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Learning From Falling

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Walkers fall frequently, especially during infancy. Children (15-, 21-, 27-, 33-, and 39-month-olds) and adults were tested in a novel foam pit paradigm to examine age-related changes in the relationship between falling and prospective control of locomotion. In trial 1, participants walked and fell into a deformable foam pit marked with distinct visual cues. Although children in all 5 age groups required multiple trials to learn to avoid falling, the number of children who showed adult-like, 1-trial learning increased with age. Exploration and alternative locomotor strategies increased dramatically on learning criterion trials and displays of negative affect were limited. Learning from falling is discussed in terms of the immediate and long-term effects of falling on prospective control of locomotion.

Prospective Control of Locomotion

Adaptive locomotion requires prospective control: detecting upcoming threats to balance, selecting appropriate locomotor strategies, and modifying them continuously. Walkers' own movements and the environmental layout provide perceptual information that serves as the basis for prospective control. Adult walkers are so exquisitely adept at avoiding obstacles that prospective control appears seamless and effortless. For example, adults lift their foot to step over a 2-cm obstacle with such fluidity that force plates and electromyography cannot detect changes in their walking patterns (Patla, Prentice, Robinson, & Neufeld, 1991). With only a few hundred milliseconds of warning, adults increase the height of their swinging foot to clear an 8-cm obstacle. When obstacles are too high to step over, adults veer at the precise location that would ensure the shortest detour (Fajen & Warren, 2003). In fact, merely knowing that there is a potential for falling is sufficient to elicit prospective modifications in adults' walking patterns. When alerted that test surfaces are coated with oil or soap, adults shorten their steps, slow down, walk more flat-footed, and hold their bodies stiffly upright (Cham & Redfern, 2002; You, Chou, Lin, & Su, 2001).

Albeit slower, clumsier, and more effortful than adults, infants can also control locomotion prospectively. After several weeks of crawling or walking experience, infants avoid falling down steep slopes, into wide gaps, off narrow bridges, and onto rippling waterbeds (e.g., Adolph, 1995, 1997, 2000; Berger & Adolph, 2003; Gibson et al., 1987). In the classic visual cliff paradigm, infants avoid falling even when the risk is only an illusion (e.g., Campos & Bertenthal, 1984; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978; Gibson & Walk, 1960; Rader, Bausano, & Richards, 1980; Richards & Rader, 1983). Despite the novelty of these situations, infants slow down as they approach the obstacles, peer over the edge, sway to and fro, touch the surface with their hands and feet, and test alternative locomotor strategies. Information gleaned from exploration leads to adaptive control of actions. Infants avoid falling by sliding over the edge on their stomachs, backing down feet first, detouring around the obstacle, appealing to the experimenter for help, or refusing to leave the starting platform altogether.

Role of Falling in Prospective Control

Several researchers have suggested that learning from falling is an impetus for prospective control of locomotion (Bertenthal & Campos, 1984; Campos, Bertenthal, & Kermoian, 1992; Campos et al., 1978). The aversive consequences of falling or experiencing disequilibrium from near-falls might instigate wariness or teach infants stimulus–response associations

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that could facilitate adaptive avoidance responses on subsequent encounters with an obstacle.

Certainly, walkers fall. Minor mishaps that cause infants to topple over and adults to lose their balance are surprisingly frequent. Adult walkers, for example, reported 3–45 instances ($M = 14.2$) of near-falls and falls over a month-long diary study, with an average of 1 loss of balance every 2 days (Joh, 2005). On average, 14-month-olds fall 0–12 times ($M = 3.8$) in only 16 min of free play and 0–14 times ($M = 4.1$) during a brief walk around a city block (Garciaguirre & Adolph, 2005). Retrospective parental reports and prospective diary data show that most crawling and walking infants do not experience a fall serious enough to warrant medical attention or a call to the pediatrician (Adolph, 2002). However, despite the rarity of serious falls, like automobile accidents and poisoning, falling is a leading cause of accidental injury and death in children under five (National Center for Injury Prevention and Control, 2003). Falling is the primary cause of playground injuries in older children (Phelan, Khoury, Kalkwarf, & Lanphear, 2001). For children born in 2001, the lifetime odds of dying from a fall-related cause is 1 in 246, a risk level equivalent to dying from an automobile accident (National Safety Council, 2001). In 2001, fall-related injuries resulted in 15,019 deaths in the United States (National Safety Council, 2001). In 1998, slips, trips, and falls resulted in 21% of emergency room visits (National Safety Council, 1998) and 64% of workplace injuries (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001).

Despite ample opportunities for learning from falling, researchers know little about walkers' ability to profit from such mishaps. The extant data suggest that adults may be fooled once by a tricky surface, but rarely twice. For example, on their first encounter with a set of steel rollers embedded in their path, adults walked straight onto the rollers and experienced a dramatic slip (Marigold & Patla, 2002). One-trial learning from an unexpected near-fall resulted in prospective control on subsequent trials. On their next encounter with the rollers, adults modified their walking patterns before stepping onto the rollers, even devising a "surfing strategy" in which they raised their arms to the sides to coast over the rollers. Modifications in step length, velocity, and body orientation were so perfectly coordinated with the offending surface that participants walked differently only on the roller section of the platform.

Infants' ability to learn from falling is an open question. On the one hand, common sense intuition suggests that infants could learn from falling. Loss of balance is specified multimodally. Infants can see their bodies teeter and sway in relation to the surroundings, feel the stretching and deformation of muscles and skin, feel the timing and the forces of their steps fall out of sync, and perceive their bodies at disequilibrium via the vestibular organ (Bertenthal, Rose, & Bai, 1997; Ledebt, Bril, & Breniere, 1998; Stoffregen, Schmuckler, & Gibson, 1987). Moreover, loss of balance may be jarring and frightening. Surely, infants could form simple associative links between the perceptual information for disequilibrium, the bodily consequences of falling, perceptual cues for properties of the ground surface, and nearby landmarks.

On the other hand, several studies suggest that falling is dissociated from prospective control of locomotion. There is no predictive relationship between parents' reports of infants' falling experiences at home and their avoidance behavior in laboratory tasks (Adolph, 1995, 1997, 2000; Scarr & Salapatek, 1970), suggesting a lack of long-term, cumulative learning from falling. In addition, infants in early stages of crawling and walking fall repeatedly in the laboratory—a lack of evidence for short-term learning from falling. For example, newly crawling 9-month-olds fell into risky gaps spanning a precipice on 61% of trials (Adolph, 2000). New crawlers and walkers fell down steep slopes on 68% and 65% of trials, respectively (Adolph, 1997). On consecutive trials at the same risky increment, infants fell a second time into gaps on 88% of repeated trials (Adolph, 2000) and down slopes on 80% of repeated trials (Adolph, 1995, 1997). Moreover, even experienced walkers may fall repeatedly on consecutive encounters with the same surface. Fifteen-month-old walking infants fell repeatedly into a small foam pit and nearly half of the infants fell into the foam pit on 10 consecutive trials (Adolph, Joh, & Friedman, 2002).

