Published in final edited form as:
Child Dev. 2013 January ; 84(1): 226–240. doi:10.1111/j.1467-8624.2012.01842.x.

Cliff or Step? Posture-Specific Learning at the Edge of a Drop-Off

Kari S. Kretch and **Karen E. Adolph**
New York University

Abstract

Infants require locomotor experience to behave adaptively at a drop-off. However, different experimental paradigms (visual cliff and actual gaps and slopes) have generated conflicting findings regarding what infants learn and the specificity of their learning. An actual, adjustable drop-off apparatus was used to investigate whether learning to distinguish a step from a cliff transfers from crawling to walking. Experienced 12-month-old crawlers (n=16) refused to crawl over risky drop-offs but novice 12-month-old walkers (n=17) stepped repeatedly over the edge. Experienced 18-month-old walkers (n=18) refused to walk over risky drop-offs, but descended using alternative methods. These findings suggest that infants do not acquire generalized responses like fear or wariness of heights. Rather, infants learn to perceive affordances for the experienced action.

Affordances for Locomotion

The development of independent locomotion reflects important advances in motor control. Improvements in balance, strength, and coordination facilitate crawling on hands and knees, walking upright, scooting in a sitting position, and the countless other ways that infants get from one place to another. Mobility also reflects crucial advances in perception (E. Gibson & Pick, 2000). Infants must decide which movements to do and how to execute them. To guide locomotion adaptively, infants must perceive possibilities for action, or what J. Gibson (1979) termed *affordances*.

An affordance is the fit between the characteristics of the environment and the capabilities of the animal that make a particular action possible (Adolph & Berger, 2006). J. Gibson's (1979) distinction between a step and a cliff provides a beautiful example of the reciprocal relation between animal and environment: A step is a drop-off that is small relative to the animal, and a cliff is a drop-off that is large relative to the animal. This means that at a specific height relative to each infant's capabilities and intended form of locomotion, a drop-off ceases to be a step and becomes a cliff. The transition point between step and cliff depends on the size, strength, and flexibility of the supporting limbs, coordination between the relevant body parts, and the ability to maintain balance during descent. For example, to walk down a step, infants must support themselves upright on one leg while they stretch the other leg down. To crawl down a step, infants must support their body weight with their arms until a knee or foot reaches the bottom. Scooting down in a sitting position or backing down feet first place other demands on infants' balance, strength, and coordination.

Corresponding author: kari.kretch@nyu.edu.

Portions of this work were presented at the 2009 meeting of the International Society for Developmental Psychobiology, Washington, D.C, and the 2010 International Conference on Infant Studies, Baltimore, MD.

As J. Gibson (1979) wrote, “A falling-off edge is dangerous, but a stepping-off edge is not” (p. 157). Therefore, the essential task for perception is to determine which edges are cliffs and which are steps, and the task for development is to learn to perceive this distinction. Developmental changes in motor skills make the task more challenging. Crawling and walking, for example, are accompanied by different relations between body and environment—differences in vantage point relative to the ground surface and upcoming obstacles; visual, haptic, and proprioceptive information that accompanies movements and the inputs generated by forces against the ground surface; parts of the body used for support and propulsion relative to the friction, rigidity, extent, and slant of the ground surface; and so on. In short, affordances for crawling and walking are different (E. Gibson et al., 1987).

A wealth of evidence suggests that adaptive responding at the edge of a drop-off requires a protracted period of locomotor experience (for reviews, see Adolph & Berger, 2006, 2010). However, different labs have used different experimental equipment and procedures, and subsequently generated conflicting findings regarding what infants learn and the specificity or generality of their learning. In particular, do infants use what they learned as crawlers to distinguish cliffs from steps after they begin walking? An affirmative answer would indicate that infants learn something quite general such as wariness of heights or that large drop-offs are dangerous. However, lack of transfer—that is, specificity of learning between crawling and walking—would suggest that infants learn to perceive affordance relations between self and environment.

The Visual Cliff

The best-known paradigm for studying infants’ behavior at the edge of a drop-off is the “visual cliff,” pioneered by E. Gibson and Walk (for review, see Adolph & Kretch, in press). As shown in Figure 1A, the apparatus is a glass platform divided by a narrow centerboard. The apparatus was originally designed to test visual depth discrimination; thus, the glass surface covering both sides was intended to control for nonvisual (tactile, auditory, etc.) cues (E. Gibson & Walk, 1960; Walk & E. Gibson, 1961). One side looks like a small step: A checkerboard surface lies flush against the underside of the safety glass. The other side looks like a cliff: The surface lies 102 cm beneath the glass, creating the visual illusion of a large drop-off. In the traditional *crossing* paradigm, infants begin on the centerboard. Caregivers encourage their infants to cross from one side of the apparatus and then the other.

Several lines of evidence suggest that locomotor experience is related to infants’ behavior on the visual cliff. Human infants (and altricial animals such as kittens) require several weeks of self-produced locomotor experience before they avoid the deep side of the visual cliff (Bertenthal, Campos, & Barrett, 1984; Held & Hein, 1963; Walk, 1966).

What do infants learn via self-produced locomotion? One well-known hypothesis, cited in many popular textbooks (Bee & Boyd, 2010; Berk, 2003; Bukatko & Daehler, 1998; Siegler, DeLoache, & Eisenberg, 2011), is that locomotor experience leads to “the emergence of fear on the visual cliff” (Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). The fear of heights hypothesis assumes (1) that infants learn that drop-offs of a given size are dangerous independent of their own action capabilities and (2) that adaptive responses are mediated by fear. Indeed, previous work found that avoidance does not depend on whether infants are crawling or walking: At 12 months of age, 65% of experienced crawlers avoided the deep side of the cliff, and 90% of novice walkers avoided, suggesting that crawlers may acquire a generalized wariness of heights that is maintained or even strengthened over the transition from crawling to walking (Witherington, Campos, Anderson, Lejeune, & Seah, 2005). Additional evidence that locomotor experience leads to wariness of heights comes from an alternative *placing* paradigm in which infants are slowly lowered onto the shallow and deep sides of the visual cliff while changes in heart rate are monitored. Crawling infants displayed increased heart rate—a standard index of fear—when lowered onto the deep side, but prelocomotor infants did not (Campos, Bertenthal, & Kermoian, 1992; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). However, the placing and crossing paradigms are at odds with each other: Infants show accelerated heart rate on the deep side within two weeks after crawling onset, but do not avoid the deep side until many weeks later. In fact, a recent study showed no relation between individual infants' heart rate accelerations and their avoidance responses when encouraged to crawl over the safety glass (Ueno, Uchiyama, Campos, Dahl, & Anderson, 2011). Infants' hearts pound while hovering over the cliff whether or not they crawl over the glass. Moreover, infants do not display fearful facial expressions in either the placing or crossing paradigms; their faces are neutral or positive (Campos et al., 1992; Saarni, Campos, Camras, & Witherington, 2006; Sorce, Emde, Campos, & Klinnert, 1985). Thus, the primary evidence that fear or wariness of heights mediates avoidance is the avoidance response itself. The argument is circular.

Although a classic paradigm, the visual cliff suffers from several methodological limitations that threaten the validity of the findings. The safety glass covering both sides is not ideal for studying multimodal exploration at the edge of a real drop-off. For infants who have not yet learned about transparent surfaces, the safety glass presents conflicting perceptual information: The drop-off looks risky, but feels safe, and is, in fact, perfectly safe for locomotion. For infants who have experience with transparent surfaces, the glass is perceived as a solid, traversable—albeit creepy—surface (Campos et al., 1978; Eppler, Satterwhite, Wendt, & Bruce, 1997, Titzer, 1995). Indeed, infants quickly figure out the trick and so can only be tested in one or two trials before avoidance attenuates. Thus, results must be reported in terms of the number of infants who avoid or cross rather than the proportion of avoidance or crossing trials per infant, a measure that would be more sensitive to subtle perceptual distinctions and to individual differences. Moreover, the safety glass may lead to underestimation of infants' errors. Infants sometimes step onto the glass or lean on the glass with hands or feet and then retreat, and are scored as avoiding the drop-off (Campos et al., 1978; Witherington et al., 2005), but without the glass, they would have fallen. Because the glass prevents infants from using a variety of otherwise viable descent strategies (e.g., backing feet first), infants usually cross headfirst on their hands and knees, and so researchers cannot examine infants' selection of action as further evidence of their perception. In addition to the problems posed by the glass, the dimensions of the visual cliff are fixed, precluding researchers from testing the accuracy of infants' responses across a range of drop-off heights.

Veritable Slopes and Gaps

An alternative to a visual cliff is a real obstacle with a real falling-off place (for reviews, see Adolph & Berger, 2006, 2010). In lieu of the safety glass, an experimenter follows alongside infants and catches them if they begin to fall. With a real drop-off and a real penalty for errors, infants can be tested in dozens of trials and avoidance responses do not attenuate. An adjustable apparatus circumvents the problems associated with the fixed dimensions of the visual cliff. Using a psychophysical procedure allows researchers to determine actual affordances for locomotion, and to assess the accuracy of infants' perceptual judgments by comparing their responses on possible increments within their abilities and on impossible increments beyond their abilities. Without safety glass, researchers can observe infants' haptic exploration of the edge and alternative methods of descent.

Previous studies testing infants at the edge of real obstacles indicate that experienced crawlers and walkers guide locomotion adaptively, but experience crawling does not transfer to walking. For example, on an adjustable slope apparatus (Figure 1B), 12-month-old experienced crawlers accurately judged which slopes were safe for crawling, but age-matched novice walkers did not (Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008).

