.org/
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Introduction

As infants gain mobility, new opportunities arise for moving their bodies and exploring the environment. For example, stairs become a source of newfound delight and challenge as parents expand infants' opportunities for locomotor exploration while ensuring safety. As vigilant gatekeepers, once infants are able to dart across the room and creep up to those alluring steps, parents run after them removing infants from treacherous stairs or preventing access using baby gates. When parents are finally ready to allow access to stairs, the American Academy of Pediatrics (AAP) offers recommendations on when and how to broach the issue. By infants' second year of life, the AAP recommends that parents start teaching their infants to back down stairs. Parents are advised to situate infants on steps and guide their legs while verbally instructing them (Revermann, 2013). After repeated hands-on support, physical supports should be gradually reduced as infants improve their backing strategy. Parenting blogs and pediatricians herald backing as the safest strategy to introduce to infants (LaBuz, 2020). Parents seem to heed these recommendations. In a survey study of 732 parents, parents reported actively teaching stair descent at home. Once infants were able to successfully descend, parents reported it was by implementing the backing strategy (Berger et al., 2007).

The AAP and "mommy blogs" frequently champion the backing strategy as a safe and effective method of stair descent. Infants' balance while using alternative stair descent strategies such as walking or bum-scooting is less stable due to infants' top-heavy proportions, and these postures are prone to falls (Cromwell & Wellmon, 2001). Despite the fanfare, infants may struggle with implementing the backing strategy. When observed on stairs in the lab for 30 minutes, 13.5- and 18-month-olds rarely executed the backing strategy spontaneously (Berger et al., 2015). Instead, most infants walked down, scooted on their bottoms, or did a combination of both when locomoting on lab stairs alone (with an experimenter spotting).

Demands of Backing

One explanation for why backing is so rarely executed by infants in the lab is that implementing the backing strategy is cognitively demanding. A cognition-action trade-off account posits that infants solving a motor task must allocate finite attentional resources between cognitive processes—such as strategy selection, inhibition of a poor strategy, focusing attention on and evaluating relevant visual stimuli—and motor behavior, such as maintaining balance, haptically exploring, and locomoting (Berger et al., 2018; DeMasi & Berger, 2021). Thus, if additional attentional resources are needed in one domain, they are allocated at the expense of attention in the other. Previous work investigating the relation between locomotor experience and performance on a tunnel task showed that newly walking infants struggled to maintain a hands-and-knees position and would revert to standing or walking in the middle of the task, despite having been able to successfully complete the task as crawlers. Infants had the motor capability to perform the correct strategy, but inhibiting walking in favor of crawling was too cognitively demanding to perform, as they had to allocate attentional resources away from devising alternative strategies and towards maintaining their newly acquired posture (Horger & Berger, 2019). Backing down stairs similarly requires infants to inhibit behavior in multiple ways simultaneously—they have to inhibit a frequently used strategy (walking), inhibit facing the direction they are headed, and inhibit moving in the direction they are facing (Diamond, 1991; Lockman & Adams, 2001)—all the while keeping the goal in mind when it is not in view. However, even when attentional resources are freed up with gains in locomotor experience, backing is infrequently demonstrated. On stairs in the lab, experienced walkers, who were more frequently successful at inhibiting walking than new walkers, overwhelmingly opted for scooting over backing (Berger et al., 2015). Thus, in addition to the cognitive demands of maintaining backing in-the-moment, infants may have difficulty coming up with the backing strategy in the first place.

Caregiver Influence

When infants navigate stairs in their homes, they rarely do so independently. Parents report playing an active teaching role in their infants' stair exploration (Berger et al., 2007). Caregiver influence, then, may explain why infants do not descend by backing down in the lab, but are reported to do so in the home. Caregivers' real-time involvement in infants' learning of stair descent has not been well-documented in the developmental literature, so, despite its prevalence, the nature and influence of caregivers' behavior within the context of infant stair descent acquisition remains relatively unknown.

Previous work investigating caregivers' role in infants' motor performance has shown variable effectiveness and modality of caregiver involvement. In the home parents use various strategies to ensure infant safety, by staying nearby, keeping watch, and modifying the environment, for example by adding a baby gate to the stairs (Morrongiello & Cox, 2016). Once infants transition from pre-mobile to mobile, parents alter the relative frequencies of each strategy, typically decreasing supervision in favor of increasing teaching about safe practices. Parents play both a supervising and teaching role with their mobile infants on stairs, given the inherent risk of injury but may favor teaching over supervision as they do in more general contexts. As infants navigate obstacles in laboratory tasks—crossing steps, cliffs, slopes, and bridges—mothers encourage and discourage infants' crawling and walking using various words, gestures, facial expressions and tones of voice (Adolph et al., 2008; Karasik et al., 2008; Karasik et al., 2016; Tamis-LeMonda et al., 2008). Such caregiver influence shapes infant motor responses. Infants change their typical method of locomotion in line with mothers' messages, although only when uncertain about what to do. Otherwise, infants ignore their mothers' messages and proceed using their typical locomotor method. In all of these laboratory studies, mothers instruct from a distance, usually positioned a few feet away from their locomoting infants; an experimenter walks alongside infants to ensure their safety. Although this experimental setup allows researchers to test infants' abilities and whether infants heed mothers' advice, the laboratory setting does not accurately reflect everyday teaching scenarios, in which caregivers are nearby likely offering hands-on assistance. In laboratory studies, mothers' messages are delivered consistently within an experimental condition—mothers are prompted to encourage or discourage descent—even though they are not directed about how to deliver the message. Thus, it is still unknown how mothers teach infants stair descent when left to their own devices, and how this teaching might be evaluated and implemented by their infants.

Aims

Our goal of documenting and characterizing caregiver-infant interactions on stairs was three-fold. Our first aim was to document the types and frequencies of caregivers' teaching strategies and infants' stair descent strategies. Although previous work has directly observed infants' behavior on stairs in a laboratory setting (Berger et al., 2015; Berger, 2004) and has interviewed parents about the circumstances surrounding their infants' learning to climb stairs (Berger et al., 2007), we still lack a fundamental understanding of the real-time process underlying parents' and infants' negotiations of a challenging motor task. To document this interaction as it unfolds in real-time, we instructed caregivers to teach their newly walking infants to descend stairs using whatever methods they chose. Due to the novelty of the task for the infants and the unstructured guidelines for the caregivers, we expected to observe individual differences in the type, frequency, and duration of caregivers' teaching and infants' descent strategies as teaching and learning unfolded naturally between and within dyads. Infants in the process of learning a new motor skill will often employ a trial-and-error meta-strategy, performing a wide range of motor behaviors and selecting efficient patterns of movement over iteration (Schlesinger et al., 2000; Siegler, 1999; Thelen et al., 1993; von Hofsten, 1982). We expected a similarly wide range of behaviors to be exhibited by infants trying to solve the problem of stair descent, although it was unclear whether the 10-minute experimental trial would be long enough for iterative rounds of behavior to emerge.

Our second aim was to investigate the co-occurrence of and contingency between specific teaching strategies and infants' demonstrated behavior. Because caregivers were explicitly instructed to teach (but not how), and because infants tend to heed caregivers' advice in ambiguous perceptual-motor contexts, we expected to find relations between specific teaching strategies and backing down stairs—the reported caregiver-preferred strategy (Berger et al., 2007). Specifically, we expected caregivers' verbal encouragement and instruction to both co-occur with and predict subsequent backing, indicating that infants heeded their message. In addition, infants may benefit from caregivers modeling effective strategies on the stairs. Paulus and colleagues (2011) proposed a two-stage process of infants' imitational learning from observed actions and action effects, which suggests that infants may benefit from first seeing their caregiver demonstrate backing on stairs to then activate that behavior in the infant. Given this, we expect that caregiver modeling will be positively associated with infant backing.