Unfortunately, previous laboratory studies with infants were designed to test how infants avoid falling and thus were not well designed to examine infants' ability to learn from falling. One problem is that infants did not have sufficient opportunities to learn from falling. In some cases, the number of trials or trial presentation order precluded conclusions about learning from falling. In the visual cliff and rippling waterbed studies, for example, infants received only one or two trials per condition (e.g., Campos & Bertenthal, 1984; Campos et al., 1978; Gibson et al., 1987; Gibson & Walk, 1960; Rader et al., 1980; Richards & Rader, 1983; Walk & Gibson, 1961). Despite dozens of trials in studies with slopes, gaps, and bridges, risk level varied widely from trial to trial (Adolph, 1995, 1997, 2000; Berger & Adolph, 2003; Berger, Adolph, & Lobo, in press). In other cases, infants' own expertise contributed to lack of opportunities to learn from falling. Many infants never fell in the laboratory tasks. After several weeks of crawling or walking experience, infants avoided falling over cliffs, slopes, gaps, and bridges (Adolph, 1995, 1997, 2000; Berger & Adolph, 2003). Apparently, visual depth cues were sufficient to elicit adaptive avoidance responses or alternative locomotor strategies (Adolph & Eppler, 1998; Adolph, Eppler, Marin, Weise, & Clearfield, 2000). Another problem is that previous studies eliminated the salient consequences of falling. After one trial on the visual cliff, infants learned that the surface was safe and slowly crawled over the safety glass on the next trial (Campos et al., 1978; Eppler, Satterwhite, Wendt, & Bruce, 1997). In the gaps, slopes, bridges, and foam pit studies, an experimenter caught infants after they lost their balance and began to fall (Adolph, 1995, 1997, 2000; Adolph et al., 2002; Berger & Adolph, 2003; Berger et al., in press). Thus, the apparent dissociation between falling and prospective control might be a methodological artifact.

This Study

We devised a novel paradigm to determine the role of falling in prospective control of locomotion. To avoid the methodological limitations of previous experiments, we constructed a wooden walkway interrupted by a large gap filled with soft foam blocks to create a deformable foam pit. The quality and location of the foam pit were marked by salient visual cues. In contrast to the flat surface and squared edges of the wooden platform, the foam blocks were bumpy with rounded edges. A colored, patterned cloth covered the foam pit to delineate its location on the walkway. A string of blinking holiday lights arched over the edge of the foam pit and the clutter of the laboratory provided additional landmarks. On the first foam pit trial, we examined whether sudden changes in the appearance of the ground induce caution or hesitation in walkers. The foam pit was soft enough to guarantee participants' safety while ensuring that they would fall if they attempted to traverse it upright; the large size of the foam pit freed the experimenter from catching children as they fell, increasing the salience of the falls. To promote learning, we presented participants with multiple, consecutive, foam pit test trials. To further draw children's attention to the presence of the foam pit, sets of foam pit trials were alternated with sets of baseline trials in which the walkway was continuously rigid and lined with a contrasting cover.

Our primary goal was to examine the relationship between falling and prospective control of locomotion in the short term. In particular, does falling on previous trials lead to avoidance on subsequent trials? And, if so, how? Might falling instigate a search for perceptual information that can serve as the basis for prospective control? What do walkers learn from falling? Do they learn to link the consequence of falling with the appearance of the ground cue or nearby landmarks? To address these questions, we counted the number of trials on which participants fell to determine the speed of learning and we coded their locomotor strategies to avoid falling. We analyzed changes in participants' hesitation, exploratory behaviors, and affect before and after they learned from falling.

Finally, we investigated age-related changes in learning from falling by comparing children at 6-month age intervals from 15 to 39 months of age. In previous work (Adolph, 1995; Adolph & Avolio, 2000; Berger & Adolph, 2003; Berger et al., in press), 14–16-month-old walkers avoided falling down steep slopes and off narrow bridges by executing a range of adaptive gait modifications (e.g., smaller, slower steps) and alternative locomotor strategies (e.g., crawling, backing, refusing traversal). Thus, in this experiment, we expected the youngest 15-month-olds to be equipped with a variety of adaptive responses in their repertoire if they could link the visual cues for the foam pit with the consequence of falling. In addition, we tested college-age adults as a comparison group on the assumption that, at least by adulthood, walkers would learn from falling. We expected that adults might avoid falling on the first trial based on the visual cues for the foam pit; failing that, we expected that adults would quickly learn from falling by demonstrating prospective control of locomotion after a single fall.

Method

Participants

Seventy-two children were tested within 1 week of their target age (18 infants at 15 and 21 months; 12 children at 27, 33, and 39 months). Groups were balanced for gender. All children were healthy and born at term. Children were White ($n = 52$), Hispanic ($n = 7$), African American ($n = 6$), Asian ($n = 5$), and Other/Unidentified ($n = 2$); their parents' mean SES score was 73.05 (Nakao & Treas, 1992). Children were recruited through commercially available mailing lists, flyers, and referrals, and received framed photos and diplomas as souvenirs of participation. Eight additional children were excluded from the final sample because of fussiness (3 at 15 months, 4 at 21 months, and 1 at 39 months) and 2 because of experimenter error.

Parents reported their children's locomotor histories in a structured interview at the start of the session, using calendars and baby books to augment their memories (Adolph, 2002). The average duration of walking experience (dating from parents' estimates of the day when their children walked approximately 10 ft independently) was 2.89 months for the 15-month-olds ($SD = 1.30$), 8.59 months for the 21-month-olds ($SD = 1.80$), 14.12 months for the 27-month-olds ($SD = 2.05$), 20.56 months for the 33-month-olds ($SD = 1.89$), and 26.74 months for the 39-month-olds ($SD = 1.60$). Based on close-ended probes, all mothers reported that their children had weekly experience standing or locomoting on various surfaces where the consequences of falling were similar to those in the current experiment (e.g., mattress, couch, pillow): range = 8–16 surfaces. Five children (1 from each age group) had experienced a serious fall that required medical attention.