When tested longitudinally, infants' motor decisions became more accurate over weeks of crawling experience, but learning started all over again when they began to walk (Adolph, 1997). Experienced 18-month-old walkers precisely scaled walking attempts to the probability of success (Adolph, Karasik, & Tamis-LeMonda, 2010; Tamis-LeMonda, Adolph, Lobo, Karasik, & Dimitropoulou, 2008). In all cases, novice and experienced crawlers and walkers displayed primarily positive or neutral facial expressions and vocalizations—not negative ones—while plunging, avoiding, or selecting alternative strategies on risky increments, suggesting that they were not afraid (Adolph et al., 2010; Adolph et al., 2008; Tamis-LeMonda et al., 2008).

More generally, in experiments with real obstacles, previous work showed that experience in an earlier developing posture does not transfer to a later developing posture. When tested at the edge of a 76-cm deep gap with adjustable horizontal dimensions (Figure 1C), 9-month-olds precisely gauged their ability to span the gap in an experienced sitting posture, but erred repeatedly—even at the largest 90-cm gap—when tested in a novice crawling posture (Adolph, 2000). Similarly, novice 11-month-old walking infants stepped straight into the same impossibly wide gaps (Adolph, Berger, & Leo, 2011).

Evidence from the slopes and gaps paradigms suggests that locomotor experience teaches infants to detect information about the current affordance relations between body and environment, not a generalized wariness of heights or general rules about risks of falling. Like adults wearing platform shoes (Mark, Balliet, Craver, Douglas, & Fox, 1990), backpacks (Regia-Corte & Wagman, 2008), or "pregnancy packs" (Franchak & Adolph, 2011), experienced infants instantly recalibrate to altered affordances induced by lead-weighted shoulder packs (Adolph & Avolio, 2000) or Teflon-soled shoes (Adolph et al., 2010), indicating that affordances are detected online, not memorized. Infants gather perceptual information about the current affordances through active exploration. They peer over the edge of the precipice, stretch their arm over the gap and then retract it, and feel the degree of slant by placing hands or feet at the brink of a slope (Adolph, 1997, 2000). With locomotor experience, exploratory actions become more efficient, and lead to more accurate motor decisions. Moreover, when a surface does not afford crawling or walking, experienced infants select alternative methods of locomotion (such as backing or sliding down slopes in a sitting position) rather than avoid the obstacle. This evidence suggests that infants' behavior on gaps and slopes is mediated by online perception of affordance relations, not a generalized response such as wariness of heights.

However, as Witherington et al. (2005) suggested, a sheer drop-off like a cliff may be a different story from gaps and slopes. The gap apparatus involved a drop-off between the two platforms, but infants could see a solid surface on the other side of the precipice and the height of the drop-off was constant. The slope apparatus involved an increasingly high drop-off as the degree of slant increased (Eppler, Adolph, & Weiner, 1996), but the slanting surface presented a continuous gradient rather than an abrupt visual and haptic discontinuity (Witherington et al., 2005). In other words, like the visual cliff, neither slopes nor gaps challenged infants with parametric variations in the height of a sheer drop-off.

Current Studies: Cliff or Step?

The current studies used a new, adjustable drop-off apparatus and the psychophysical procedure used in previous work to explore what infants learn through locomotor experience and to address discrepancies between findings from the visual cliff versus slopes and gaps. We tested experienced crawlers and walkers and novice walkers at the edge of a real drop-off. On some trials, the drop-off was small enough to afford locomotion (a step), and on other trials, the drop-off was impossibly high (a cliff). Rather than protecting infants with safety glass as on the visual cliff, an experimenter rescued them if they began to fall as on slopes and gaps (Adolph, 1997; 2000). Our primary question was whether infants perceive the difference between a step and a cliff and whether learning transfers from an earlier developing crawling posture to a later developing walking posture.

Experiment 1: Experienced Crawlers and Novice Walkers

To determine whether experience transfers from an earlier developing crawling posture to a later developing walking posture, we observed experienced crawlers and novice walkers—all 12 months of age as in Adolph et al. (2008) and Witherington et al. (2005)—on our adjustable drop-off apparatus. If infants acquire a generalized wariness of heights—and the discrepancies in earlier work were due to qualitative differences between abrupt drop-offs and slopes or gaps—then both groups of infants should behave adaptively, attempting to crawl or walk when the drop-off is possible (a step) and avoiding when it is impossible (a cliff). A related possibility is that newly walking infants do not perceive affordances as accurately as experienced crawlers, but that a generalized wariness of heights leads them to avoid the very largest cliffs. However, if infants learn to perceive affordances for particular actions—and the discrepancies were merely the result of methodological limitations of the visual cliff apparatus—then the crawlers should avoid drop-offs beyond their ability, but the walkers should not.

Method

Participants

Thirty-three healthy, full-term 12-month-olds (± 1 week) were recruited from mailing lists, referrals, and local hospitals. Most were white and middle-class. Families received souvenirs for participation. Data from 6 additional infants were excluded due to fussiness ($n = 3$), experimenter error ($n = 2$), or equipment failure ($n = 1$).

Sixteen infants (eight boys, eight girls) were crawlers and 17 (11 boys, 6 girls) were walkers. Caregivers reported infants' locomotor experience in the context of a structured interview, using baby books and calendars to augment their memories (as in Adolph et al., 2011). Crawlers averaged 4.20 months ($SD = 1.63$) of crawling experience (dating from the first day they crawled 10 feet continuously), and walkers averaged 1.20 months ($SD = 0.80$) of walking experience (dating from their first success at walking 10 feet continuously). Crawlers had more crawling experience than walkers had walking experience, but total locomotor experience was similar between groups (M crawling + walking = 4.80 months for walkers, $SD = 1.37$); $t(31) = -1.14$, $p = .27$. Two crawlers and 2 walkers had descended a flight of stairs on their own. Three crawlers and 8 walkers had experienced a serious fall from a drop-off.

Crawling experience in our sample was comparable to the 12-month-old crawlers in Witherington et al.'s (2005) and Adolph et al.'s (2008) studies. Walking experience was similar to the 12-month-old walkers in Adolph et al.'s (2008) study, but our novice walkers were more experienced than the novice walkers in Witherington et al.'s (2005) study in which infants with more than two weeks of walking experience were excluded.

Drop-off apparatus

The apparatus consisted of wooden starting (90 cm wide × 90 cm long) and landing platforms (120 cm wide × 120 cm long) placed side by side (Figure 1D). The starting platform stood at a fixed height of 120 cm. The landing platform rested on a 30-cm high hydraulic lift. By pushing a foot pedal to activate the hydraulic pump, an assistant adjusted the height of the landing platform up and down in 1-cm increments to create drop-offs varying from 0–90 cm. The largest drop-off was comparable to the deep side of the visual cliff (Walk & E. Gibson, 1961). Both platforms were lined with high-density foam for safety and covered with a black and white checkerboard pattern to increase the salience of depth information and to facilitate comparisons with findings on the visual cliff. An experimenter panned a video camera from the side of the apparatus and a stationary camera recorded the height of the drop-off from a ruler attached to the side of the fixed platform; both camera views were mixed onto a single video (30 fps).

Procedure

Sessions lasted approximately 60 min. At the start of each trial, the experimenter placed infants on the starting platform either on hands and knees (for crawlers) or standing upright (for walkers). Caregivers stood at the end of the landing platform and encouraged infants to descend using toys and dry cereal as incentives. An experimenter followed alongside infants to ensure their safety. Trials lasted 30 s or until infants attempted descent, whichever came first.

To ensure that infants were comfortable crawling or walking over the apparatus, they first received 4 warm-up trials with both platforms set at 120 cm to create a flat, continuous surface. We used the psychophysical staircase procedure developed in earlier work to estimate the transition point from step to cliff for each infant, that is, the largest drop-off infants could navigate in their typical crawling or walking posture (Adolph, 1995, 2000). Staircase protocols began with a tiny 1-cm baseline step. After successful trials (infant crawled or walked safely), the experimenter increased the size of the drop-off by 3 cm. After two consecutive trials on which infants failed (tried to crawl or walk but fell) or refused to descend in their typical crawling or walking posture (used alternative method of descent or avoided), the experimenter decreased the size of the drop-off by 2 cm. Baseline trials were presented after failures and refusals to keep infants motivated to continue. The procedure continued with the experimenter adjusting the apparatus up and down to create larger and smaller drop-offs until converging on an *affordance threshold* with a 67% criterion—the largest drop-off with at least 2 out of 3 successful trials and at least 2 out of 3 unsuccessful trials at the next 1-, 2-, and 3-cm drop-offs. There was no evidence that infants' perception of affordances improved over the series of staircase trials, and previous work using this procedure did not show evidence of within-session learning (Adolph 1995, 1997, 2000; Adolph & Avolio, 2000; Adolph et al., 2011).

To assess infants' ability to distinguish cliffs from steps, the experimenter presented additional probe trials at increasingly risky increments: two trials each at 6 cm and 9 cm larger than the affordance threshold and two trials at the largest, 90-cm high drop-off (the height of a visual cliff). One walking infant was not tested on the 90-cm cliff due to fussiness. The total number of trials per session ranged from 25 to 70 and did not differ between crawlers ($M = 43$ trials) and walkers ($M = 38$ trials). At the end of the session, the experimenter measured infants' recumbent height, weight on a pediatric scale, leg length from hip to ankle, and arm length from shoulder to fingertip. Due to fussiness, we could not obtain body measurements from 2 walkers and 4 crawlers.

Data coding

Video data from the sessions were coded using a computerized video coding system, OpenSHAPA (www.openshapa.org). A primary coder scored 100% of the data, and a second coder scored 25% of each infant's data to ensure inter-rater reliability. Percent agreement was 95%–99% for all categorical variables ($\kappa = .68$ to .98); the correlation coefficient for the latency duration was $r(418) = .99$.