Our third aim was to examine the extent of change in caregiver and infant behavior over the session. Change of behavior over the session would indicate whether and how learning occurred during the teaching session. Successful learning would be indicated by a decrease in "bad" or "risky" strategies (those in the walking posture) and an increase in safe strategies like scooting, but preferably, backing down. In previous studies of infants learning to solve novel locomotor problems, when infants acted alone, they rarely demonstrated in-lab learning, even after dozens of trials (e.g., Berger & Adolph, 2003; Berger et al., 2015). If it occurred at all, learning took the form of inhibiting a poor strategy, but not exhibiting an efficient one in its place. However, in the current study, a key difference was the involvement of the parent during problem solving. Thus, we entertained the possibility that learning as defined above could occur even though infants were novices, tackling a challenging task, and engaging in a short 10-minute teaching session.

Infants and caregivers approach an interaction with unique profiles of experience, competence, cognitive ability, expressiveness, and perceptual awareness, each of which influences the behaviors that emerge in that interaction (Bornstein et al., 2002). One such influential characteristic is the infant's motor experience. In the current study, infants' crawling and walking experience varied, but all walked as their primary mode of locomotion. We did not expect crawling experience to predict which infant behaviors were exhibited and how frequently because infants' perceptual judgements of obstacles are posture-specific. All participating infants were walkers, so we expected walking, not crawling, experience to affect how infants perceived stairs and their own ability to successfully descend (Adolph et al., 2008). Accordingly, we expected walking experience to be associated with strategy choice. Specifically, we expected that walking experience would be negatively associated with walking over the course of the session on stairs and positively associated with scooting and backing. This is consistent with the finding that experienced walkers were more successful than less experienced walkers at inhibiting walking down stairs in favor of safer, more appropriate strategies (Berger et al., 2015). Although infants in the lab did not independently back, we predict that with more walk experience, motor demands of the stair context lessen, and infants will be better able to incorporate and act upon their caregivers' teaching to back.

Caregivers adjust their communication with infants in line with infants' competence (Namy & Nolan, 2004; Masur, 1998), so we did expect that caregivers would adjust their teaching attempts to infants' abilities after trying different strategies to see what worked—especially in response to infants' lack of success. Furthermore, infants' temperamental behaviors, responsiveness, response saliency, and predictability influence how parents interpret and react to infant behavior (Putnam et al., 2002; Goldberg, 1997) An infant who responds predictably and saliently to parents' teaching allows caregivers to quickly interpret the infant's state and determine and respond appropriately (Bornstein et al., 2002). Thus, we would expect that caregivers who adjusted their behaviors over the course of the trial would be those whose infants who are consistently performing poor strategies in response to parent teaching in the beginning of the trial, clearly indicating the ineffectiveness of their caregivers' teaching and prompting reevaluation and adjustment of teaching strategy.

Methods

Participants

This study was not preregistered. Fifty-nine caregivers (M_{age} = 33.18 years, *SD* = 2.92, range = 28-40, n_{mothers} = 50) and their walking infants (M_{age} = 13.60 months, *SD* = 2.00, range = 9.86-19.53 months, n_{female} = 30, n_{male} = 29) participated. Fifty caregiver-infant pairs were mother-infant dyads, four were father-infant dyads. For five infants, the mother and father took turns participating within one session. To be eligible for the study, infants needed to be able to walk 10 feet independently without stopping, falling, or resting and unable to independently descend stairs. Before the scheduled data collection, caregivers completed an online questionnaire detailing their infants' locomotor history. Participants were recruited though ChildrenHelpingScience (https://childrenhelpingscience.com/), snowball recruitment in Brazil, and at local libraries and community events in New York City. Crawling, walking, and prior stair experience were confirmed with caregivers at the start of the data collection using an established interview protocol (Berger et al., 2007). Infants had an average of 2.04 months of walking experience (*SD* = 1.40 months, range = 6-226 days) and an average of 5.33 months of crawling experience *(SD* = 2.24 months, range = 18-370 days). Three infants were missing walking data and eight were missing crawling data. Caregivers lived in the USA (81.36%), Brazil (10.17%), Canada (6.78%), Italy (1.69%), and Spain (1.69%). Data collections were conducted in the native language of the caregiver. Caregivers identified their infant as White or of European descent (74.58%), Black (8.47%), Asian (11.86%), Hispanic/Latino (15.25%). Race/ethnicity data was unavailable for 18.6% of participants. Totals add to greater than 100% because some parents reported multiple races/ethnicities. Most families had stairs in their homes (86.44%), and those who did not conducted the study in other places with stairs, such as apartment buildings, a relative's house, or outdoors steps leading to a backyard or in a public space (13.56%). Families received a gift card and a diploma for their participation.

Procedure

Researchers used video conferencing technology such as Zoom or Facetime (Zoom Video Communications Inc., 2016; Apple, Inc., Cupertino, CA) to reach families in their own homes and recorded the video call. Researchers asked caregivers for their consent to be recorded and for the use of their information, then cautioned them of the risk of placing their baby on the stairs. Researchers guided caregivers as they positioned their camera at the foot of the stairs to capture as much of the staircase as possible, paying special attention to keeping the bottom steps in the frame.

At the start of the observations, infants and caregivers were observed on stairs to warm up and to corroborate parents' reports that infants were unable to descend independently. We confirmed that 72.9% of the infants were able to independently ascend stairs; none were able to independently descend.

Researchers then instructed caregivers to teach their infant to independently descend the stairs using any teaching method desired for a period of 10 minutes. If infants reached the bottom of the stairs, caregivers were instructed to place them back at the top of the staircase and continue teaching until the end of the 10 minutes. Caregivers received a 5-minute warning when they were halfway through the teaching session.

Data Coding

The codes and definitions of caregiver and infant behaviors are found in Table 1. Our instructions to the caregivers were for them to teach their infants to descend stairs. Thus, we labelled caregivers' behaviors as teaching, as this was their interpretation of our instructions to teach. Additionally, we do consider supporting behaviors such as hands-on and hands-off spotting as teaching. Although not explicit instruction, these behaviors scaffold and provide opportunities for infants to test out movements on the stairs that they might not otherwise. A primary coder coded behavior frame-by-frame in the session recordings using the data coding software Datavyu (http://datavyu.org). Bilingual researchers coded the sessions recorded in a language different than English. Each behavior was identified according to operational definitions. Onset and offset timestamps of the behaviors were recorded, and onset was subtracted from offset to obtain duration. Caregiver behaviors (aside from off-task verbal behaviors, see Table 1) were only coded when the infant was actively descending stairs, or the behavior was explicitly related to stair descent. For example, if the infant was going up the stairs and the caregiver said, *"come back down",* this would be considered a relevant caregiver behavior. Caregiver verbal behaviors required a minimum duration of at least 0.3s, and there had to be at least 1s between the offset and onset time of consecutive verbal bouts of the same category for those bouts to be considered separate (Cote & Bornstein, 2021). Verbal behavior subcodes were mutually exclusive—verbal phrases from one individual cannot overlap each other and each phrase was coded with only one subcode. Verbal, non-verbal, and hands-on behaviors were not mutually exclusive and subcodes within non-verbal and hands-on behaviors were not mutually exclusive. For example, a caregiver could be verbally encouraging and gesturing at the same time or coaxing with a toy and modeling at the same time. Bouts of non-verbal and hands-on behaviors were considered separate if there was at least one frame of video between the two bouts where the behavior was not being exhibited.