Additionally, we tested 12 adults (6 women, 6 men; $M = 19.79$ years, $SD = 1.06$) in a comparison group. They were recruited from an introductory psychology course and participated for credit toward their course requirements. Adults were White ($n = 9$), Asian ($n = 2$), and Hispanic ($n = 1$). Only 2 adults had experienced a serious fall that required medical attention.

Walkway and Visual Cues

A large, adjustable wooden walkway (488 cm long × 97 cm wide × 58 cm high) was constructed for testing. A detachable section (122 cm long × 97 cm wide × 38 cm deep) near the center of the walkway could be removed and filled with three large soft foam blocks to create a deformable foam pit. All exposed wooden surfaces were lined with high-density protective foam padding (3.8 cm thick) to prevent possible injuries from falling. A blue vinyl cloth striped with horizontal blue ribbons was laid over the protective padding over the entire walkway during baseline trials and over the starting and landing platforms in the foam pit condition (Figure 1A). The wooden platforms looked flat and the foam pit appeared slightly bumpy. In addition, the exact dimensions of the foam pit were delineated with an arbitrary *ground cue:* a brown fabric covering (122 cm long × 102 cm wide) patterned with large white flowers draped over the top of the foam blocks. The ground covering was stretchy and yielded readily to infants' light body weight. Additionally, the individual foam blocks were stuffed into pillowcases made from the ground covering material so that if participants accidentally disrupted the ground covering as they walked into the foam pit, they would see only the pillowcases. Finally, a string of colored blinking lights arched over the right side of the walkway at the edge of the foam pit to serve as a *location cue*. The lights remained in view on all trials, but blinked on and off only during the foam pit test trials (Figure 1B).

Procedure

Participants were tested in a single session lasting approximately 60 min for children and 30 min for adults. During the consent process, the experimenter warned adults that the walkway's surface would vary on some trials. All participants began each trial in a standing position on the beginning of the starting platform. The experimenter told the adults to "start down the walkway" when the camera operator said "go." Trials began when children looked forward and the experimenter released them. Parents sat at the far end of the landing platform and encouraged their children to cross the walkway using verbal encouragement, toys, and dry cereal as incentives. Parents were instructed to use only positive encouragement (e.g., "Come, give Mommy a hug") and not to warn their children that they might fall (e.g., "Watch your step"), caution them (e.g., "Be careful"), or provide them with particular locomotor strategies for traversing the foam pit (e.g., "Sit down"). Trials lasted 30 s or until participants left the starting platform, whichever happened first. An experimenter followed alongside participants on every trial to ensure their safety, but allowed infants to fall face down into the foam pit to increase the salience of consequences. The foam pit area was not large enough to accommodate adults' falls; therefore an experimenter caught adults if they lost their balance or fell. Two camera views—a side view of the participants as they crossed the walkway and a front view of their faces—were mixed into a single frame along with a small view of an abacus keeping track of trial number.

All sessions began with 4 initial baseline trials to document participants' normal walking patterns and to teach infants the game of walking over the walkway. A pair of baseline trials followed the end of each set of foam pit trials to provide a contrast between the conditions. In addition, the baseline trials renewed infants' motivation to walk and tested whether changes in infants' and adults' performance

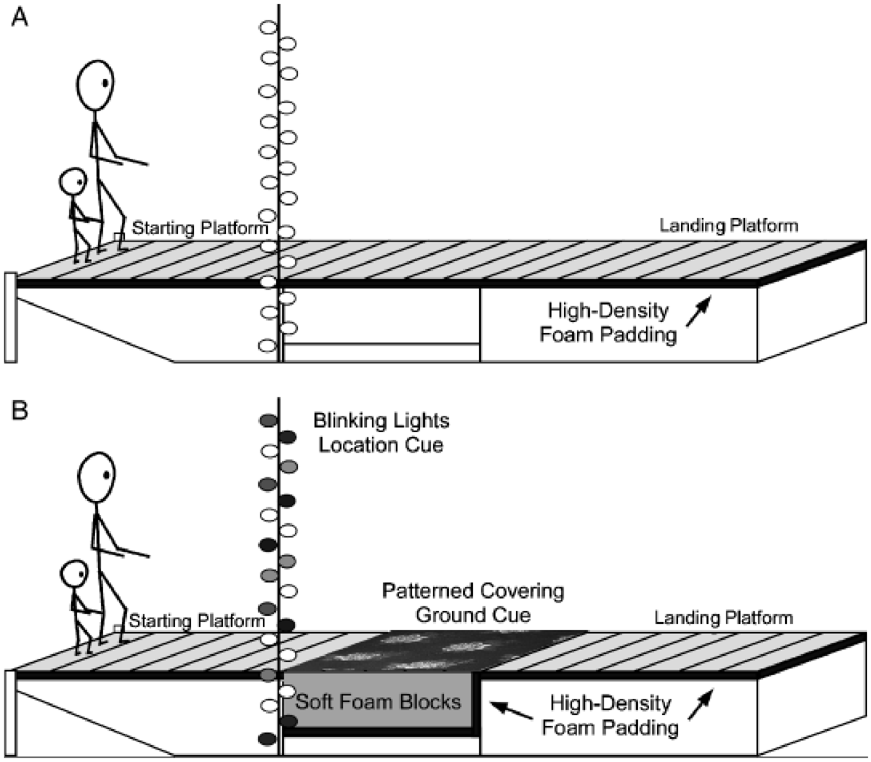

Figure 1. Configuration of walkway and foam pit. (A) The walkway remained continuously solid during baseline trials, (B) but was interrupted by a deformable foam pit in the test trials. The foam pit was always marked by the patterned ground covering and blinking colored lights landmark. The stick figures represent approximately scaled sizes of infant and adult participants.

were due to boredom or fatigue. Participants received foam pit trials in blocks of 4 alternating with 2 baseline trials. The foam pit and baseline trials continued until participants met the *learning criterion* (2 consecutive trials in which participants avoided falling into the foam pit) or a maximum of 16 foam pit trials had been presented. Participants took a short break between conditions while the walkway was reconfigured. During this time, children in the 15- and 21-month-old age groups remained in the room during condition changes and played with their parents and the experimenter (they appeared oblivious to the manipulations), and children in the older age groups played in an adjoining room during condition changes. Adults were told that the surface of the walkway was being changed and they were escorted to an adjoining waiting room until the start of the following condition.