The coders rescored each trial for success, failure, and refusal, and recalculated affordance thresholds. All but one threshold coded from video matched those calculated online. For refusal trials, the coders noted whether infants used alternative means of descent—*backing* (on their bellies feet first), *sitting* (on their bottoms), *crawling* (for walkers)—or simply *avoided* descent by remaining on the starting platform. Coders also scored two measures of exploration: *Latency* was the time to initiate descent (from the moment the experimenter released infants on the starting platform until the video frame when infants began to move over the brink). *Touching* included trials when infants paused with hands or feet at the edge of the drop-off (with fingers or toes curled over the edge), or reached their hand down toward the landing platform and then retracted it.

Results and Discussion

Affordance thresholds

Affordance thresholds varied widely among infants (range = 1–22 cm), confirming the necessity of individualizing risk levels (Figure 2A). Within groups, the data were evenly distributed over the range with the exception of one outlier in the walker group who navigated 19 cm successfully—nearly the length of his inseam—by lowering one leg flush with the riser and then slowly lowering his other leg. On average, thresholds were larger for crawlers ($M = 13.06$ cm, $SD = 5.69$) than walkers ($M = 5.94$ cm, $SD = 4.42$), $t(31) = 4.03$, $p < .01$, possibly because crawlers were more experienced and proficient with their method of locomotion and crawling capitalizes on torso length for descent. Similarly, in previous longitudinal work, infants displayed a decrement in affordance thresholds for descending slopes over the transition from crawling to walking (Adolph, 1997). With all 17 infants included in the analysis, walking experience was marginally related to walking thresholds, $r(15) = .44$, $p = .08$, but with the outlier removed, walking experience and thresholds were positively correlated, $r(14) = .65$, $p < .01$, attesting to the reliability of parental reports of experience. Crawling experience and body dimensions did not predict thresholds in either group.

Crawling and walking attempts and alternative methods

To compare infants' behavior at equivalent levels of risk, we divided trials into 5 relative risk levels based on drop-off height relative to affordance thresholds—drop-offs that were 2, 3, and 4 cm smaller than threshold (denoted by the midpoint *−3 cm*), the threshold drop-off and surrounding increments 1 cm smaller and larger than threshold (*0 cm*), drop-offs that were 2, 3, and 4 cm larger than threshold (*+3 cm*), drop-offs that were 5, 6, and 7 cm larger than threshold (*+6 cm*), and drop-offs that were 8, 9, and 10 cm larger than threshold (*+9 cm*). We also compared infants' behavior at the baseline 1-cm drop-off and the largest 90-cm drop-off, the two increments that approximated the shallow and deep sides of the visual cliff. We calculated attempt rates for each risk level based on the number of successes and failures divided by the total number of trials (successes, failures, and refusals).

Crawlers perceived affordances for descent but walkers did not (Figure 3A). Attempt rates for crawlers closely tracked the probability of success at each relative risk level, decreasing from $M = 89\%$ at the −3-cm drop-off to $M = 10\%$ at the +3-cm drop-off. In contrast, walkers walked over the brink of impossibly large drop-offs on repeated trials, and 6 walkers never refused to walk. Attempt rates were $M = 80\%$ at the +3-cm increment, 77% at +6 cm, and 75% at +9 cm. A 2 (postures: crawler vs. walker) × 5 (relative risk levels) mixed design ANOVA (with repeated measures on the second factor) confirmed main effects for locomotor posture, $F(1, 31) = 60.63$, $p < .01$, partial $\eta^2 = .66$, and risk level, $F(4, 124) = 45.10$, $p < .01$, partial $\eta^2 = .59$, and an interaction between the two factors, $F(4, 124) = 16.49$, $p < .01$, partial $\eta^2 = .35$. Sidak-corrected pairwise comparisons confirmed higher attempt rates for walkers at each of the 0 to +9 risk levels ($ps < .01$). We also found specificity between crawling and walking at the increments that approximated the shallow and deep sides of the visual cliff. Both crawlers and walkers attempted the 1-cm baseline increment on nearly every trial (Ms = 99% and 100%), but the 90-cm drop-off was a different story. None of the crawlers attempted to crawl over the 90-cm drop-off, but 10 of 16 walkers (63%) attempted to walk and the average attempt rate was 50%. A 2 (postures) × 2 (1 cm vs 90 cm) mixed design ANOVA confirmed the interaction between locomotor posture and drop-off size, $F(1, 30) = 18.70$, $p < .01$, partial $\eta^2 = .38$, and pairwise comparisons confirmed a higher attempt rate in walkers than crawlers only on the 90-cm drop-off ($p < .01$).

Our findings do not replicate Witherington et al.’s (2005) previous work on the visual cliff where 35% of experienced 12-month-old crawlers and 10% of novice 12-month-old walkers ventured over the safety glass on the deep side but are consistent Adolph et al.’s (1997; 2008) findings of specificity of learning in crawling and walking infants on slopes. The data suggest that discrepancies among previous studies are not explained by different levels of fear induced by an abrupt drop-off vs. a continuous slope but may be due to methodological limitations of the visual cliff apparatus. Even when we analyzed infants’ responses using the criteria employed by Witherington et al. (2005)—avoidance versus any crossing method—crawlers still showed higher rates of avoidance than walkers on risky increments (Figure 3B), with main effects for locomotor posture, $F(1, 31) = 7.92$, $p < .01$, partial $\eta^2 = .20$, and risk level, $F(4, 124) = 12.60$, $p < .01$, partial $\eta^2 = .29$, and an interaction between the two factors, $F(4, 124) = 4.92$, $p < .01$, partial $\eta^2 = .14$. The interaction was also significant on the extreme increments (1 cm vs. 90 cm), $F(1, 30) = 9.09$, $p < .01$, partial $\eta^2 = .23$, and pairwise comparisons confirmed higher rates of avoidance in crawlers than walkers on the 90-cm drop-off ($p < .01$). In fact, no infant avoided the 1-cm step. Eleven crawlers but only 5 walkers always avoided the 90-cm cliff, χ^2 $(1, N = 32) = 4.50$, $p = .03$.

Figure 4A shows that on trials scored as refusals, infants avoided descent on a majority of trials ($M = 54\%$ for crawlers, $SD = 42$, and $M = 68\%$ for walkers, $SD = 45$) and used alternative descent strategies on the remainder. Crawlers and walkers did not differ significantly in their rate of avoidance on refusal trials, $t(25) = .80$, $p = .43$, indicating that alternative methods were available in walkers’ repertoires and that walkers could inhibit forward locomotion by avoiding descent. The problem for walkers is that they rarely refused to walk.

Posture-specific experience predicted attempts to walk on risky cliffs. As shown by the open circles in Figure 5, walkers’ error rates (averaged over all cliffs larger than affordance threshold) were negatively correlated with walking experience, $r(15) = -.63$, $p < .01$, but were unrelated to crawling experience or total locomotor experience, suggesting that learning resulted only from posture-specific experience. Crawling experience (open triangles in Figure 5) did not predict error rates for crawlers, likely due to a floor effect (crawlers rarely attempted risky cliffs). However, the sole crawler whose error rate exceeded 20% (54%) also had the least crawling experience (40 days). Stair experience and previous falls did not predict error rates or any other outcome measure.

Exploration

Both crawlers and walkers spontaneously explored risky drop-offs by hesitating, looking, and touching. Overall, crawlers hesitated (latency > 0) before descent on 40% ($SD = 16$) of trials and walkers hesitated on 33% ($SD = 20$), $t(31) = 1.08$, $p = .29$. During the time that they hesitated, infants peered over the edge, touched the brink, called to their caregivers, or engaged in displacement activities such as playing with their clothes or looking at the ceiling lights. As shown in Figure 6A, latency increased on risky drop-offs, but more steeply for crawlers; this effect was explained by higher rates of avoidance at risky increments. A 2 (postures) × 5 (risk levels) mixed design ANOVA confirmed main effects of posture, $F(1, 31) = 8.11$, $p = .01$, partial $\eta^2 = .21$, risk level, $F(4, 124) = 19.05$, $p < .01$, partial $\eta^2 = .38$, and an interaction between the two factors, $F(1, 124) = 4.73$, $p < .01$, partial $\eta^2 = .13$. Post-hoc comparisons revealed differences between crawlers and walkers at the 0- to +6-cm increments (ps < .03). There was also a significant interaction on the extreme increments, $F(1, 30) = 9.99$, $p < .01$, partial $\eta^2 = .25$; pairwise comparisons confirmed that crawlers hesitated longer than walkers only at the 90-cm increment, $p = .01$.

Crawlers touched the brink or reached into the precipice more frequently than walkers ($M = 24\%$ of trials, $SD = 15$ for crawlers, $M = 13\%$ of trials, $SD = 16$ for walkers), $t(31) = 2.169$, $p = .04$. Crawlers only touched with their hands, and walkers primarily touched with their feet. As shown in Figure 6B, touching increased on risky increments but showed different trends for crawlers than walkers. A 2 (postures) × 5 (risk levels) mixed design ANOVA revealed a marginal main effect of posture, $F(1, 31) = 3.60$, $p = .07$, partial $\eta^2 = .10$, a significant main effect of risk level, $F(4, 124) = 4.26$, $p < .01$, partial $\eta^2 = .12$, and a significant interaction, $F(4, 124) = 2.46$, $p = .05$, partial $\eta^2 = .07$. Post-hoc tests showed differences between crawlers and walkers only at the 0- and +3-cm increments (ps ≤ .05). Trend analyses confirmed more touching for crawlers at the middle risk levels with a significant quadratic effect for crawlers, $F(1, 15) = 10.01$, $p < .01$, partial $\eta^2 = .40$, but not for walkers, $F(1, 16) = 0.02$, $p = .88$, partial $\eta^2 < .01$. This result suggests that crawlers touched more on ambiguous increments, as if to test whether crawling were possible; indeed, most of the cases where crawlers reached their arm down into the precipice occurred at the 0- and +3-cm increments. At the extreme increments, there was a significant interaction, $F(1, 30) = 6.81$, $p = .01$, partial $\eta^2 = .185$. Pairwise comparisons confirmed that crawlers touched more ($M = 50\%$, $SD = 41$) than walkers ($M = 14\%$, $SD = 29$) at the 90-cm drop-off, $p < .01$. This suggests that crawlers wanted to descend, were not wary of approaching the drop-off, but could not find an alternative method to descend.