Table 1

Behavior code definitions, frequencies, and proportions

Participant	Category	Subcategory	Definition	M frequency (SD)	M % session (SD)
Caregiver	Hands-on	Moving infants' body	Manually moving infants' limbs into place	8.71 (7.47)	9.17% (11.24%)
		Spotting	Supporting infant physically but not restricting movement	10.19 (7.98)	13.71% (12.45%)
	Non-verbal support	Coaxing with toy	Luring infant to goal with toy as motivation	3.12 (5.00)	3.14% (5.68%)
		Gesturing	Using gesture to motivate infant (e.g., pointing towards goal)	6.34 (7.87)	2.17% (2.31%)
		Modeling	Modeling desired gross motor behavior (e.g., caregiver crawls backward down stairs)	1.58 (2.77)	1.89% (4.23%)
		Hands-off spotting	Anticipatory support, hands are behind infant but not touching	4.07 (5.03)	3.44% (6.45%)
	Verbal	Description	Describing something that is happening in the moment	2.66 (4.51)	2.38% (2.98%)
		Encouragement	Praising infant locomotor attempts (e.g., "good job!")	16.38 (12.88)	6.67% (5.16%)
		Instruction	Telling infant how to descend (e.g., "slow down" or "scoot on your bottom")	17.84 (15.71)	8.74% (8.90%)
		Off-task	Vocalization that has nothing to do with the task	13.74 (10.92)	7.70% (7.70%)
		On-task	General speech or sound-effects related to the task (e.g., "ok ready?" or "almost there")	24.74 (16.08)	12.97% (9.50%)
Infant	Descent	Backing	Crawling down stairs backwards independently	3.41 (4.63)	7.36% (11.67%)
		Scooting	Descending in a seated position, resting on each step	2.51 (3.98)	5.21% (10.16%)
		Stepping forward	Attempting to walk down (resulting in being caught by caregiver or stumbling)	0.93 (1.73)	0.43% (1.02%)
		Walking down supported	Walking down while holding railing and/or being supported by caregiver	3.78 (4.28)	7.63% (11.38%)

A second coder coded 23.49% of all behaviors (1,849 out of 7,871) to test inter-rater reliability. Discrepancies between primary and reliability coders were discussed and resolved. For categorical variables, kappa coefficients ranged from .96-.97 (ps < .001). For continuous variables (durations for hands-on teaching, non-verbal support teaching, and infant behaviors), single measure intraclass correlation coefficients (ICCs) ranged from .95-.96 (ps < .001). The ICC for duration of verbal behaviors were considerably lower, but still acceptable (ICC = .76, $p < .001$). The data and study materials used are available on request.

Results

Preliminary analyses

Caregiver behaviors did not differ between mother-infant and father-infant dyads. When two caregivers were present in the session, the switch was seamless and only one caregiver contributed at a time. Thus, dyad types were collapsed over subsequent analyses. To ensure there were no systematic differences by country, as a first step we compared infant and maternal behavior and found no significant or meaningful differences. Crawling onset age, walking onset age, and age at test did not differ by families' country of origin. Neither did country of origin predict any parents' teaching strategies or infant descent behaviors.

Primary analyses

For the purposes of this study, only behaviors that occurred during the 10-minute segment when caregivers were actively teaching their infant to descend stairs were included in the analysis. Our first question was about the nature of caregivers' and infants' strategies for teaching and stair descent. Mean session duration was 9.31 minutes (SD = 1.92, range = 2.66-

10.92). Across the sample, there were 822 infant descent behaviors, 901 caregiver non-verbal support behaviors, 1,645 caregiver hands-on behaviors, and 4,503 caregiver verbal behaviors. Table 2 shows the number of behaviors and percent of session duration, calculated from the difference between onset and offset times of behavior bouts, for both infants and caregivers. Both caregivers and infants had several types of behaviors in their repertoires. For example, infants as a sample exhibited ten different descent strategies and on average spent 20.88% (*SD* = 16.11%, range = 0-70%) of the teaching session in some form of stair descent. Consistent with caregiver reports that they prefer to teach their infants to use the safest, most stable descent strategies (Berger et al., 2007), when infants were descending the stairs, they spent most of the descent time backing and scooting. On average parents spent 7.14% of the time in off-task verbal behaviors (*SD* = 6.58%, range = 0-25%). Caregivers used an average of 7.75 unique teaching strategies (range = 4-10, *SD* = 1.41) while infants used an average of 2.22 unique descent strategies (range = 1-4, *SD* = 0.87).

Table 2

Descriptive statistics of infant and caregiver behaviors

		Frequency	% session
Infant descent	*M*	13.93	20.88%
	SD	8.26	15.33%
	range	1 - 39	0 - 70%
Caregiver non-verbal support	*M*	15.27	9.68%
	SD	11.54	9.73%
	range	1 - 55	0 - 54%
Caregiver hands-on	*M*	27.88	35.41%
	SD	15.46	17.21%
	range	6 - 77	7 - 80%
Caregiver verbal	*M*	77.64	28.59%
	SD	40.23	13.10%
	range	15 - 183	6 - 60%

Latent Profile Analysis

Using the three categories of caregiver behaviors (*non-verbal support*, *hands-on*, *verbal*) as predictors, latent profile analysis (LPA) was used to identify patterns of mothers' teaching strategies and to identify the number of profiles that best fit the data. We chose to select the broader categories of caregiver behaviors for our analysis rather than subcodes of these categories to allow for meaningful interpretation of profiles. We wanted to examine whether broader modailities of teaching—i. e. verbal, touch, non-physical support—rather than individual behaviors comprised unique caregiver teaching "styles". Off-task verbal behaviors were excluded from analysis because they are not teaching behaviors. Using the tidyLPA and mclust packages in RStudio (Rosenberg et al., 2019; Scrucca et al., 2016), a series of models with one to six profiles was evaluated. With each model, an additional profile was added. The bootstrap likelihood ratio test (BLRT) compares each new iteration of the model to the previous one, with a small probability value indicating a significantly better fit than the previous model (Tein, et al, 2013). The most common indices of fit are the Akaike information criterion (AIC) and Bayesian information criterion (BIC), based on the maximum likelihood estimates of the model, with lower values indicating a better fit. An additional measure of fit is entropy, an index of classification uncertainty. A higher entropy value indicates a better fit.

Table 3. Latent Profile Analysis Model Fit

Classes	*Log Likelihood*	*AIC*	*BIC*	*Entropy*	*BLRT*	*p*
1	107.83	-204.20	-191.83	---	---	---
2	115.90	-212.87	-192.27	0.89	16.65	0.03
3	119.49	-211.21	-182.36	0.78	6.28	0.31
4	135.24	-234.78	-197.69	0.86	31.59	0.01
5	133.66	-236.24	-190.91	0.86	9.50	0.21
6	133.66	-229.05	-175.47	0.81	0.93	0.68

Note. Smaller log-likelihood values indicate better model fit. AIC = Akaike information criterion; BIC = Bayesian information criterion; BLRT = bootstrap likelihood ratio test. The bootstrap likelihood ratio test compares the K_0-class model to a K_{-1}-class model.

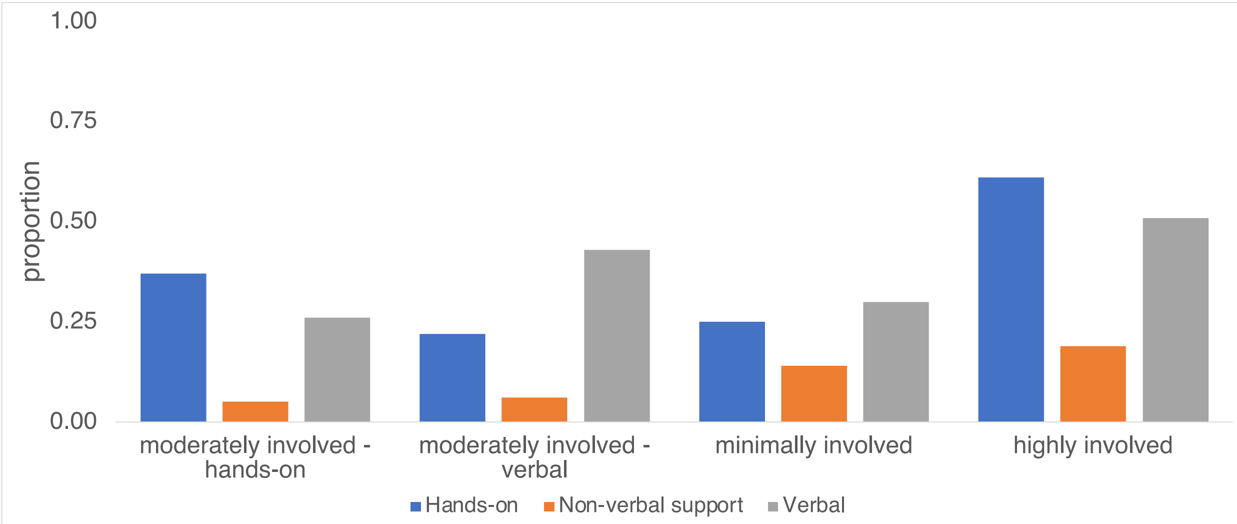
Although AIC and BIC were lower for the models with one profile and six profiles, respectively, the BLRT test indicated that the five-model profile (*p*-value > .05) was not a significantly better fit than the four-profile model (see Table 3). Because the four-model profile was a theoretically better fit, the model with four profiles was selected.