Data Coding

A primary coder scored each trial from video as either a *fall* (participant walked onto the foam pit and fell) or a *no-fall* (participant used an alternative locomotor strategy or refused to embark onto the foam pit). Alternative methods of locomotion into the foam pit were *crawling* on hands and knees, *backing/sitting* and scooting in feet first, *diving* or cannonballing into the foam pit head first or with knees tucked, *lowering* themselves slowly on one foot while maintaining a vertical body orientation, stepping while *holding* onto the experimenter for support, and, in the case of adults, *leaping* over the foam pit (Figure 2). Participants were scored as *refusing* to embark onto the foam pit if they remained on the starting platform for the duration of the trial or detoured off the side or back of the starting platform.

To examine behavioral changes concomitant with locomotor learning, the primary coder also scored participants' exploratory and affective behaviors on the starting platform. *Latency* was the duration of time from the moment the experimenter released infants or adults' first step on the walkway to the time that participants stepped onto the foam pit area, detoured off the starting platform, or 30 s, whichever occurred first. Discrete *shifts* in locomotor position (e.g., shift from standing to crawling) reflected a search for alternative locomotor strategies. Haptic or proprioceptive exploration occurred if participants *touched* the foam pit area by pressing or patting it

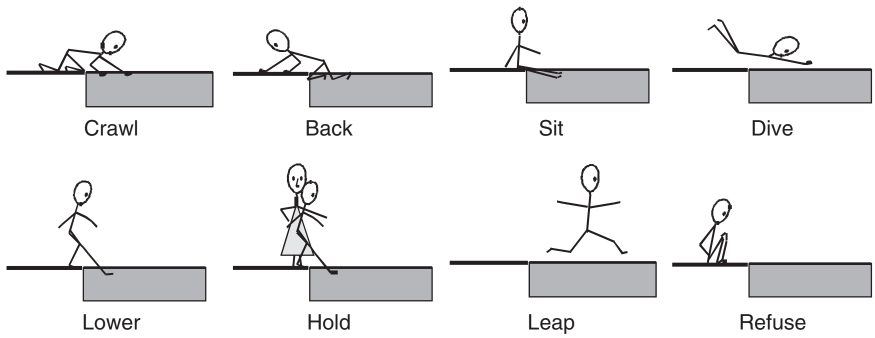

Figure 2. Alternative locomotor strategies for avoiding falling. Note, that backing and sitting are drawn separately here for clarity, but were coded as a single back/sit strategy.

with hands or feet, rocking at the brink over their ankles, or maintaining contact for at least 0.5 s without moving forward. *Negative affect* included downward curls of the mouth, frowns, and vocalizations such as whining or crying.

A second coder independently scored 25% of each participant's trials for reliability. For each group, coders' agreement ranged from 93% to 100% of trials for falling, alternative methods of locomotion, shifts, touches, and negative affect. Disagreements were resolved through discussion. For all groups, the correlation coefficient for latency was +1.00.

Results

Learning From Falling

Children

All children walked without incident over the platform on the initial and interspersed baseline trials. Thus, intentional alterations of their locomotor strategy on the foam pit trials would indicate that children had learned the consequence of falling into the foam pit. Despite the sudden introduction of the bumpy foam blocks, patterned floor covering, and blinking lights on the first test trial, every child walked straight onto the deformable surface and fell. Many children expressed their surprise at losing their balance by gasping, laughing, or calling out. A 5 (age group) $\times$ 2 (condition) mixed measures ANOVA comparing children's latency on the initial block of baseline trials and the first foam pit trial confirmed that latency was similar across age groups and hesitation did not increase on the first foam pit trial, ps $> .23$. (On the first foam pit trial, one 15-month-old stopped to touch and admire the blinking lights, but he resumed walking and fell into the foam pit like the rest of the children.)

Figure 3 shows the number of foam pit trials required by each child to meet the learning criterion and the average number of trials to criterion for each age group. As shown, most children fell into the foam pit repeatedly. Four 15-month-olds (22%) fell on all 16 foam pit trials. Only 11% of 15-month-olds, 17% of 21- and 27-month-olds, 25% of 33-month-olds, and 50% of 39-month-olds avoided falling after one trial. A logistic regression confirmed that the number of children who showed 1-trial learning increased with age, $\chi^2(1, N = 72) = 5.75$, $p < .02$.

Speed of learning was analyzed in two ways. Initially, we subjected data from all children to a one-way ANOVA and found that speed of learning was related to age, $F(4, 67) = 3.44$, $p = .01$. Tukey's honestly significant different (HSD) revealed that 15-month-olds learned more slowly (M trials to learning criterion $= 7.06$, $SD = 5.68$) than 21-month-olds ($M = 3.22$, $SD = 1.73$; $p = .03$) and 39-month-olds ($M = 2.75$, $SD = 2.09$; $p < .02$). Despite a lower number of trials required for learning, on average, speed of learning in 27- and 33-month-olds ($M = 3.67$, $SD = 2.71$ and $M = 4.83$, $SD = 4.39$, respectively) was not statistically different from the 15-month-olds.

However, as shown in Figure 3, the 15-month-olds' group average was inflated by the data from

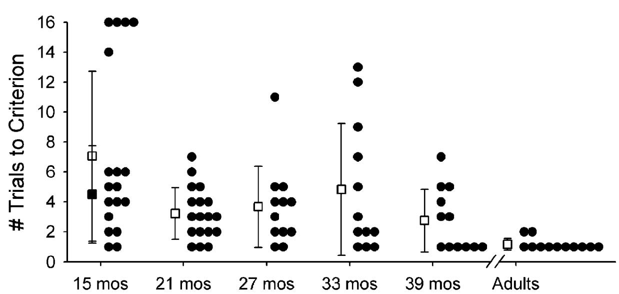

Figure 3. Individual and group data for number of trials to learning criterion (two consecutive no-fall trials). Each filled circle represents each participant. Open squares represent means for all participants in each age group. Filled square represents group means for the 15-month-old learners. Error bars denote mean standard deviations.

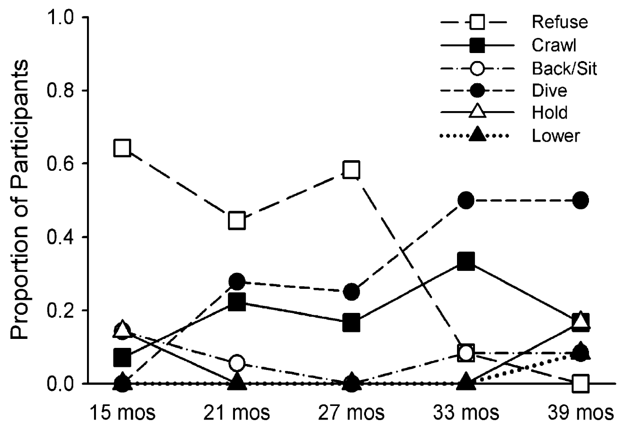

Figure 4. Children's locomotor strategies on their first learning criterion trial (first of two consecutive no-fall trials).