Experiment 2: Experienced Walkers

As a comparison with the experienced 12-month-old crawlers and novice walkers in Experiment 1, we observed a sample of older, larger, more experienced, and more skilled 18-month-old walkers. Based on previous work with 18-month-olds descending slopes, we expected them to respond adaptively at the edge of the drop-off. Presumably, given several months of walking experience, 18-month-old walkers should respond similarly to 12-month-old crawlers by scaling their attempts to their abilities.

Of special interest was infants’ behavior on refusal trials: If locomotor experience leads infants to acquire wariness of heights, then they should avoid descent of risky drop-offs, rather than descend using alternative methods. Consistent with previous studies of 11- and 12-month-old infants descending slopes (Adolph et al., 2008; Mondschein, Adolph, & Tamis-LeMonda, 2000), in Experiment 1, on most refusal trials, infants avoided descent rather than using an alternative descent method such as backing or scooting. However, in previous work with older 14- and 18-month-olds, infants used a variety of alternative methods to descend risky slopes, suggesting that infants perceived when slopes were too steep to afford walking, but they were not wary of the slopes. Similarly, we reasoned that if experience facilitates perception of affordances but does not cause infants to be wary of heights, then the 18-month-olds in Experiment 2 might use alternative means of descent—even at the most extreme increments.

In addition, we were interested in whether body dimensions would be related to affordance thresholds in this older group of more skilled infants. For new walkers in Experiment 1, the critical factor determining affordances was the ability to maintain upright balance; more experienced infants had larger affordance thresholds. However, once balance control improves, affordances may be predicted by body size. Indeed, for adults and older children, stair-climbing ability is scaled to leg length (Pufall & Dunbar, 1992; Warren, 1984). We obtained body measurements to examine the factors that determine affordances in 18-month-old experienced walkers.

Method

Eighteen 18-month-olds (±1 week; eight boys, ten girls) were recruited as in Experiment 1, and were mostly white and middle class. None had participated in Experiment 1. One infant completed the psychophysical procedure but became fussy during the probe trials; her data are included in figures and analyses of thresholds and refusal strategies. Data for exploratory behavior were unavailable for one infant because the video file was accidentally erased; we used on-line codes to determine her threshold, attempt rate, and descent methods. Data from 3 additional infants were excluded due to fussiness ($n = 1$) and experimenter error ($n = 2$). All infants were experienced walkers ($M = 5.21$ months walking experience, $SD = 1.71$) and had significantly more walking experience than the walkers in Experiment 1, $t(33) = -8.78$, $p < .01$. Eleven infants could descend a flight of stairs, and 2 had previously fallen from a drop-off.

Infants were tested using the same apparatus and psychophysical procedure as in Experiment 1. At the end of the session, the experimenter obtained body measurements and interviewed parents about infants' locomotor experience. Due to fussiness, we were unable to obtain measures of weight in 1 infant, height in 4 infants, and leg length in 6. Walking attempts, alternative methods of descent, latency, and exploratory touching were coded as in Experiment 1. All thresholds recoded from video matched those calculated online. Coders agreed on ≥ 95% of trials for attempts, descent methods, and touching ($\kappa \geq .79$); interrater reliability for latency was $r(658) = .99$.

Results and Discussion

Affordance Thresholds

Eighteen-month-olds showed a wide range of affordance thresholds, from 2 to 28 cm (Figure 2B), but on average, thresholds were larger ($M = 14.89$) than those of the 12-month-old walkers in Experiment 1, $t(33) = -4.21$, $p < .01$. Thresholds were not correlated with walking experience, $r(16) = .32$, $p = .20$. However, affordances were scaled to infants' bodies: Thresholds were positively correlated with leg length, $r(10) = .68$, $p = .01$, and marginally correlated with height, $r(12) = .50$, $p = .07$, but not related to weight, $r(15) = .16$, $p = .53$. The fact that leg length predicted thresholds in experienced but not novice walkers suggests that different factors determine possibilities for action at different points in development. At first, the ability to maintain balance may be the limiting factor in determining affordances for walking. However, for more skilled walkers, the size of the relevant body parts may become more important.

Walking attempts and alternative methods

Figure 3C shows that 18-month-olds perceived affordances for walking. Like the experienced crawlers in Experiment 1 and 18-month-olds in previous studies of infants descending slopes (Adolph et al., 2010; Tamis-LeMonda et al., 2008), experienced walkers scaled their attempts to the limits of their abilities; attempts decreased from $M = 83\%$ at the −3-cm increment to $M = 22\%$ at the +3-cm increment. A repeated-measures ANOVA on relative risk levels confirmed the effect of risk level, $F(4, 64) = 139.82$, $p < .01$. On the extreme increments, experienced walkers were also similar to experienced crawlers from

Experiment 1: They attempted to walk down the 1-cm step on most trials ($M = .99$), but none attempted to walk down the 90-cm cliff.

Walking experience did not predict error rates in the 18-month-olds because of a floor effect, as shown by the filled circles in Figure 5, $r(16) = -.21$, $p = .40$. However, pooling data across crawlers and walkers from both experiments revealed a strong effect of posture-specific experience, $r(49) = -.73$, $p < .01$. Regardless of age or posture, infants with less than 40 days of posture-specific experience misjudged affordances, infants with over 90 days of experience correctly judged affordances, and infants with intermediate durations of experience displayed intermediate error rates. Like the 12-month-olds in Experiment 1, stair experience and previous falls did not predict error rates or any other outcome measures.

As shown in Figure 3D, experienced walkers rarely avoided risky cliffs in the +3-cm to +9-cm range ($M = 2\%$), but avoided 59% of trials at the 90-cm drop-off. As shown in Figure 4B, instead of avoiding, infants used alternative methods: backing ($M = 37\%$ of refusals), scooting ($M = 45\%$), and crawling ($M = 5\%$). Every infant used alternative methods in the +3 to +9-cm range, and 8 backed down the 90-cm drop-off.

Although 18-month-old infants avoided the 90-cm drop-off on a majority of trials, it is illuminating to compare avoidance of the large cliff between novice walkers in Experiment 1 and experienced walkers in Experiment 2. Mean rates of avoidance of the 90-cm cliff were not significantly different between the two groups of walkers, $t(31) = 1.30$, $p = .20$, and the 53% of experienced walkers who always avoided is not significantly different from the 31% of novice walkers who always avoided, $\chi^2 (1, N = 33) = 1.59$, $p = .21$. In other words, 12-month-old novice walkers and 18-month-old experienced walkers both tried to descend the 90-cm cliff. The difference was that 12-month-olds attempted to walk and 18-month-olds backed down. This suggests that what 18-month-old infants gained through their months of walking experience was the ability to perceive affordances for walking, not wariness of heights.

Exploration

By 18 months, infants were so efficient at gathering perceptual information that brief glimpses at the ground ahead were sufficient to inform their decisions (Figure 6C–D). In general, both latency and touching were very low. Infants hesitated longer and touched the brink more around their affordance thresholds, where presumably decisions about whether to walk or use alternative methods were less clear. This pattern was confirmed by significant quadratic trends for both latency, $F(1, 15) = 7.084$, $p = .02$, partial $\eta^2 = .321$, and touching, $F(1, 15) = 11.31$, $p = .01$, partial $\eta^2 = .34$. Latency was higher on the 90-cm cliff than the 1-cm step, $t(15) = 5.59$, $p < .01$ (likely reflecting higher rates of avoidance), but touching did not differ, $t(15) = 0.41$, $p = .69$.

General Discussion

Two experiments investigated infants' ability to distinguish a step from a cliff. Our findings with infants on a real adjustable drop-off differ from previous findings with infants on a visual cliff, but are consistent with previous work with infants on adjustable slopes and gaps: Experiment 1 revealed no evidence of transfer from experienced crawling to novice walking in 12-month-olds, and Experiment 2 confirmed adaptive responding in experienced 18-month-old walkers. These findings suggest that infants do not acquire a generalized wariness of heights or general rule about dangerous drop-offs; rather, crawling experience teaches infants to perceive affordances for crawling and walking experience teaches infants to perceive affordances for walking.

Learning Fear of Heights?

Traditionally, researchers invoke fear of heights as the mechanism underlying avoidance on the visual cliff (Bertenthal et al., 1984; Campos et al., 1978). Findings from the current study argue against the idea that locomotor experience teaches infants generalized knowledge about cliffs—that drop-offs of a particular height are dangerous irrespective of infants' abilities and body size. Our findings also cast doubt on the idea that fear mediates adaptive responding at the edge of an impossibly large drop-off. Fear is a slippery concept in the infant literature. Although we did not formally score infants' facial expressions or obtain physiological measures of fear, some researchers have argued that the only indication of fear on the visual cliff is refusal to crawl or walk over the brink because facial expressions and heart rate are not reliable indicators (Saarni et al., 2006). Infants who avoid crawling over the deep side "do not show prototypic fear expressions. Indeed, they often *smile*!" (Saarni et al., 2006, p. 231). Accelerated heart rate when being lowered toward the deep side of the visual cliff may be indicative of arousal, not fear, because the same infants with accelerated heart rate in the placing paradigm crawl over the glass in the crossing paradigm (Ueno et al., 2011). Thus, in the current study, we observed infants decisions to crawl or walk, and did not find evidence of fear: If infants learned through crawling experience to be afraid of heights, newly walking infants (with equivalent locomotor experience to "fearful" experienced crawlers) should not revert to fearlessness.