The next step was to identify the four profiles, which are described in Table 4 and depicted in Figure 1. The most prevalent profile was *moderately involved—hands-on* based on the lowest levels of *non-verbal support* and *verbal* strategies relative to the other profiles. The second profile was *moderately involved—verbal* based on the lowest level of *hands-on* relative to the other profiles. The third profile was *minimally involved* based on low to moderate rates of behavior across all teaching styles. The fourth profile was *highly involved* based on the highest rates of all teaching strategies relative to the other profiles. To confirm the profile distinctions, one-way ANOVAs tested whether the four profiles significantly differed in their use of teaching strategies. There were significant main effects of profile on all teaching strategies (see Table 4). Post-hoc Bonferroni tests revealed that these main effects were driven by significant differences between *moderately involved—hands-on* and *moderately involved—verbal* versus *minimally involved* and *highly involved* for non-verbal support strategies; between *highly involved* and all others for hands-on strategies; and between *moderately involved—hands-on* versus *moderately involved—verbal* and *highly involved,* and between *minimally involved* and *highly involved* for verbal. All *p*-values < .01.

Table 4. Caregiver Behavior Differences

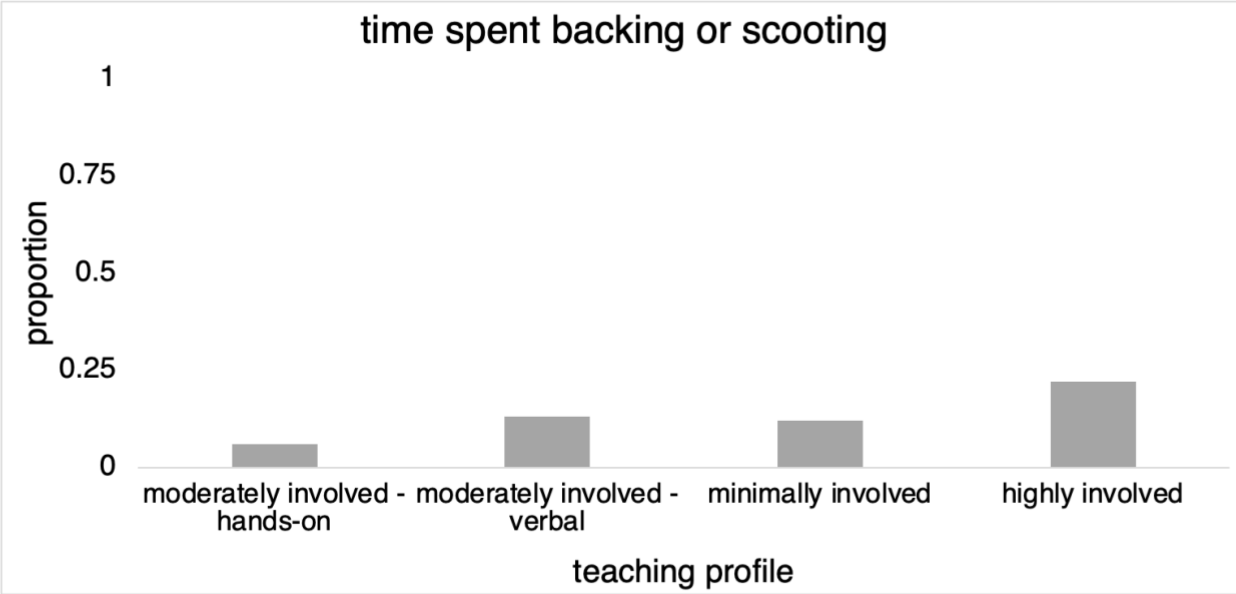
	moderately involved - hands-on		*moderately involved - verbal*		*minimally involved*		*highly involved*		
	n = 23		*n = 11*		*n = 10*		*n = 15*		
	Mean	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*F*
Hands-on	0.37	0.02	0.22	0.03	0.25	0.02	0.61	0.07	17.17***
Non-verbal support	0.05	0.01	0.06	0.01	0.14	0.01	0.19	0.04	12.89***
Verbal	0.26	0.02	0.43	0.03	0.30	0.03	0.51	0.05	12.42***

Figure 1.
Average proportions of each caregiver behavior category by profile.



A series of one-way ANOVAs with mother's teaching strategy profile as the between-subjects factor tested whether teaching profile predicted infants' safe stair descent behaviors. A main effect of profile strategy was found only for the proportion of time that infants spent either backing or scooting, $F(3, 55) = 3.67$, $p < .02$; partial $\eta^2 = .21$. A post-hoc Bonferroni test revealed that the main effect was driven by a significant difference between *moderately involved—hands-on* and *highly involved, p* < .01.

Figure 2.
Combined average proportions of infant scooting and backing by caregiver profile.



Contingency between caregiver strategies and infant stair descent

Our second question asked whether specific caregiver teaching strategies were related to infant descent strategies. Specifically, we asked whether given teaching strategies significantly co-occurred in time with target infant descent behaviors. We selected 6 caregiver teaching strategies that we expected to be related to backing and scooting behaviors: instruction, encouragement, hands-on spotting, hands-off spotting, moving infants' body, and modeling. We chose instruction and encouragement out of the verbal behaviors because these were frequently exhibited. In addition, previous work has demonstrated that infants do respond to caregivers' encouragement (Karasik et al., 2008). We chose instruction over on-task verbal because although on-task verbal behaviors were exhibited more frequently, they did not explicitly include information about which strategy to use, while verbal instruction did. We also selected hands-on spotting, hands-off spotting, and moving infants' bodies because of their high relative frequencies, and because these are directly involved in the physical positioning of the infant. Finally, we selected modeling in accordance with previous work that suggests that infants learn the association between an action (backing) and effect (descending stairs) by observing them in real time (Paulus et al., 2011). Although infants struggle to devise the backing strategy themselves, perhaps they may learn to do so through observing caregivers' modeling.

To examine the contingency between caregivers' teaching and infants' behavior on stairs, we computed a series of odds ratios (ORs) to quantify either the likelihood of a co-occurrence of a caregiver behavior and infant behavior or the likelihood of an infant behavior following a caregiver behavior. Following Bakeman and Quera (2011), we created 2 x 2 contingency tables for each caregiver behavior/infant behavior dyad of interest during the teaching session. For example, contingency tables for the infant crawling backwards while the caregiver offered encouragement tallied the number of times (*a*) caregivers encouraged while infants backed (*b*) caregivers encouraged while infants did not back (*c*) infants backed while caregivers did not encourage, and (*d*) neither encouragement nor crawling backwards. ORs were calculated as OR = [(*a/b*)/(*c/d*)]. ORs lower than 1 indicate that one behavior is less likely to occur in the presence of the other. ORs higher than 1 indicate that one behavior is more likely to occur in the presence of the other (Bakeman & Quera, 2011). For example, the odds of an infant backing down stairs while the caregiver offered instruction were 183-100 (Table 5, Row 1). That is, for each additional bout of caregiver instruction, the odds of backing down stairs increased by .83 (Rico-Villademoros, 2012).