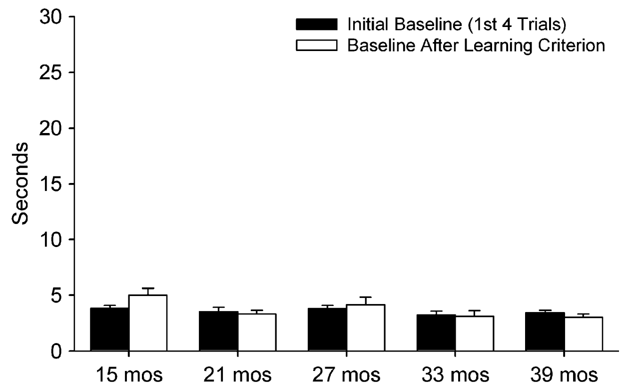

Figure 5. Comparison of children's latencies on the four initial baseline trials and the two baseline trials immediately following the learning criterion trials (the two consecutive no-fall trials).

the 4 infants who never learned from falling. Thus, to consider the possibility that the age trend was driven by the nonlearners' data, we performed a second one-way ANOVA on only the learners' data. With this analysis, we found that speed of learning was not related to age, $p = .33$. Instead, as shown by the filled square in Figure 3, the 15-month-olds resembled the older children with respect to speed of learning (M trials to learning criterion $= 4.50$, $SD = 3.25$). There were no detectable differences between the fourteen 15-month-old learners and the four nonlearners in terms of walking experience, exposure to surfaces varying in rigidity, gender, and experience with serious falls (ps $> .05$).

In addition, we analyzed the first learning criterion trial (the first of two consecutive no-fall trials) to determine whether children's use of alternative locomotor strategies varied with age. As shown in Figure 4, refusing to embark onto the foam pit decreased with age, $\chi^2(4, N = 68) = 18.57$, $p < .01$: Approximately 50% of 15- to 27-month-olds refused to embark onto the foam pit on the first learning criterion trial, whereas only 8% and 0% of 33- and 39-month-olds refused, respectively. In contrast, diving into the foam pit, $\chi^2(4, N = 68) = 10.87$, $p < .03$, increased with age: None of the 15-month-olds dove into the foam pit on their first no-fall trial, but nearly 30% of 21- and 27-month-olds and 50% of 33- and 39-month-olds did. Crawling, backing/sitting, holding onto the experimenter, and cautiously lowering the body into the foam pit did not vary with age.

Children's strategies for avoiding falling on the first learning criterion trial (refusing, crawling, backing/sitting, diving, holding onto the experimenter, and lowering) were not related to speed of learning, gender, previous falling experience, or exposure to various types of surfaces. Walking experience was related to 21-month-old infants' choice of locomotor strategy, $F(3, 14) = 3.67$, $p = .04$, but not for other age groups. Tukey's HSD showed that 21-month-olds who dove into the foam pit had more walking experience (M walking experience $= 10.45$ months, $SD = 1.24$) than infants who refused to embark onto it ($M = 7.87$ months, $SD = 1.85$; $p = .01$).

In general, no-fall trials appeared to be linked with visual cues for the foam pit rather than global wariness of the walkway or the task. Figure 5 shows that latency remained low on the baseline trials immediately following the learning criterion trials for all but the 15-month-old age groups. We compared children's latency on the initial block of 4 baseline trials with the 2 baseline trials immediately following the learning criterion foam pit trials to examine signs of global wariness prompted by falling. A 5 (age group) $\times$ 2 (pre- and postlearning criterion baselines) mixed measures ANOVA showed a main effect for age, $F(4, 63) = 2.94$, $p < .03$, and an interaction between condition and age, $F(4, 63) = 2.95$, $p < .03$. Follow-up ANOVAs showed age effects for the baseline trials following the learning criterion trials, $F(4, 63) = 3.93$, $p < .01$, but not for the initial set of baseline trials, $p = .70$. The interaction was caused by the 15-month-olds' longer latency on the baseline trials following the learning criterion trials ($M = 5.51$ s, $SD = 2.82$) compared with their latency on the 4 initial baseline trials ($M = 3.88$ s, $SD = 1.18$; $p = .02$).

Adults

Like the children, every adult in the comparison group walked straight into the foam pit and fell on their first foam pit trial. They conveyed surprise by shrieking or laughing. In fact, paired t-tests showed that adults' latency decreased on the first foam pit trial compared with the baseline trials, $t(11) = 2.97$,

Table 1
Exploratory and Affective Behaviors

	A. Latency (s)						B. Shifts (mean number)						C. Touching (proportion of trials)					D. Negative affect (proportion of trials)				
	B	*SD*	P	*SD*	LC	*SD*	B	*SD*	P	*SD*	LC	*SD*	B	P	*SD*	LC	*SD*	B	P	*SD*	LC	*SD*
15-month-olds	3.99	1.36	6.82	5.58	16.37	8.13	0.07	0.27	0.04	0.13	1.43	1.07	0	0.21	0.43	0.50	0.52	0	0.07	0.18	0.36	0.41
21-month-olds	3.33	1.26	4.80	2.16	14.85	12.40	0	0.06	0.17	0.97	1.12	0	0.06	0.25	0.24	0.44	0	0	0			
27-month-olds	3.94	1.36	7.07	6.60	19.60	11.70	0.04	0.14	0.25	0.50	1.21	1.25	0	0.33	0.49	0.58	0.51	0	0			
33-month-olds	3.23	0.97	4.21	2.01	8.04	8.57	0	0.13	0.31	0.75	1.06	0	0.08	0.29	0.42	0.51	0	0	0			
39-month-olds	3.63	1.31	4.45	1.72	6.39	5.04	0	0.08	0.29	0.29	0.50	0	0.08	0.29	0.42	0.51	0	0	0			
Adults	3.48	0.76	2.91	0.44	4.72	2.73	0	0	0	0	0	0.25	0.45	0	0	0						

Note. B = First 2 trials in the initial block of baseline condition, P = last two prelearning foam pit trials, LC = two learning criterion foam pit trials.

$p = .01$, as if participants had become more relaxed and confident about the task. On subsequent trials, most adults displayed 1-trial learning (*M* trials to learning criterion = 1.17, *SD* = .39): Eighty-three percent avoided falling on their second foam pit trial and the remaining 17% avoided falling on their third trial. On their first learning criterion trial, 67% of participants carefully lowered their bodies into the foam pit and 33% leapt over the entire foam pit area. As with the children, adults' latency remained consistently low across the initial block of baseline trials and the baseline trials immediately following their learning criterion trials, $p = .41$.