Exploratory and descent behaviors provide further evidence against wariness of heights. If infants were wary of heights, we would expect them to shy away from the edge of a 90-cm drop-off, but they did not. Experienced crawlers showed high rates of exploratory touching and reaching, lingering with their faces and hands over the brink. Likewise, experienced walkers did not shy away from the brink. When visual information indicated that a drop-off was too high to walk down, infants immediately shifted to another method of descent. They cheerfully crawled, scooted, or backed down every risky increment, even the 90-cm drop-off. The pattern of refusal trials coupled with exploratory touching and alternative descent methods indicate that experienced crawlers and walkers distinguished cliffs from steps, but were not afraid of either. That is, in the absence of fear or any other general response to drop-offs, they learned to perceive affordances.

By adulthood, many people are afraid of heights. In contrast to infants, some adults are deeply afraid to approach the edge of a drop-off, look over the railing on a balcony, climb a steep precipice, or walk over an open-mesh bridge. A question for future research is to determine how fear of heights develops and whether it builds on infants' earlier perceptual sensitivity to a large drop-off.

Learning to Perceive Affordances

What distinguishes a cliff from a step? As J. Gibson pointed out, affordances are inherently relational—a drop-off is a cliff or a step only relative to a particular animal performing a particular action. Accordingly, we found that affordances varied relative to infants' capabilities. Consistent with previous work (Pufall & Dunbar, 1992; Warren, 1984), one important predictor of affordance thresholds was the size of the relevant body parts. For experienced 18-month-old walkers, affordance thresholds were related to leg length.

However, affordances are more than simple geometric relations (Adolph & Berger, 2006; Konczak, Meeuwson, & Cress, 1992; Snapp-Childs & Bingham, 2009). Affordances also depend on animals' dynamic capabilities. In Experiment 1, affordance thresholds were predicted by walking experience, suggesting that coordination and upright balance control affect possibilities for walking. A related point is that affordances can only be considered relative to a specific action. Affordances for walking, crawling, backing, and so on are different. Just as a lake affords swimming but not walking (for most animals), a high drop-off may afford one action, but not another. For 12-month-olds, crawling and walking thresholds were different; for 18-month-olds, a cliff for walking was a step for backing or scooting.

Posture-specific locomotor experience was the only predictor of infants' ability to perceive affordances. Experience falling from a drop-off did not teach infants to avoid drop-offs. Experience descending stairs did not teach infants to recognize a step. Months of crawling experience did not teach newly walking infants to be wary of heights. Crawling experience taught infants to perceive affordances for crawling, and walking experience taught infants to perceive affordances for walking. Everyday locomotor experience consists of immense amounts of practice moving over varied terrain: 12-month-old walkers average 1456 steps and fall 32 times per hour; by 18 months, the number of steps has more than doubled and the number of falls has fallen by more than half (Adolph et al, 2011). More research is needed to identify what aspects of everyday locomotor experience contribute to learning to perceive affordances for locomotion.

Methodological Considerations

Why were our results so discrepant from those of Witherington et al. (2005)? Our 12-month-old walkers were more experienced than theirs and should have been more cautious. However, their novice walkers avoided the deep side of the visual cliff and our novice walkers plunged over the edge of a real drop-off. What's more, several of their experienced crawlers crossed the deep side, but all of ours refused to crawl over the 90-cm drop-off.

The visual cliff apparatus and coding system may be biased toward overestimating attempts to cross in crawlers and underestimating attempts in walkers. On the deep side of the visual cliff, 45% of the crawlers in Witherington et al.'s (2005) study touched the safety glass. Although the lack of a visible surface dissuaded most infants from crossing (think of standing on the glass floor at the top of Toronto's CN tower), haptic information specified a solid surface and 35% of infants decided to cross. On the real 90-cm cliff, infants felt empty space beneath their fingertips because visual and haptic information were in agreement and subsequently in the current study 100% refused to crawl.

In an upright position, infants typically explore the layout with their feet (Adolph & Berger, 2006), the same two feet they use for balance and locomotion. In both experiments reported here, walkers touched less frequently than crawlers (Figure 6B,D). In Witherington et al. (2005), however, touching did not differ between crawlers and walkers. On the visual cliff, walkers can shift their weight onto the foot touching the safety glass and the behavior would be scored as exploratory touching, rather than attempting to walk. But on an actual cliff with no safety glass, these infants would fall.

Eliminating the safety glass removed several methodological concerns with the visual cliff. However, could replacing the safety glass with a human "spotter" have led infants to behave rashly because they learned that the experimenter would catch them? If 12-month-old walkers attempted impossibly high drop-offs because they learned that they would be rescued, we would expect 12-month-old crawlers and even more cognitively advanced 18-month-old walkers to expect rescue as well. But they did not. Moreover, when tested longitudinally crawling and walking down slopes, infants become more cautious, not more reckless as would be expected if they were learning that they would be rescued (Adolph, 1997). When tested using within-subject designs, the same infants who made dozens of errors in a novice crawling posture—and experienced dozens of rescues by the experimenter—refused impossibly wide gaps when tested minutes later in an experienced sitting posture

(Adolph, 2000). Therefore, the spotting method seems to offer a significant improvement over the safety glass method for testing infants' perception of safe and risky ground.

Methodological and conceptual considerations are closely intertwined. How a question is asked affects the answers that are attained. The current experiments suggest that a real, adjustable drop-off and a psychophysical procedure to precisely measure affordances and normalize risk offer some improvements over the visual cliff with its fixed dimensions and safety glass.

Conclusions

The current studies suggest that, through weeks of locomotor experience, infants learn to perceive affordances for locomotion, and that this learning is specific to crawling and walking postures. Infants avoided a falling-off place as experienced crawlers but plunged right over the edge as novice walkers. These findings refute widely-held theories that infants' behavior at a drop-off is motivated by wariness of heights or any other generalized response, and highlight the methodological limitations of a classic paradigm in developmental psychology.

Acknowledgments

This research was supported by National Institute of Health and Human Development Grant R37-HD33486 to Karen E. Adolph.

We gratefully acknowledge Lana Karasik and the members of the NYU Infant Action Lab for helping to collect and code data. We thank Samira Iravani for her beautiful illustrations.

References

Adolph KE. Psychophysical assessment of toddlers' ability to cope with slopes. Journal of Experimental Psychology: Human Perception and Performance. 1995; 21:734–750. [PubMed: 7643046]

Adolph KE. Learning in the development of infant locomotion. Monographs of the Society for Research in Child Development. 1997; 62(3, Serial No. 251)

Adolph KE. Specificity of learning: Why infants fall over a veritable cliff. Psychological Science. 2000; 11:290–295. [PubMed: 11273387]

Adolph KE, Avolio AM. Walking infants adapt locomotion to changing body dimensions. Journal of Experimental Psychology: Human Perception and Performance. 2000; 26:1148–1166. [PubMed: 10884014]

Adolph, KE.; Berger, SE. Motor development. In: Kuhn, D.; Siegler, RS., editors. Handbook of child psychology: Vol. 2. Cognition, perception, and language. 6th ed. New York: John Wiley & Sons; 2006. p. 161-213.

Adolph, KE.; Berger, SE. Physical and motor development. In: Bornstein, MH.; Lamb, ME., editors. Developmental Science: An advanced textbook. 6 ed. Mahwah, NJ: Lawrence Erlbaum Associates; 2010. p. 241-302.

Adolph KE, Berger SE, Leo AJ. Developmental continuity? Crawling, cruising, and walking. Developmental Science. 2011; 14:306–318. [PubMed: 21399716]

Adolph KE, Karasik LB, Tamis-LeMonda CS. Using social information to guide action: Infants' locomotion over slippery slopes. Neural Networks. 2010; 23:1033–1042. [PubMed: 20875725]

Adolph KE, Komati M, Cole WG, Garciaguirre JS, Badaly D, Lingeman JL, Chan G, Sotsky RB. How do you learn to walk? Thousands of steps and hundreds of falls per day. Manuscript under review. 2011

Adolph, KE.; Kretch, KS. Infants on the edge: Beyond the visual cliff. In: Slater, A.; Quinn, P., editors. Refreshing Developmental Psychology. London: SAGE Publications; (in press)

Adolph KE, Tamis-LeMonda CS, Ishak S, Karasik LB, Lobo SA. Locomotor experience and use of social information are posture specific. Developmental Psychology. 2008; 44:1705–1714. [PubMed: 18999332]

Bee, H.; Boyd, D. The developing child. 12th ed. Boston, MA, US: Allyn & Bacon; 2010.

Berk, LE. Child development. 6th ed. Boston, MA, US: Allyn & Bacon; 2003.

Bertenthal, BI.; Campos, JJ.; Barrett, KC. Self-produced locomotion: An organizer of emotional, cognitive, and social development in infancy. In: Emde, RN.; Harmon, RJ., editors. Continuities and discontinuities in development. New York: Plenum Press; 1984. p. 175-210.

Burkato, D.; Daehler, MW. Child development: A thematic approach. 3rd ed. Boston, MA, US: Houghton Mifflin; 1998.

Campos JJ, Bertenthal BI, Kermoian R. Early experience and emotional development: The emergence of wariness of heights. Psychological Science. 1992; 3:61–64.

Campos, JJ.; Hiatt, S.; Ramsay, D.; Henderson, C.; Svejda, M. The emergence of fear on the visual cliff. In: Lewis, M.; Rosenblum, L., editors. The development of affect. New York: Plenum; 1978. p. 149-182.

Eppler MA, Adolph KE, Weiner T. The developmental relationship between infants' exploration and action on slanted surfaces. Infant Behavior & Development. 1996; 19:259–264.

Eppler, MA.; Satterwhite, T.; Wendt, J.; Bruce, K. Infants' responses to a visual cliff and other ground surfaces. In: Schmuckler, MA.; Kennedy, JM., editors. Studies in Perception and Action IV. Mahway, NJ: Lawrence Erlbaum Associates; 1997. p. 219-222.