Likelihood of co-occurrence

A series of one-sample *t-tests* compared the average OR for each behavior combination to an OR of 1 (chance). We examined the likelihood of six teaching strategies occurring simultaneously with scooting and backing down the stairs. Infants were more likely than chance to back (Table 5, top section) or scoot (Table 5, middle section) down the stairs while caregivers were providing instruction or encouragement, while caregivers were moving the infant's body into position, spotting the infant, and modeling the target descent strategy.

To test the possibility that caregivers might engage in these teaching behaviors regardless of what infants are doing, we also examined the likelihood that caregivers' teaching strategies occurred when infants were off-task—not engaged in any descent strategy. Infants were significantly less likely than chance to be off task when caregivers were engaged in teaching (Table 5, bottom section).

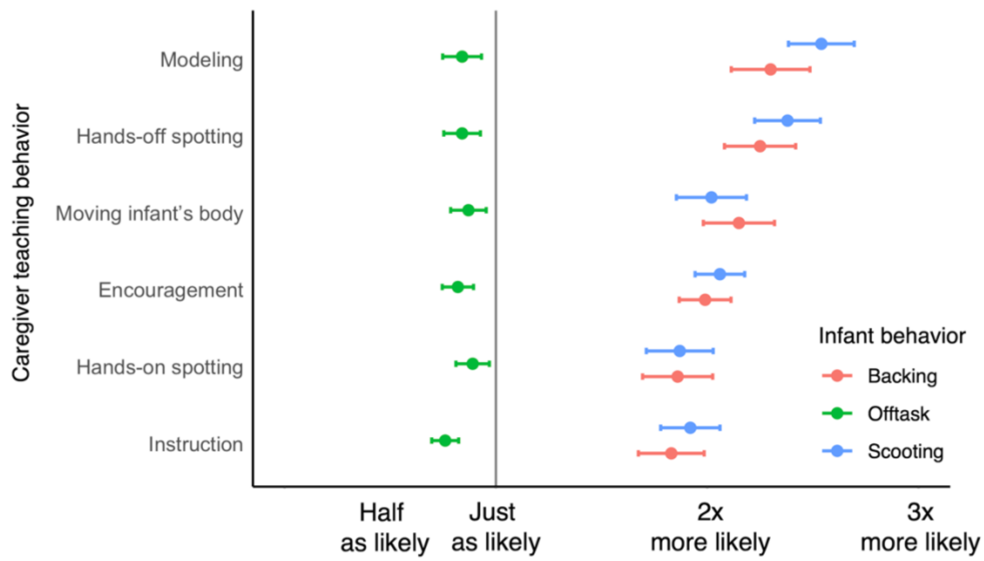
Table 5

Contingencies between caregiver behavior and infant backing, scooting and off task

	Mean OR	*SD*	*SE*	*n*	*t*	*p*	95% CI Lower	95% CI Upper	Base rate
Crawling backwards &									
Instruction	1.83	0.61	0.08	59	10.58	<.001	0.68	0.99	395
Encouragement	1.99	0.48	0.06	59	15.85	<.001	0.86	1.11	504
Moving infant's body	2.15	0.66	0.09	59	13.38	<.001	0.98	1.32	899
Hands-on spotting	1.86	0.65	0.08	59	10.18	<.001	0.69	1.03	739
Hands-off spotting	2.25	0.66	0.09	59	14.65	<.001	1.08	1.43	272
Modeling	2.30	0.73	0.10	59	13.67	<.001	1.11	1.49	3
Scooting down &									
Instruction	1.92	0.55	0.07	59	12.82	<.001	0.78	1.06	268
Encouragement	2.06	0.46	0.06	59	17.78	<.001	0.94	1.18	364
Moving infant's body	2.02	0.65	0.08	59	12.08	<.001	0.85	1.18	111
Hands-on spotting	1.87	0.62	0.08	59	10.79	<.001	0.71	1.03	443
Hands-off spotting	2.38	0.61	0.08	59	17.43	<.001	1.23	1.54	150
Modeling	2.54	0.61	0.08	59	19.43	<.001	1.38	1.70	136
Off task &									
Instruction	0.76	0.25	0.03	59	-7.23	<.001	-0.31	-0.17	2549
Encouragement	0.82	0.29	0.04	59	-4.93	<.001	-0.26	-0.11	1730
Moving infant's body	0.87	0.33	0.04	59	-3.02	0.004	-0.22	-0.04	2069
Hands-on spotting	0.89	0.31	0.04	59	-2.84	0.006	-0.19	-0.03	3498
Hands-off spotting	0.84	0.34	0.04	59	-3.67	<.001	-0.25	-0.07	1007
Modeling	0.84	0.36	0.05	59	-3.47	<.001	-0.26	-0.07	468

Given the caregiver's teaching strategy, the OR values presented in Table 5 are interpreted as the odds of the infant behavior occurring simultaneously with that caregiver behavior. A series of repeated-measures ANOVAs revealed a significant main effect of infant behavior for all teaching strategies. In this case, the repeated-measures are the likelihoods of each of the caregiver teaching strategies with each of the infant behaviors being compared to each other, not repeated-measures in the sense that within-subjects measures are compared to each other. Post hoc t-tests showed that the main effect was driven by significantly lower odds of infants being off-task while the caregiver was engaged in a teaching strategy than scooting or backing down the stairs (all *p*'s < .001). There were no significant differences between scooting and backing for any teaching strategy (see Figure 3).

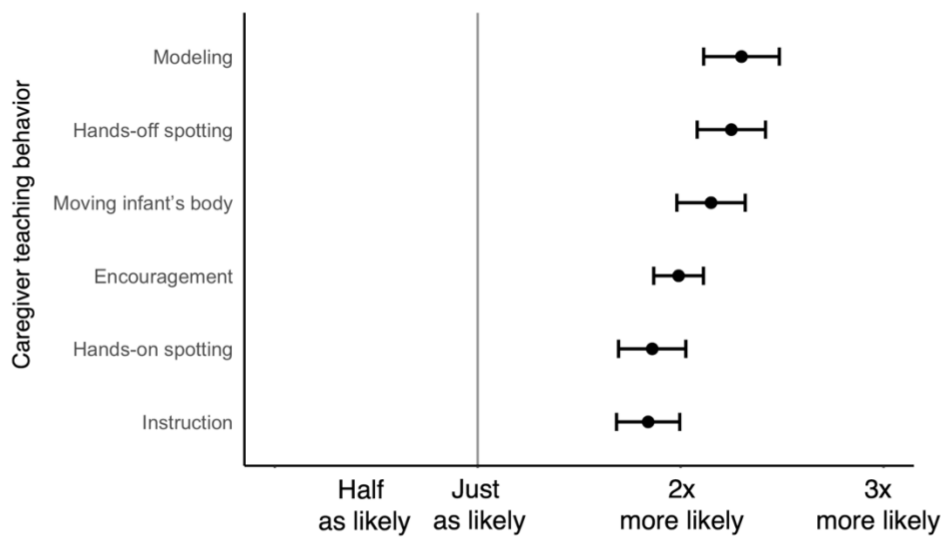
Figure 3
ORs of infant descent behaviors occurring contingently during caregiver teaching behaviors.



Likelihood of predicting backing

Given backing down is reported to be caregivers' preferred stair descent strategy, we asked which teaching strategies prompted infants to back down the stairs. To do so, we determined the likelihood that infant backing would be the subsequent behavior following any of the six teaching strategies performed by the caregiver. We created a lag variable whereby the infant behavior was shifted one unit forward. This meant that the likelihood of contingencies between infant and parent behaviors calculated via an odds ratio, actually reflected the parent behavior predicting the infant behavior. Figure 4 shows caregivers' teaching strategies that significantly predicted infants' subsequent backing. Infants were significantly more likely than chance to attempt to back down the stairs following caregivers' teaching strategies (all p's < .001). Although backing was more likely to follow each of these strategies than not, some were more successful than others—moving the infant's body into a backing position, hands-off spotting of the infant during descent, and modeling the backing behavior for the infant were more likely than either of the verbal teaching strategies or having hands on the infant (all p's $\leq$ .04).