Exploratory and Affective Behaviors

Children

In the next set of analyses, we examined how learning from falling might be linked with prospective control of locomotion on subsequent trials. One possibility is that falling might elicit a search for information on the next foam pit trial, evidenced by increased exploration on prelearning criterion trials. A second possibility is a temporal lag between falling on prelearning trials and exploration on learning criterion trials, as if exploratory behaviors await children's full-blown realization that the foam pit cannot support normal walking. A third possibility, of course, is that children might simply link the visual cues for the foam pit with the consequence of falling without recourse to additional information-gathering behaviors.

To determine the link between learning from falling and exploration, we compared changes in children's latency, position shifts, and exploratory touching in the last two prelearning trials (the last 2 foam pit trials children received before meeting the learning criterion) and learning criterion trials (the two consecutive foam pit trials on which children avoided falling). We also examined whether negative affect might be associated with prelearning and learning criterion trials. The first two trials from the initial block of baseline trials served as a comparison for children's exploratory behaviors and affect in a context in which they never fell. Table 1 and Figure 6 show group means for exploratory behaviors and negative affect in the prelearning and learning criterion trials and in the comparison set of initial baseline trials.

The four 15-month-old infants who failed to meet the learning criterion were excluded from these analyses. Separate analyses with the nonlearners showed that all four of these infants walked straight down the starting platform without hesitating, shifting, touching, or displaying negative affect on trial after trial in the foam pit condition.

Latency. A 5 (age groups) × 3 (initial baseline, prelearning foam pit, and learning criterion foam pit conditions) ANOVA showed significant main effects for condition, $F(2, 124) = 47.47$, $p < .01$, and age group, $F(4, 62) = 4.68$, $p < .01$, and a condition × age interaction, $F(8, 124) = 3.04$, $p < .01$. Across ages, post hoc comparisons (adjusted $\alpha = .05/3$ tests = .017) for the condition effect indicated that falling increased wariness slightly on the two prelearning foam pit trials ($M = 5.45$ s, $SD = 4.12$) compared with the baseline trials ($M = 3.61$ s, $SD = 1.27$; $p < .01$), but that sharp increases in latency were linked with learning to avoid falling: Latency was considerably higher on the learning criterion trials ($M = 13.28$ s, $SD = 10.64$) compared with the prelearning trials ($p < .01$; see Figure 6A and Table 1, column A).

To determine the cause of the condition × age interaction, we analyzed the data for each condition via separate one-way ANOVAs. We found no age-related differences in latency during the initial baseline and prelearning foam pit trials, $ps > .23$. However, the ANOVA for the learning criterion trials revealed age-related differences in latency, $F(4, 62) = 4.07$, $p < .01$. Tukey's HSD showed that latency was higher in the 27-month-olds compared with the 33-month-olds ($p = .04$) and the 39-month-olds ($p = .01$).

Position shifts. Because only two children displayed position shifts during the two initial baseline trials (most cell means are 0 in Table 1, column B, see also Figure 6B), we compared the age groups only in the prelearning and learning criterion conditions. A 5 (age groups) × 2 (prelearning and learning criterion conditions) ANOVA showed a main effect for condition, $F(1, 61) = 44.68$, $p < .01$, and an age × condition interaction, $F(4, 61) = 2.50$, $p = .05$. Across ages, children displayed more position shifts on the learning criterion trials ($M = .95$, $SD = 1.08$) than on the prelearning trials ($M = .10$, $SD = .30$). However, falling did instigate a small increase in position shifts on the prelearning criterion trials relative to baseline. A one-sample t test showed that children's shifts during prelearning trials differed from 0, $t(66) = 3.45$, $p < .01$. Separate one-way ANOVAs for each condition showed that the condition × age interaction was caused by a trend for age in the learning criterion trials only, $F(4, 62) = 2.23$, $p = .08$. Tukey's HSD showed that the 15-month-olds shifted more on the learning criterion trials than the 39-month-olds ($p = .06$).

Touching. None of the children touched the foam pit area of the walkway on the two initial baseline trials. Thus, we tested children's frequency of touching with a 5 (age groups) × 2 (prelearning and learning criterion conditions) ANOVA, which yielded a main effect for condition only, $F(1, 61) = 15.39$, $p < .01$. Children touched the foam pit area more frequently on the learning criterion trials (M proportion of trials = .42, $SD = .50$) compared with the prelearning trials ($M = .15$, $SD = .36$; see Figure 6C and Table 1, column C). Further testing revealed a small increase in touching on prelearning foam pit trials compared with baseline. A one-sample t test showed that touching on prelearning criterion trials differed from 0, $t(65) = 3.41$, $p < .01$.

Negative affect. In general, children were positive throughout the entire session (Figure 6D; Table 1, column D). All cases of negative affect stemmed from the 15-month-olds, who fussed or cried on 7% of prelearning and 36% of learning criterion foam pit trials.

To summarize, falling elicited a small increase in information-gathering behaviors on subsequent prelearning criterion trials, but a large increase in exploration accompanied the learning criterion trials. Learning and exploration were not associated with negative affect in the 21- to 39-month-old children. Nearly all findings stayed the same when we analyzed children's exploratory and affective behaviors with all four trials in the initial block of baseline condition, all of children's prelearning foam pit trials (the number varied depending on children's learning speed), and the two learning criteri-