Franchak JM, Adolph KE. Perceiving changing affordances for action: Pregnant women walking through doorways. 2011 Manuscript in preparation.

Gibson, EJ.; Pick, AD. An ecological approach to perceptual learning and development. New York: Oxford University Press; 2000.

Gibson EJ, Riccio G, Schmuckler MA, Stoffregen TA, Rosenberg D, Taormina J. Detection of the traversability of surfaces by crawling and walking infants. Journal of Experimental Psychology: Human Perception and Performance. 1987; 13:533–544. [PubMed: 2965745]

Gibson EJ, Walk RD. The "visual cliff". Scientific American. 1960; 202:64–71. [PubMed: 13827949]

Gibson, JJ. The ecological approach to visual perception. Boston: Houghton Mifflin Company; 1979.

Held R, Hein A. Movement-produced stimulation in the development of visually guided behavior. Journal of Comparative and Physiological Psychology. 1963; 56:872–876. [PubMed: 14050177]

Konczak K, Meeuwson HJ, Cress EM. Changing affordances in stair climbing: The perception of maximum climbability in young and older adults. Journal of Experimental Psychology: Human Perception and Performance. 1992; 3:691–697. [PubMed: 1500869]

Mark LS, Balliet JA, Craver KD, Douglas SD, Fox T. What an actor must do in order to perceive the affordance for siting. Ecological Psychology. 1990; 2:325–366.

Mondschein ER, Adolph KE, Tamis-LeMonda CS. Gender bias in mothers' expectations about infant crawling. Journal of Experimental Child Psychology. 2000; 77:304–316. [PubMed: 11063631]

Pufall PB, Dunbar C. Perceiving whether or not the world affords stepping onto and over: A developmental study. Ecological Psychology. 1992; 4:17–38.

Regia-Corte T, Wagman JB. Perception of affordances for standing on an inclined surface depends on height of center of mass. Experimental Brain Research. 2008; 191:25–35.

Saarni, C.; Campos, JJ.; Camras, LA.; Witherington, D. Emotional development: Action, communication, and understanding. In: Eisenberg, N., editor. Handbook of child psychology, Vol. 3. Social, emotional, and personality development. 6th ed. New York: John Wiley & Sons; 2006. p. 226-299.

Siegler, R.; DeLoache, J.; Eisenberg, N. How children develop. 3rd ed. New York, NY, US: Worth Publishers; 2011.

Snapp-Childs W, Bingham GP. The affordance of barrier crossing in young children exhibits dynamic, not geometric, similarity. Experimental Brain Research. 2009; 198:527–533.

Sorce JF, Emde RN, Campos JJ, Klinnert MD. Maternal emotional signaling: Its effects on the visual cliff behavior of 1-year-olds. Developmental Psychology. 1985; 21:195–200.

Tamis-LeMonda CS, Adolph KE, Lobo SA, Karasik LB, Dimitropoulou KA. When infants take mothers' advice 18-month-olds integrate perceptual and social information to guide motor action. Developmental Psychology. 2008; 44:734–746. [PubMed: 18473640]

Titzer, R. The developmental dynamics of understanding transparency; Paper presented at the meeting of the Society for Research in Child Development; Indianapolis, IN. 1995 Mar.

Ueno M, Uchiyama I, Campos JJ, Dahl A, Anderson DE. The organization of wariness of heights in experienced crawlers. Infancy. (in press).

Walk RD. The development of depth perception in animals and human infants. Monographs of the Society for Research in Child Development. 1966; 31(5, Serial No. 107)

Walk RD, Gibson EJ. A comparative and analytical study of visual depth perception. Psychological Monographs. 1961; 75(15, Whole No. 519)

Warren WH. Perceiving affordances: Visual guidance of stair climbing. Journal of Experimental Psychology: Human Perception and Performance. 1984; 10:683–703. [PubMed: 6238127]

Witherington DC, Campos JJ, Anderson DI, Lejeune L, Seah E. Avoidance of heights on the visual cliff in newly walking infants. Infancy. 2005; 7:285–208.

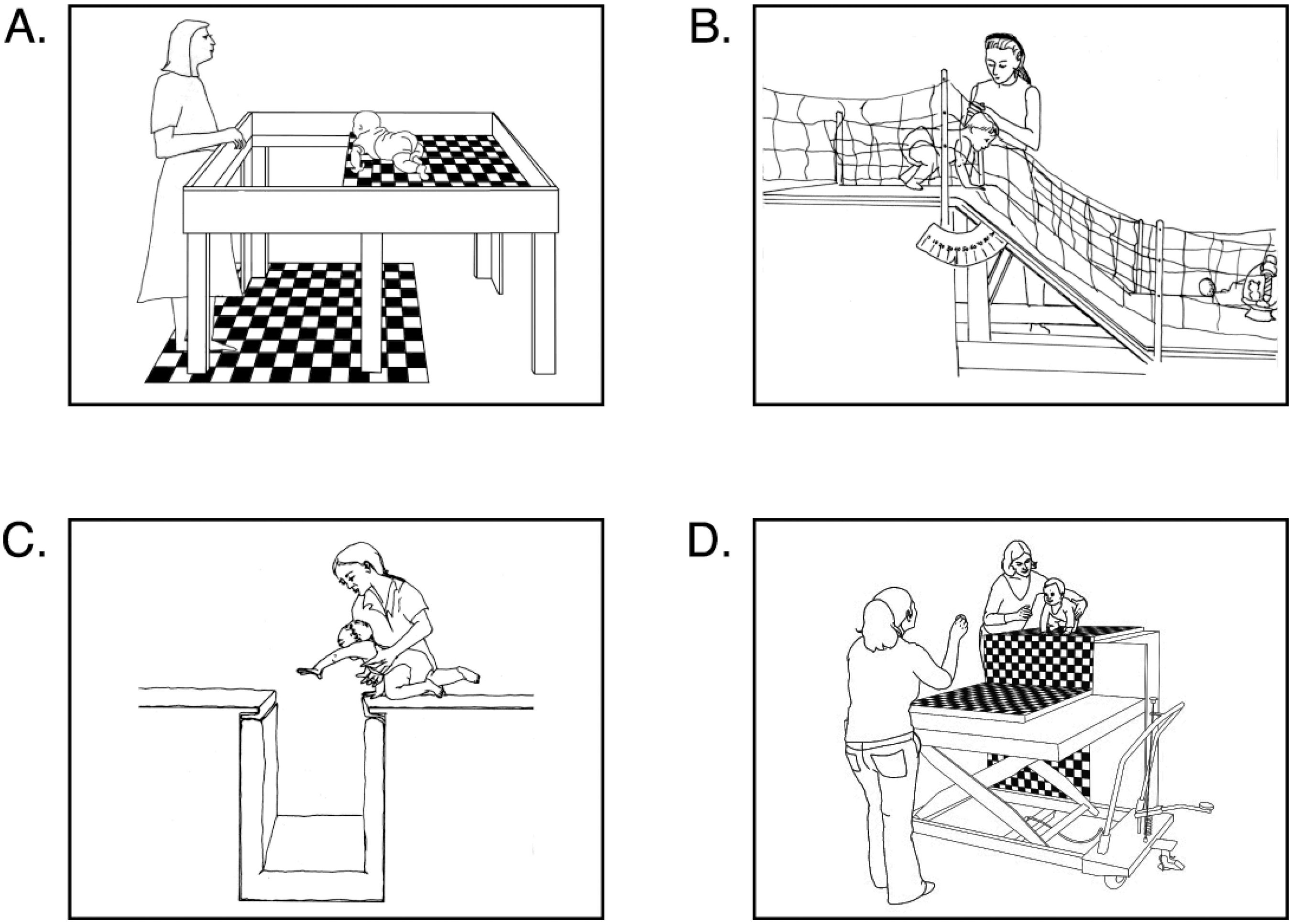

Figure 1.

Apparatuses used to study infants' behavior at the edge of a drop-off. (A) Visual cliff. (B) Adjustable slope apparatus used in Adolph et al. (2008). The slope angle adjusts from 0° to 50° in 2° increments. (C) Adjustable gap apparatus used in Adolph (2000). The gap width adjusts from 0 to 90 cm in 2-cm increments. (D) Adjustable drop-off apparatus used in the current study. The drop-off height adjusts from 0 to 90 cm in 1-cm increments.