Figure 4
ORs of infant backing following caregiver teaching behavior.



Change in caregiver strategy and infant stair descent

To answer whether caregivers and infants adjusted their teaching strategies and descent strategies respectively over the course of the teaching session, we compared strategies that took place during the first half of the session to strategies that took place during the second half of the session. These analyses were restricted to dyads whose teaching session lasted at least 8 minutes. For this subsample (n = 52 for non-verbal behaviors, n = 51 for verbal behaviors as one infant was missing audio), mean session duration was 9.95 minutes (SD = 0.51, min = 8.80, max = 10.92). Table 6 shows results from a series of paired samples t-tests comparing infant descent behavior and caregiver teaching behavior from the first half of the session to the second half of the session. Infants did not change the proportion of behavior from the first half to the second half for any tested behavior. However, the group average masked patterns of individual infants.

Table 6

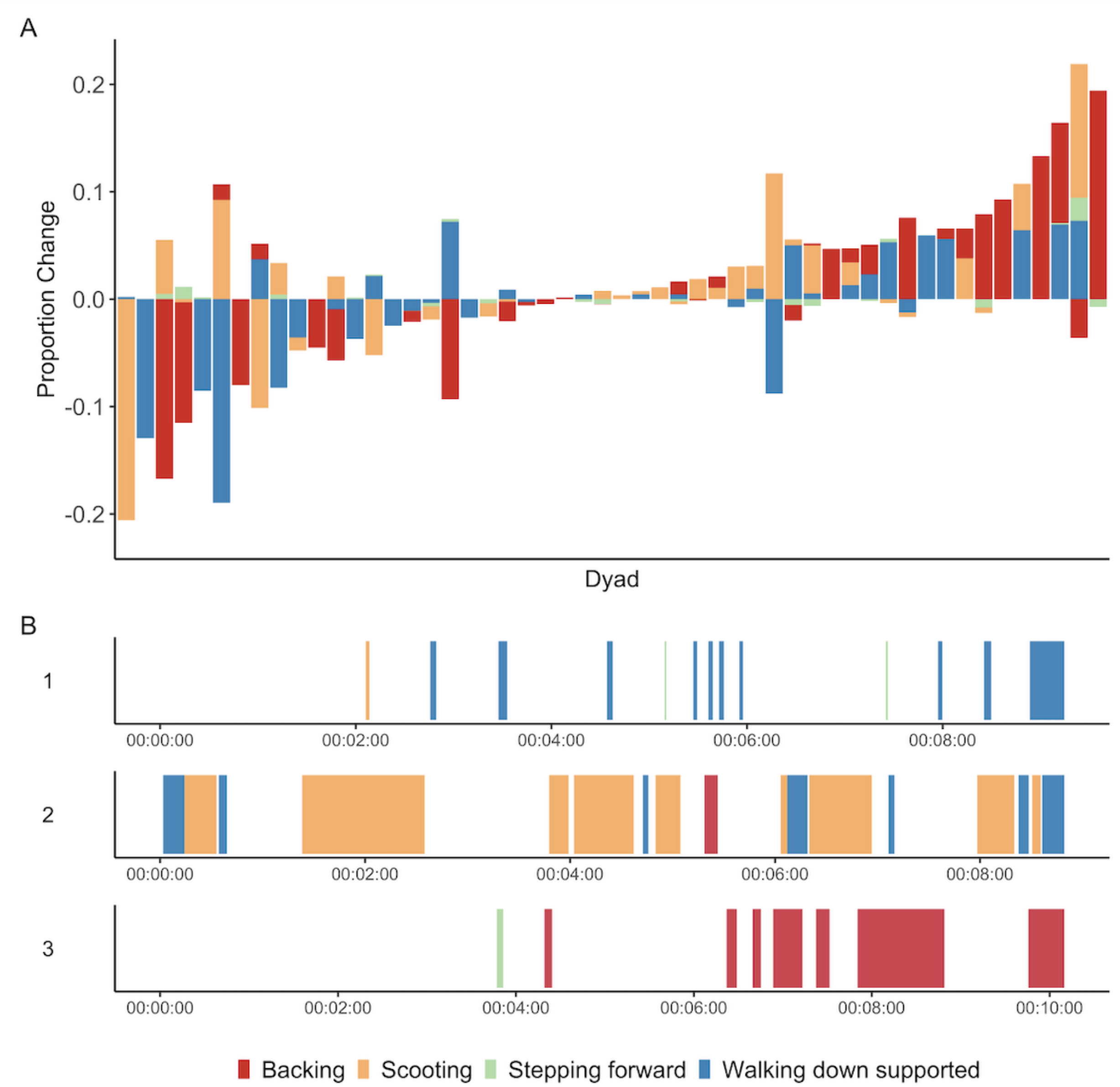
Paired samples t-tests of change in proportions and frequencies of behaviors from first half to second half of teaching sessions

Participant	Variable	1st Half *M* (*SD*)	2nd Half *M* (*SD*)	*t*	*p*	*N*
Infant (ppn of time)	Backing	0.074 (0.137)	0.083 (0.129)	-0.55	0.586	52
	Scooting	0.053 (0.112)	0.064 (0.120)	-0.86	0.397	52
	Stepping forward	0.005 (0.010)	0.005 (0.013)	-0.24	0.809	52
	Walking down	0.067 (0.134)	0.063 (0.103)	0.3	0.762	52
Caregiver (frequency)	Coaxing with toy	1.58 (2.97)	1.90 (3.13)	-0.74	0.462	52
	Gesturing	3.54 (3.84)	3.46 (5.02)	0.15	0.881	52
	Hands-off spotting	2.31 (3.52)	1.98 (2.51)	0.72	0.476	52
	Modeling	1.15 (2.17)	0.60 (1.22)	2.01	.050*	52
	Hands-on spotting	6.10 (5.16)	5.00 (3.96)	1.74	0.088	52
	Moving infant's body	6.08 (5.42)	3.56 (3.27)	3.69	<.001**	52
	Description	1.75 (2.58)	1.16 (2.51)	2.25	.029*	51
	Encouragement	9.69 (8.36)	7.90 (6.04)	1.98	0.053	51
	Instruction	10.63 (8.38)	8.71 (8.44)	2.85	.006*	51
	Off task	6.65 (5.00)	8.00 (6.79)	-2.15	.037*	51
	On task	15.31 (9.36)	11.39 (7.21)	5.35	<.001**	51

Note. *ppn* indicates that those variables are proportions of time while *frequency* indicates that those variables were frequencies. All *ppns* are infant behaviors and all *frequencies* are caregiver behaviors.