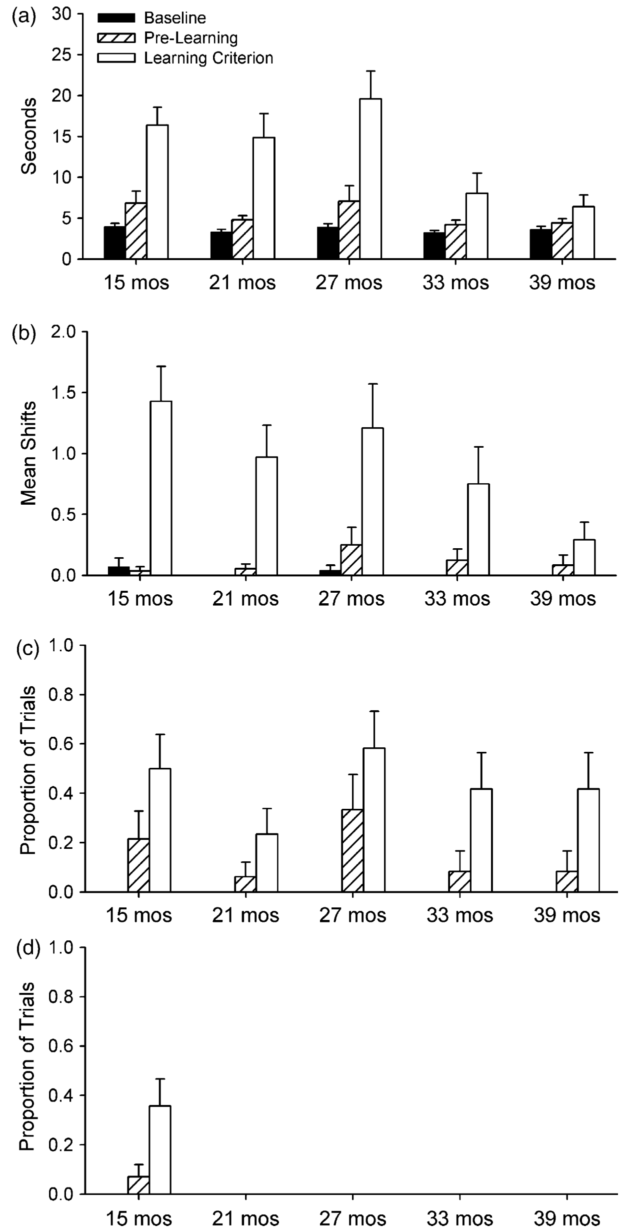

Figure 6. (A) Latency, (B) position shifts, (C) touching, (D) and negative affect on children's first two initial baseline trials, last two prelearning foam pit trials, and two learning criterion foam pit trials. The four 15-month-olds who did not meet the learning criterion were excluded from these graphs.

on trials in the analyses. The only exception was position shifts, in which the condition × age interaction became a trend instead of remaining statistically significant.

Adults

As a point of comparison to the children's behavior, we examined adults' exploratory and affective behaviors (Table 1). In contrast to the children, in adults, falling on the previous trial was linked with prospective control on subsequent trials without recourse to additional information-gathering behaviors. Rather, after falling, adults walked straight to the foam pit and gingerly lowered themselves or leaped over it. An ANOVA across the two initial baseline trials, the last two prelearning foam pit trials, and the two learning criterion trials revealed a significant condition effect for adults' latency, $F(2, 22) = 4.63$, $p = .02$. Post hoc comparisons (adjusted $\alpha = .017$) showed that the effect was due to a *decrease* in latency between the initial baseline and the prelearning trials ($p = .01$), as if the adults were initially hesitant about the task but gained confidence over the baseline trials. Using the adjusted alpha level, we found no difference in latency between adults' learning criterion and prelearning foam pit trials and baseline trials (ps $> .03$). Although several adults explored the foam pit by tapping it with their feet on the learning criterion trials, the incidence of exploratory touching was low and did not differ from the baseline and prelearning foam pit trials (ps $= .08$). Adults never shifted from their upright position and never displayed negative affect.

Discussion

Infants and adults fall frequently in everyday walking (Garciaguirre & Adolph, 2005; Joh, 2005). Despite previous suggestions that the cumulative effects of falling might contribute to the development of prospective control of locomotion (Bertenthal & Campos, 1984; Campos et al., 1978, 1992), procedural limitations in previous works preclude clear conclusions about infants' ability to learn from falling. Therefore, we created a foam pit paradigm specifically designed to test the developmental relationship between falling and prospective control of locomotion.

Why Did Participants Fall?

One revealing finding was that every participant walked straight into the foam pit on the first test trial without hesitation or prior exploration and fell. Why were they initially fooled? The foam pit looked different from the rest of the walkway: It was bumpy with rounded edges whereas the wood surface was smooth with sharp edges. Moreover, the location was marked with a visually distinct ground covering and was spatially adjacent to an unusual landmark. Trials began only after participants looked at the foam pit. In addition, a number of hints could have increased wariness. At the start of the session, adults read a consent form with a detailed description of the foam pit. After the initial set of baseline trials, the experimenter mentioned that the surface of the walkway was going to be changed and escorted adults and older children out of the laboratory. On all trials, an experimenter walked alongside adults holding onto their elbows for safety. Infants had additional hints: They remained in the room while assistants stuffed large foam blocks into the middle of the walkway for the foam pit trials.

Why, then, did participants ignore the abundance of potentially alerting visual and contextual cues on their first trial? Possibly, falling was inevitable because we presented participants with a novel change in rigidity. Rigidity, like friction, is a resistive force that is created when two surfaces (e.g., foot and the foam blocks) come into contact with each other. Despite adults' common-sense intuition that rigidity is the property of a single surface—people often talk of hard chairs, soft mattresses, and the like—rigidity only emerges as an interaction of two surfaces. The manner in which the surfaces come together (e.g., speed and angle of contact) determine how much resistive force is created. Thus, like emergent frictional forces, there are no reliable visual cues for novel changes in rigidity (Joh, Adolph, Campbell, & Eppler, in press; Joh, Narayanan, & Adolph, 2005). Hard surfaces may be bumpy or smooth with square edges or rounded ones. Similarly, slippery surfaces may be shiny or matte, black, white, or colored. Gloss, for example, is not a reliable cue for slippery surfaces (Joh et al., in press); adults' shine and slip judgments vary with surface color and viewing distance. Without a strong predictive relationship between superficial ground changes and falling, walkers may learn to ignore novel changes in the bumpiness, color, pattern, and texture of the ground until proven otherwise.

Why Did Children Fall Repeatedly?

A second important finding was age-related changes in learning from falling. After the initial fall, adults showed immediate prospective control of locomotion on subsequent trials, demonstrating that a quick association between visual cues and the consequences for falling is possible. However, children fell repeatedly despite our attempts to promote learning via contrast trials, unimpeded falls, and so on. Four of the 15-month-olds never showed evidence of learning. The other 15-month-olds averaged four to five trials to learn and only 11% showed adult-like, 1-trial learning. Although older children averaged three to four trials to learn and all eventually met the learning criterion, even by 39 months of age, only half of the children showed one-trial learning.