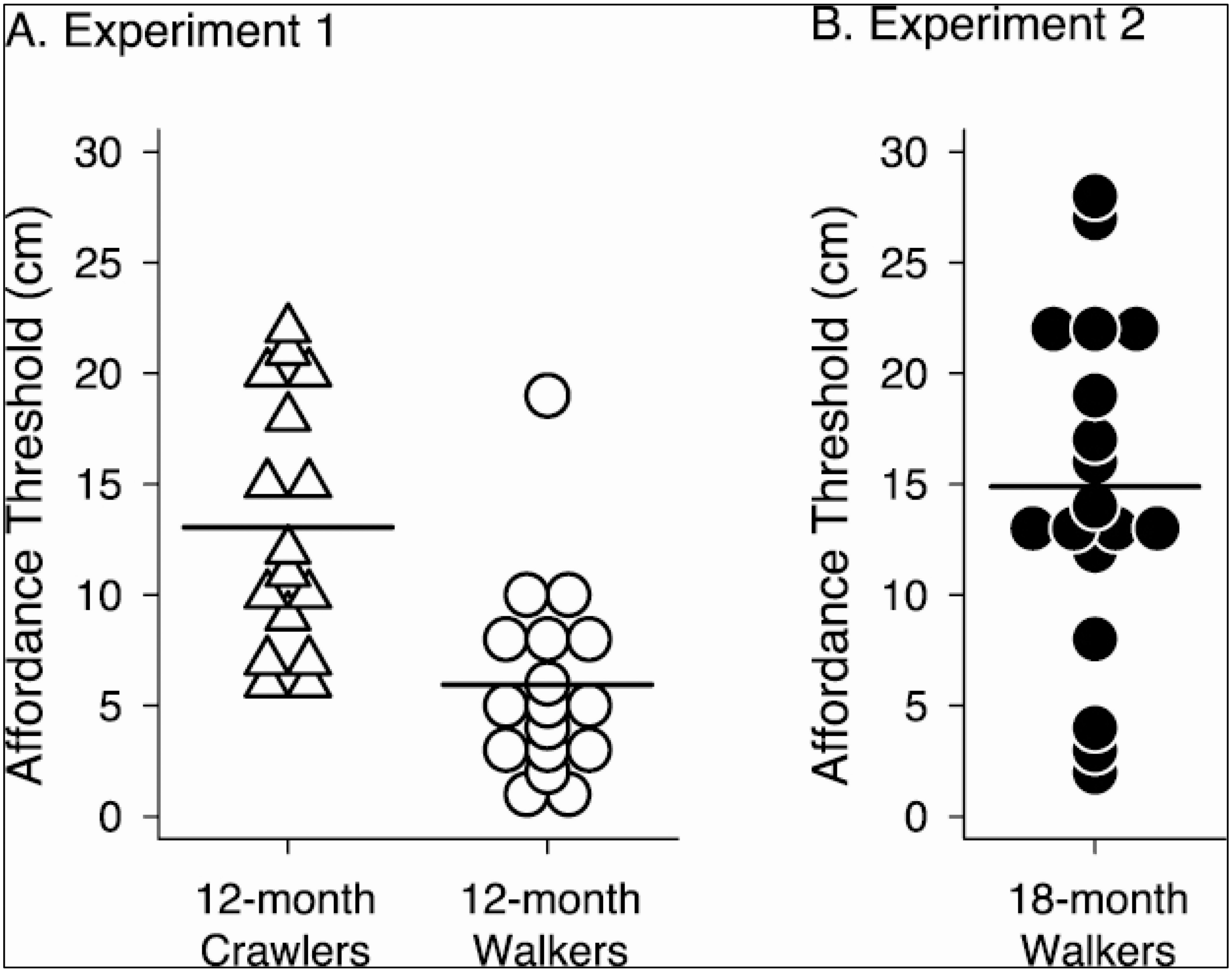

Figure 2.

Affordance thresholds for (A) 12-month-old crawlers and walkers in Experiment 1 and (B) 18-month-old walkers in Experiment 2. Each symbol represents one infant, and solid lines represent group means.

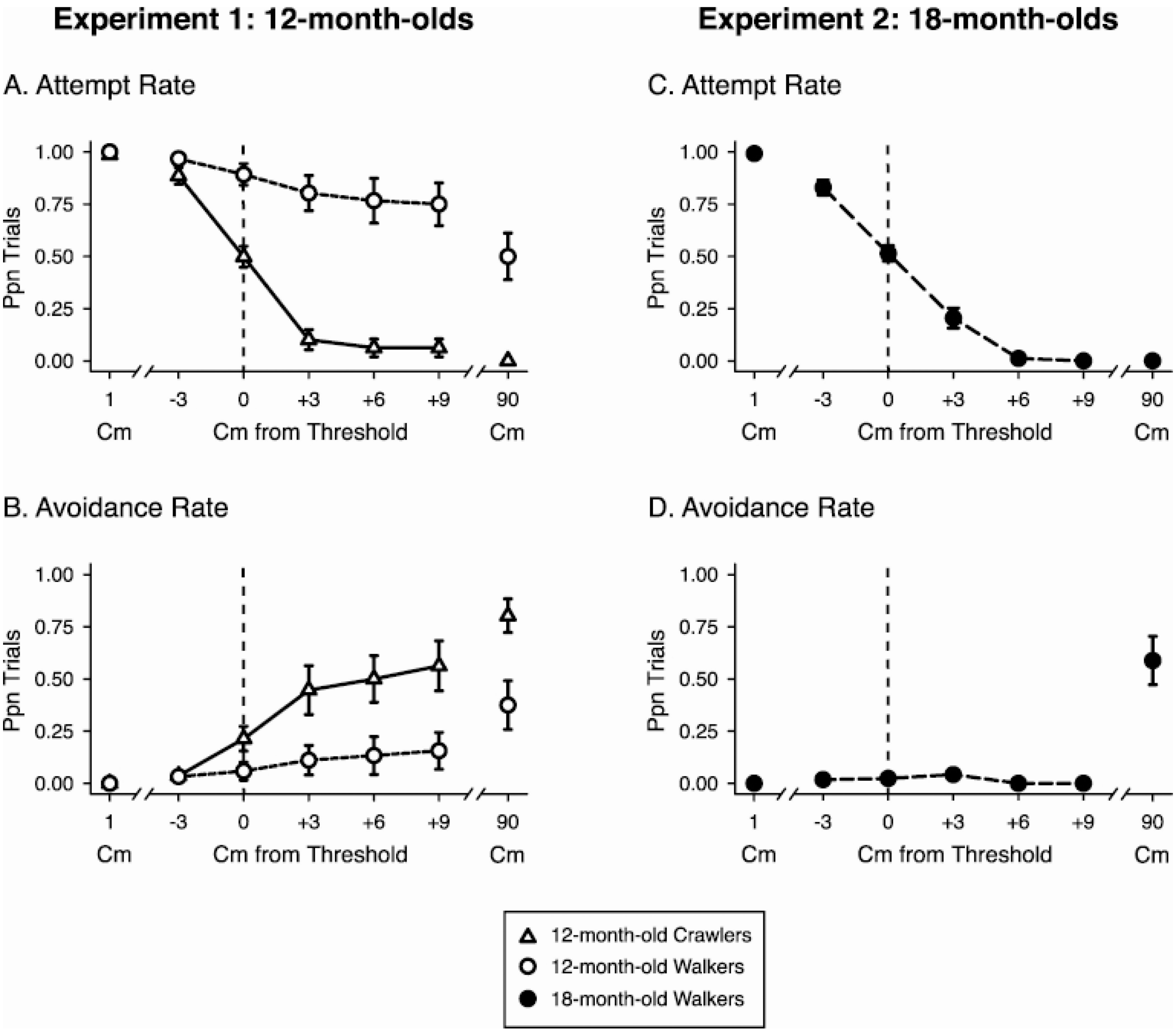

Figure 3.

Crawling and walking attempts and avoidance. Average proportion of trials in Experiment 1 in which (A) 12-month-old crawlers attempted to crawl and walkers attempted to walk over the drop-off or (B) avoided descent. Average proportion of trials in Experiment 2 in which (C) 18-month-old walkers attempted to walk over the drop-off or (D) avoided descent. Error bars denote standard errors. The dashed line represents infants' affordance thresholds, and the increments −3, +3, +6, and +9 represent safe and risky drop-offs normalized to threshold. 1 cm and 90 cm represent absolute increments.

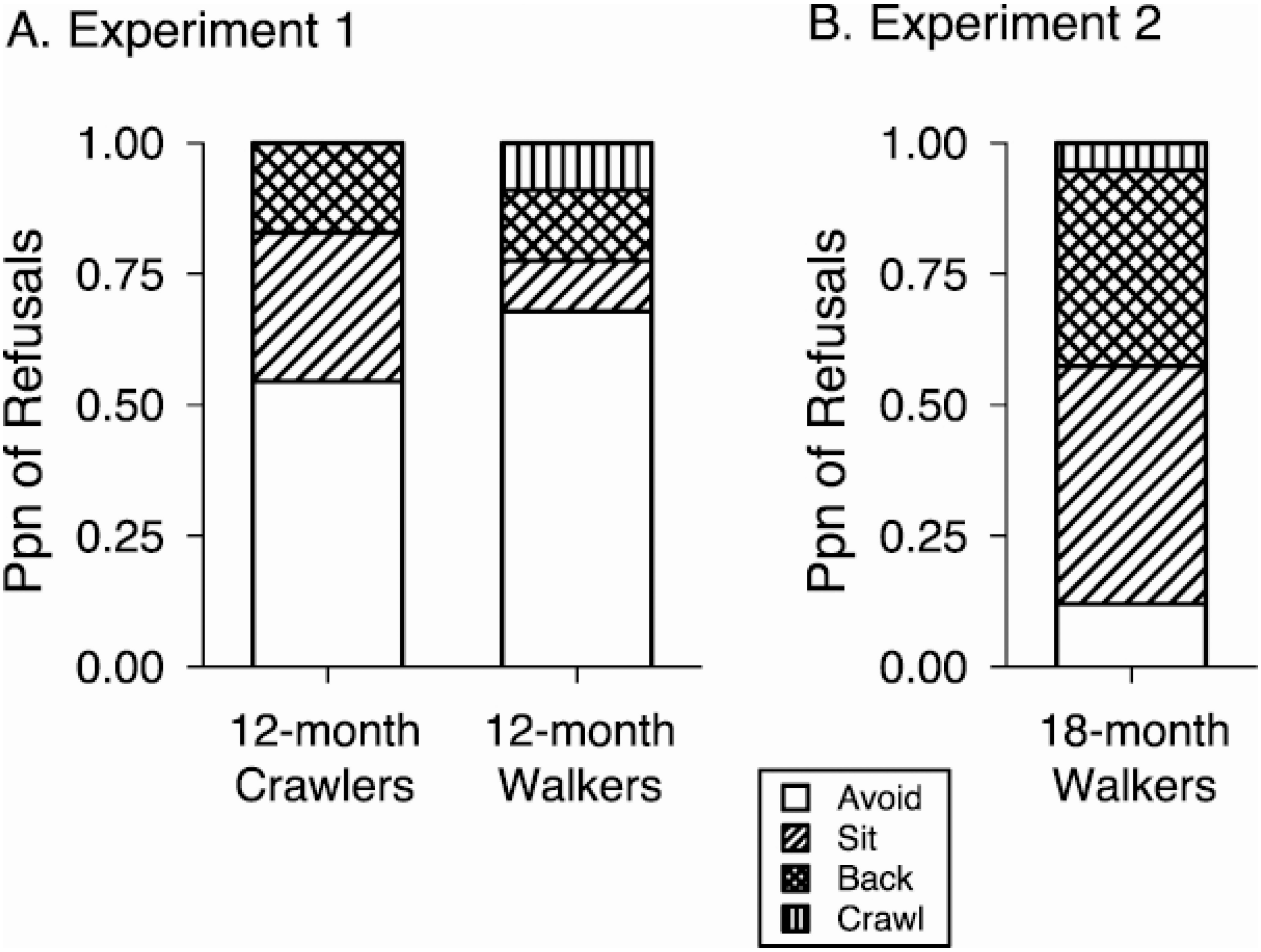

Figure 4.