Figure 5

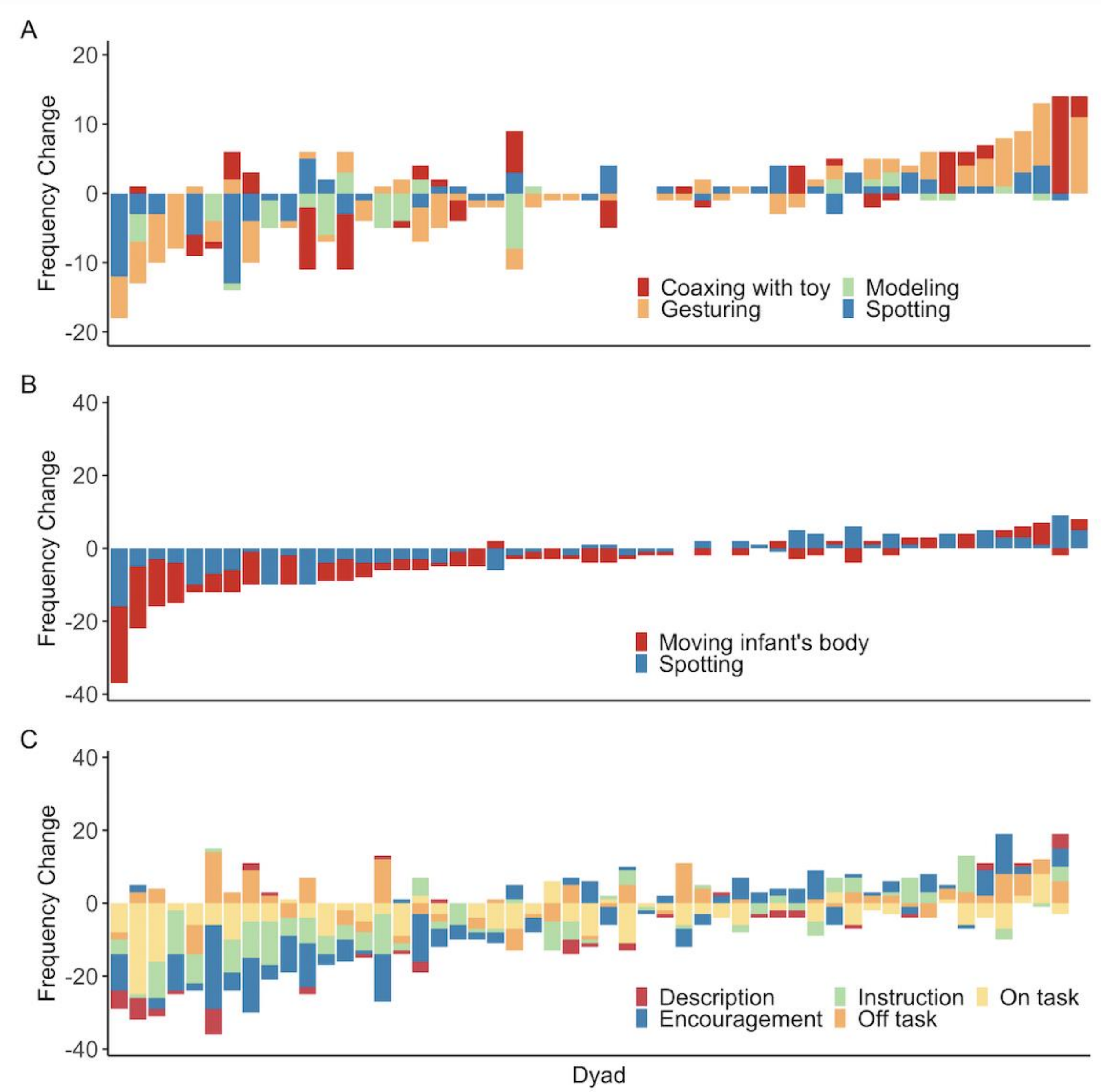
Change and individual differences in infant behavior from first half to second half of the teaching session.



Note. (A) Change in infant behavior from first half to second half of the teaching session. Positive values indicate an increase in behavior while negative values indicate a decrease in the behavior over the course of the session. (B) Exemplars of three infants' real-time descent strategy choices over the teaching session.

Caregivers significantly decreased the frequency of their behaviors from the first half to second half of the session, a potential indication that they adjusted their behaviors in response to their infants' behavior. They decreased their modeling, moving of their infant's body, and verbal description and instruction, while they increased their off-task vocalizations. Frequencies of all other behaviors did not change from the first to the second half of the session (Table 6). Figure 6 depicts the extent of individual caregiver differences in change in behaviors over the session. Individual differences in the change of caregiver behavior over the session appeared to be more uniform than those of infants.

Figure 6
Change in caregiver behavior from first half to second half of the teaching session



Note. (A) shows change in the frequency of non-verbal support behaviors, (B) shows change in hands-on behaviors, and (C) shows change in verbal behaviors. Positive values indicate an increase in behavior while negative values indicate a decrease. Zero indicates no change.

To investigate what accounted for changes in infant descent behavior, we ran a series of regressions examining holistic trends over the teaching session. Pearson correlations on changes in proportion of time that infants spent backing, scooting, and walking down supported from the first half of the session to the second half and infant age, infant walk experience, and caregiver strategies revealed that only the frequency with which caregivers used a hands-on teaching strategy was associated with the change in proportion of infant backing (see Table A in Appendix A). Corrections were not applied for multiple correlations. To further parse what aspects of caregivers' hands-on teaching strategies were related to changes in the proportion of infant backing over the session, Pearson correlations showed that the frequency of hands-on spotting (r = -.27, p = .025) and the frequency that caregivers moved the infant's body (r = -.20, p = .080) were related to changes in the proportion of the session infants spent backing at the <.15 level (the threshold for being included in a stepwise regression (Pardoe, 2012). A forward stepwise regression with total *hands-on spotting* frequency entered at step 1 and total *moving infant's body* frequency entered at step 2 showed that only hands-on spotting predicted the change in proportion of infant backing over the session (β = -.274, p = .050). The more frequently that caregivers used hands-on spotting, the lower the likelihood that their infants would back down stairs over the course of the session.

A stepwise regression predicting change in the proportion of the session spent scooting was not run because it did not correlate with any of our variables of interest. However, Pearson correlations showed that age (r = -.25, p = .044) and walk experience (r = -.43, p < .001) were related to the change in the proportion of the session infants spent walking down supported at the <.15 level. A stepwise regression with walk experience entered at step 1 and age entered at step 2 showed that only walk experience predicted change in the proportion of the session infants spent walking down supported (β = -.44, p = .002). That is, for every additional 60 days (one standard deviation) of walk experience, the difference between proportion of walking in first half to second half would decrease by 44% of a standard deviation, or about 2.2% of the session. That is, with additional walk experience, infant change scores would decrease. See Table 7 for complete stepwise regression model for predicting backing down.

Table 7

Stepwise regression predicting backing down

	Backing down	
Independent Variables	*β*	*p*
Step 1. Hands on spot	-0.27	0.05
Step 2. Move body	-0.05	0.78

Discussion

Our first aim was to document the types and frequencies of caregivers' teaching strategies and infants' motor behaviors while descending stairs. The most frequent caregiver teaching strategy was on-task vocalization and caregivers spent the most time with their hands physically on their infant. Caregivers used a variety of unique teaching strategies, up to 10, focusing on backing and scooting, typically accompanied with verbal encouragement. These observational findings align with previous surveys in which parents acknowledged the importance of teaching infants motor behaviors especially in the context of a risky situation (Berger et al., 2007). Four significant profiles of caregiver teaching emerged: *minimally involved, moderately involved—hands-on, moderately involved—verbal,* and *highly involved.* For their part, infants exhibited four unique descent strategies during the task, suggesting they were engaged and responsive to their caregivers' suggestions. Our findings confirm previous laboratory investigations where infants had to figure out how to descend stairs (Berger et al., 2015). Similar to studies in the laboratory where infants had to solve a stair descent problem independently (Berger et al., 2015), they seldom demonstrated the backing strategy, even after the 10-min teaching session, unless prompted by caregivers. Furthermore, as in laboratory studies where mothers advised infants on whether to proceed during a novel locomotor problem and infants heeded this advice, infants in the current study varied in their responses to their actively teaching caregivers (Karasik et al., 2016). When observed in natural settings, infants demonstrated frequent locomotor exploration (Adolph & Berger, 2005). Although infants were not actively descending for a large portion of the session, they still acted on the stairs—climbing up, playing with toys, and moving their bodies. Whenever they did descend, it commonly co-occurred with caregiver teaching. Infants were still fulfilling their role as explorers, but they may not yet have had enough experience on stairs—perhaps due to caregivers' gatekeeping tendencies—to turn that action into an independent, safe, or adaptive descent strategy specifically.

Our second aim was to investigate the co-occurrence of caregivers' teaching strategies and infants' behavior on stairs. Unlike previous studies, we focused on the dynamic nature of teaching and learning of a challenging motor task; infants and mothers were observed as a unit and mothers were asked to safely teach by their own means. Examining the reciprocal nature of teaching motor solutions offers insights into how infants learn from caregivers and how caregivers can learn from infants, by adjusting their behaviors in line with infants' skills and online movements.