Why did children require several falls before showing evidence of prospective control? Several possibilities can be eliminated. First, the problem was not a general inability to avoid falling on risky surfaces or a lack of alternative locomotor strategies. Even before the ages that we tested, infants avoided falling in other tasks. Nine-month-old sitters avoided falling at the edge of a real cliff (Adolph, 2000) and 12-month-old walkers avoided an apparent drop-off on the visual cliff (Witherington, Campos, Anderson, Lejeune, & Seah, 2005). Thirteen-month-old walkers used a variety of strategies—sitting, backing, and holding a banister—to descend steep stairs (Berger, 2004). Fourteen-month-old walkers in several studies found alternative strategies for descending risky slopes and scaled their attempts to walk to the degree of risk (Adolph, 1995, 1997; Adolph & Avolio, 2000). In this study, infants demonstrated various alternative locomotor strategies appropriate to their age and motor abilities. Even the youngest 15-month-old infants used several alternative locomotor strategies to avoid falling after they finally met the learning criterion, such as refusing, crawling, and sitting. Older children were less likely to refuse and showed innovative strategies, such as running down the starting platform and diving into the foam pit. A few of the oldest children even showed the adult-like strategy of carefully stepping into the foam pit while maintaining balance—presumably, a strategy that was unavailable to the youngest infants because it requires a high degree of balance control.

Second, the possibility that children enjoyed bouncing in the foam pit cannot explain their slower learning speed. We took this possibility into account by coding deliberate plunges into the foam pit as alternative strategies. Indeed, many of the older children took dives into the foam pit and we scored these behaviors as evidence of learning. In contrast, the younger infants appeared to dislike the feeling of disequilibrium. Negative affect increased on the no-fall trials and the most common strategy was to refuse to embark onto the foam pit altogether. There were no differences in instances of negative affect between the 15-month-old learners and nonlearners.

Third, repeated falls were not due to a lack of perceptual information about the foam pit. Children hesitated, shifted positions, and touched the foam pit more often on the prelearning foam pit trials than on the baseline trials. They could feel that the foam pit was deformable but still they fell. Such a discrepancy in information-gathering behavior and prospective control of locomotion can be seen at all stages of development. Newly crawling infants, for example, touch steep slopes but fall over the brink nonetheless (Adolph, 1997). Novice crawlers and cruisers extend and retract their limbs over a gap in the surface of support and then step over the precipice (Adolph, 2000; Adolph & Leo, 2005). The availability of perceptual information is only a necessary, not a sufficient, condition for adaptive responding.

Finally, infants did not fall repeatedly because they could not learn locations. Twelve-month-old crawlers and walkers can locate a toy hidden under a particular cushion in just one try (Bushnell, McKenzie, Lawrence, & Connell, 1995). Even 5-month-old infants can visually discriminate hiding places of objects (Newcombe, Huttenlocher, & Learmonth, 1999).

Perhaps everyday locomotor experience teaches infants that superficial changes in the color, pattern, and texture of the ground are not relevant for balance control. Diary data, for example, show that infants travel through most of the rooms in their homes each day (Adolph, 2002). They sit, stand, crawl, or walk on most of the floor coverings, furniture, and counter/table-top surfaces in each room, encountering some 5–12 different surfaces per day. Presumably, older children and adults are also exposed to a wide variety of surfaces during their daily activities. Most of these vary in color, pattern, and visible texture, but are sufficiently rigid for safe locomotion.

Moreover, according to Garciaguirre and Adolph (2005), over 90% of infants' everyday falls are self-induced rather than precipitated by variations in the ground surface. Infants fall because of poor control over their standing and walking movements. As a consequence, they may not have realized the value in associating visual ground cues with falling. Similarly, older children may have fallen repeatedly because they too experience multiple falls each day. (Current data can only speak to the number and type of falls experienced by 14-month-old walking infants and college-aged adults [Garciaguirre & Adolph, 2005; Joh, 2005].) If, indeed, most falls are caused by variability in infants' motor system, then children may not learn from falling because most of the time there is nothing to learn. After months and years of everyday locomotor experience, walking skill improves and falls may become limited to slips, trips, and mishaps induced by variations in the ground. Thus, cue–consequence association learning may accumulate and more children may begin to show adult-like one-trial learning because of the long-term effects of learning.

What Do Walkers Learn From Falling?

Albeit slow, most 15-month-olds eventually showed prospective control at the edge of the foam pit. As in previous studies of infant locomotion, parental reports of infants' experiences with serious falls were not related to infants' ability to avoid falling on the first trial or on subsequent trials. Together, then, our findings provide support for short-term—not long-term—learning from falling.

What did participants learn from falling? Changes in latency, shifts, and touching suggest that falling increased children's wariness of the foam pit: Compared with the baseline trials, behaviors increased slightly but significantly on prelearning criterion trials. However, a sharp increase in exploration on the learning criterion trials suggests that children eventually learned to link particular visual cues (e.g., the ground covering over the foam pit) with particular consequences (falling): Latency and postural shifts increased dramatically on the learning criterion trials, touching occurred only around the distinctly marked foam pit, and alternative locomotor strategies were exercised only on the learning criterion trials. The cue–consequence association, in turn, instigated prospective control of locomotion by prompting exploratory behaviors that provide information about the environment and by guiding the use of appropriate alternative locomotor strategies.

Compared with the younger children, the older 33- and 39-month-olds were more adult-like in that their latency and position shifts increased less dramatically on the learning criterion trials. Presumably, with development, children gain locomotor experience, their motor systems become less variable, they fall less frequently, and learning from falling accumulates over the long-term—perhaps these factors contributed to the age-related differences in children's behaviors.

By adulthood, participants showed quick, one-trial learning from falling and demonstrated prospective control on the second test trial. Adults' speedy learning suggests that learning from falling over the long term may involve acquiring general rules of thumb about the causes and cues for falling. For example, a recent study showed that adult walkers attribute falling to ground-related causes specified by visual cues that they initially ignore (Wall, Joh, Adolph, & Eppler, 2004). After falling into a foam pit marked with a patterned ground covering and a string of blinking lights, nearly all participants located the risky location based on the ground covering rather than the blinking lights or other room cues. When the ground covering was moved surreptitiously away from the foam pit, participants still pointed to it. When the ground covering was removed from the walkway altogether, participants conjured up imaginary ground cues, such as a small bump on the ground or a slight wrinkle in the covering. In postsession interviews, all participants reported that the ground cue was the most important predictor of the foam pit regardless of their experimental condition assignment. Even though other arbitrary and natural landmarks were available —and just as predictive as the ground covering —few relied on them. Similarly, participants named ground-related reasons such as "The tip of my foot caught in the carpet" and "I didn't see the small hole and stepped into it with my right ankle" as reasons for their everyday falls (Joh, 2005).

Thus, over the long term, locomotor experience may teach walkers that falling once is a good indicator that a similar mishap might reoccur in the future in a similar situation. Perhaps what develops with age and locomotor experience is the ability to search for a causal relationship between falling and predictive cues so that by adulthood a single fall can lead to immediate prospective control of locomotion.

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