Proportion of refusal trials in which (A) 12-month-old crawlers and walkers in Experiment 1 and (B) 18-month-old walkers in Experiment 2 used alternative backing, sitting, or crawling descent methods, or avoided descent.

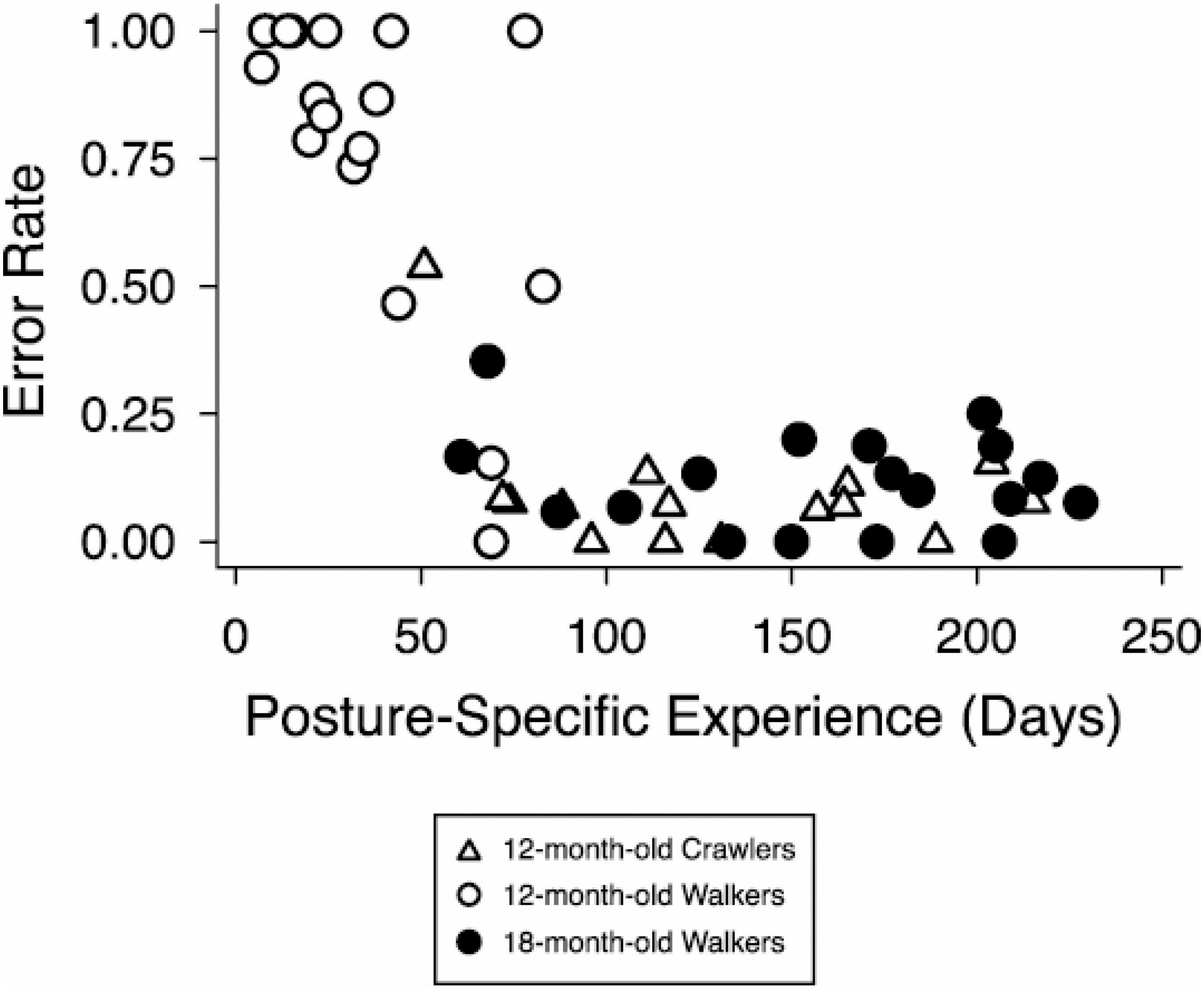

Figure 5.

Relations between posture-specific locomotor experience (days since crawling onset for crawlers, days since walking onset for walkers) and individual differences in error rates (proportion of crawling and walking attempts on risky drop-offs larger than affordance threshold).

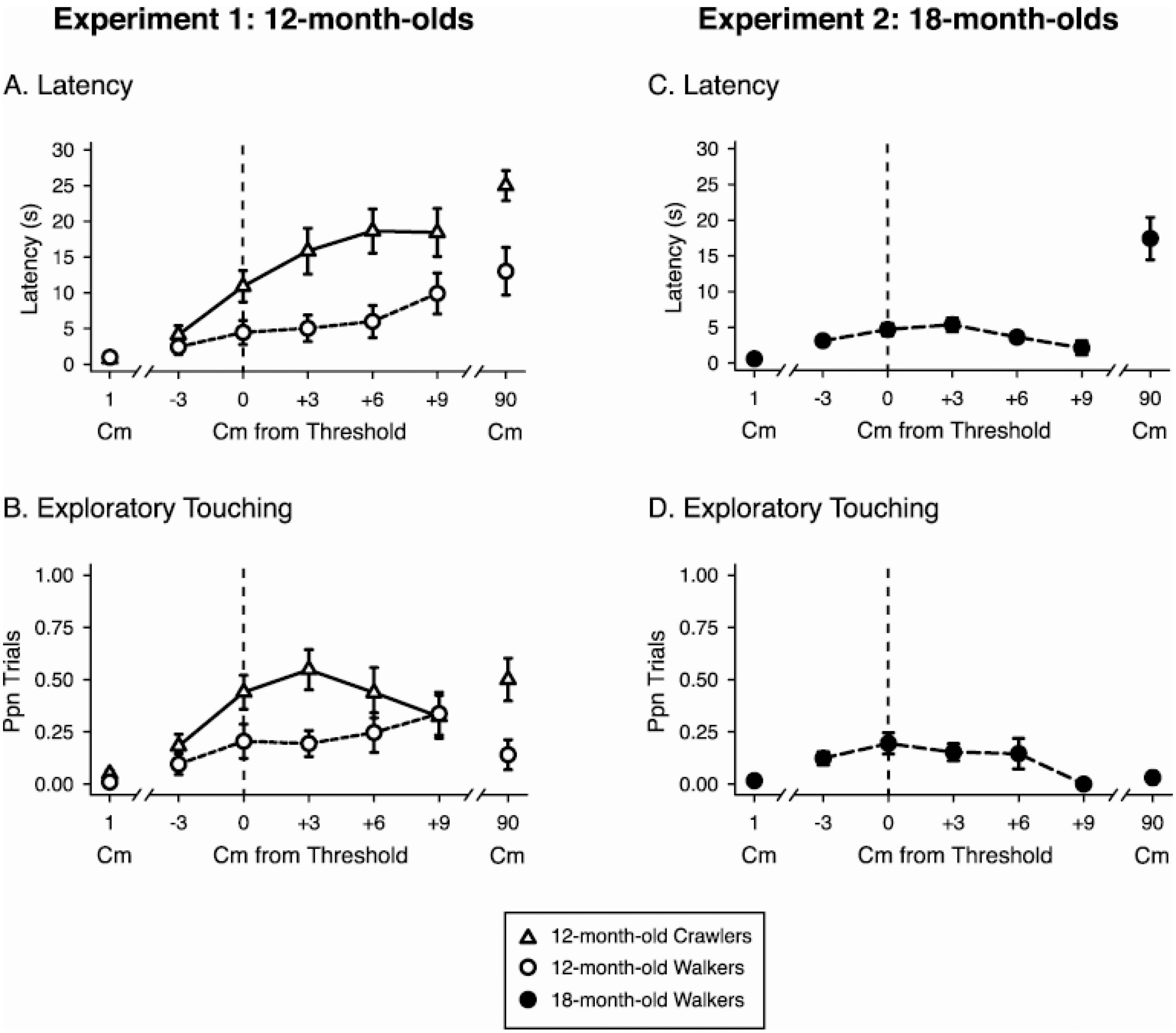

Figure 6.

Exploratory behavior. In Experiment 1, (A) mean latency for 12-month-old crawlers and walkers to descend (30-s latency indicates avoidance for the duration of the trial) and (B) average proportion of trials in which infants touched the edge with hands or feet or reached into the precipice and retracted their arms. In Experiment 2, (C) mean latency for 18-month-old walkers and (D) average proportion of trials in which they explored by touching. Error bars denote standard errors. The dashed line represents infants' affordance thresholds, and the increments −3, +3, +6, and +9 represent safe and risky drop-offs normalized to threshold. 1 cm and 90 cm represent absolute increments.