Caregiver profile was significantly predictive of the proportion of time that infants spent backing or scooting. Infants spent more time in one of these safe descent strategies if their caregivers were *highly involved* rather than only *moderately involved—hands-on.* There were no significant differences between proportion of backing and scooting times between *highly involved* caregivers and *moderately involved—verbal* and *minimally involved* caregivers. These results indicate that type, not just overall amount, of caregiver teaching predicts backing and scooting. It could be that hands-on behaviors, such as carrying the infant and holding the infant' hands, are too intrusive and do not give the infant enough agency or mobility to independently, but safely, practice backing. However, the relation could be interpreted in the other direction such that infants who tend to back and scoot less frequently alert more caution from caregivers who may be unsure of their infant's competence on stairs. Our odds-ratio analyses address the plausibility of these interpretations.

Infants were more likely to back or scoot while caregivers were simultaneously instructing, encouraging, moving infant's body, spotting the infant, or modeling, than when caregivers were not doing those behaviors. Infants were unlikely to be off-task while caregivers were actively engaged in teaching. Infants were also more likely to attempt to back down the stairs following the caregiver teaching strategies of moving the infant's body into a backing position, hands-off spotting, and modeling backing and scooting. The caregiver behaviors predicting successful, safe descent reinforce the theory that non-verbal support and verbal teaching are more conducive for safe descent than hands-on behaviors. One way of interpreting this pattern of contingent behaviors is as a glimpse into the unfolding of real-time interactions. Caregivers use teaching strategies to scaffold infants into a novel, challenging behavior and then maintain their support as that behavior is ongoing. This interpretation suggests that certain teaching behaviors can more effectively elicit and help to maintain backing than others. This may explain why infants do not spontaneously back down stairs in the lab, but are reported by their parents to do so on stairs in the home. Perhaps parents introduce the unintuitive backing strategy to their infants through teaching, which prompts them to back when they otherwise might not have.

In natural, everyday settings, newly mobile infants are not alone when navigating and negotiating challenging and potentially risky physical settings. Caregivers are typically nearby offering hands-on assistance as needed, but even when caregivers are across the room or across the playground, they offer verbal instructions. One possible explanation for the variability in infant learning is that the individual differences in caregivers' teaching styles can either facilitate or impede learning. Infants learn to distinguish between good and bad motor strategies by performing and selecting from a variety of actions. Caregiver teaching that limits infant movement, although ensuring safety, may do so to the extent where infants cannot adequately explore their motor strategy options.

Our third aim was to examine changes in caregivers' teaching strategies and infants' behaviors on stairs over the course of the session. The group trend showed no change in infant descent behavior over the session. However, very few infants (n = 8; 14%) reflected the group trend. Some infants increased how often they descended and others decreased the frequency of their descent. Infants who increased their overall descent frequency could reflect a willingness to heed caregivers' instructions. However, because we only observed infants and caregivers for 10 minutes, we may have only captured the start of the learning process. Infants who decreased how often they descended could reflect a honing in on one or two strategies, which mothers suggested. Our findings show that caregivers naturally tailored their instruction in real-time, relying on verbal information to shape and praise infants' behavior. In lab studies that asked mothers to give instructions as infants engaged in a motor task could not examine change over session because across lab studies, mothers' distal communications were experimentally held constant. Mothers delivered the message consistently across the session precluding investigation of change in the message relative to infants' behaviors. Nevertheless, those studies did find that infants selectively adhered to their caregiver's messages, at times in line with mothers' messages, and at other times in contrast to those messages (e.g., Karasik et al., 2016).

Individual differences in walking experience could also explain why few infants reflected the group trend indicating lack of learning after the 10-minute instructional session with mothers. But, at the individual level, infants with more walking experience decreased in the proportion of time they spent walking with mothers' support over the session. This suggests that walking experience helps infants avoid the specific risky descent strategy (e.g., Adolph & Kretch, 2012).

As a group, caregivers changed the frequency that they used most teaching strategies—modeling, moving the infant's body, verbal description and instruction— from the first to the second half of the session, suggesting that they adjusted their own behaviors in response to their infants' behavior. This is consistent with previous work showing that parents adjusted the frequency of their teaching behaviors according to the level of their infants' expertise (Namy & Nolan, 2004). Despite the decrease in teaching strategies over the session, off-task vocalizations increased over the teaching session, suggesting that mothers were continuously eager to interact with their babies, trying to keep them engaged in the task. But, teaching the backing strategy waned, perhaps because in the course of the teaching experience, mothers recognized infants' limitations, such as lack of motor coordination or effective cognitive strategies. Attentive and responsive development in mothers' teaching must balance infants' current (in)abilities with their potential for learning.

Caregivers took on an active teaching role, regardless of whether their strategies were effective. The more that caregivers had their hands on their infants to spot them, for example, the less likely infants were to continue backing over the course of the session, suggesting that infants and caregivers interpreted parents' hands-on teaching strategies differently. The real-time stream of behavior would show a sequence of events unfolding akin to the classic visual cliff experiments where, once the infants felt the safety of the glass, they crawled out onto the surface

(Gibson & Walk, 1960; Rader et al., 1980). Similarly, infants could subsequently have been emboldened to take risks on stairs based on the feeling of security provided by the caregiver's hand. Caregivers may have intended to provide extra support to make their teaching more effective, but to the infants, caregivers served as a tool for support, no different from a handrail or banister or safety glass (Berger & Adolph, 2003; Karasik et al., 2016).

Role of Caregivers and Infants in Learning

The role of caregivers as teachers is to provide opportunities for infants to learn and to determine when the right time would be to give infants those opportunities. Infants' role as learners is to do what they do best—move their bodies, explore their environments, and take advantage of the opportunities offered to them. Infants are typically restricted from going on stairs (Berger et al., 2007), but they learn about their bodies and their locomotor abilities by moving and exploring when unrestricted. Depending on the age and locomotor posture at which caregivers first start to give infants opportunities on stairs, infants may recognize the risk, but that does not mean that they can conjure up an alternative effective strategy. Infants' hesitation creates an opening in the negotiation for caregivers to offer guidance and instruction, and for infants to heed their mothers. Age-based recommendations, such as the AAP's recommendation of teaching infants to back down stairs at 18 months, might not be appropriate for all infants. There is no perfect age at which infants are guaranteed to be ready to learn stair descent. Instead, stair descent seems to be acquired as parents and infants create moments of interaction that offer them opportunities to learn from each other. The effectiveness of such opportunities is predicted by caregivers' teaching style and infants' motor experience, not infant age.

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Appendix A
Correlation Tables

Table A

Correlations between infant and parent behaviors and infant characteristics

Variable		1	2	3	4	5	6	7	8
1. Walking down supported	*r*	1.00							
	p								
	N	52							
2. Backing	*r*	-0.03	1.00						
	p	0.81							
	N	52	52						
3. Scooting	*r*	-0.21	-0.11	1.00					
	p	0.14	0.43						
	N	52	52	52					
4. Age	*r*	-0.23	0.02	-0.16	1.00				
	p	0.11	0.89	0.26					
	N	52	52	52	52				
5. Walk experience	*r*	-.435**	0.06	0.10	.462**	1.00			
	p	0.00	0.67	0.52	0.00				
	N	49	49	49	49	49			
6. Caregiver hands-off frequency	*r*	-0.09	-0.05	0.00	-0.11	-0.23	1.00		
	p	0.53	0.74	1.00	0.46	0.11			
	N	52	52	52	52	49	52		
7. Caregiver hands-on frequency	*r*	-0.02	-.284*	0.11	-0.08	-0.22	.627**	1.00	
	p	0.90	0.04	0.46	0.58	0.13	0.00		
	N	52	52	52	52	49	52	52	
8. Caregiver verbal frequency	*r*	-0.16	-0.09	0.07	0.04	-0.03	.603**	.714**	1.00
	p	0.27	0.55	0.62	0.78	0.86	0.00	0.00	
	N	51	51	51	51	48	51	51	51