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Locomotor Experience and Use of Social Information Are Posture Specific

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The authors examined the effects of locomotor experience on infants' perceptual judgments in a potentially risky situation—descending steep and shallow slopes—while manipulating social incentives to determine where perceptual judgments are most malleable. Twelve-month-old experienced crawlers and novice walkers were tested on an adjustable sloping walkway as their mothers encouraged and discouraged descent. A psychophysical procedure was used to estimate infants' ability to crawl/walk down slopes, followed by test trials in which mothers encouraged and discouraged infants to crawl/walk down. Both locomotor experience and social incentives affected perceptual judgments. In the encourage condition, crawlers only attempted safe slopes within their abilities, but walkers repeatedly attempted impossibly risky slopes, replicating previous work. The discourage condition showed where judgments are most malleable. When mothers provided negative social incentives, crawlers occasionally avoided safe slopes, and walkers occasionally avoided the most extreme 50° increment, although they attempted to walk on more than half the trials. Findings indicate that both locomotor experience and social incentives play key roles in adaptive responding, but the benefits are specific to the posture that infants use for balance and locomotion.

Keywords: infant locomotion, crawling, walking, social cognition, affordances

After infants begin crawling and walking, errors in judgment can have serious consequences. How do infants judge whether an action is possible or impossible, safe or risky? In this study we examined the effects of everyday crawling and walking experience and social information on infants' perceptual judgments in a novel, potentially risky situation—descending slopes.

Does Locomotor Experience Promote Adaptive Responding?

The evidence linking locomotor experience with perceptual judgments is inconsistent, even when researchers use a similar apparatus and procedures (for review, see Adolph & Berger, 2006). The standard testing paradigm is the visual cliff, where caregivers coax infants to cross an apparent drop-off covered with invisible safety glass to protect them from falling. Some research with the visual cliff suggests that experience leads infants to respond less judiciously, while other research suggests that experience is critical for adaptive responding. For example, in some cross-sectional studies, experienced crawling infants were more likely to crawl over the edge of the visual cliff than newly mobile infants (Rader, Bausano, & Richards, 1980). Similarly, when infants were tested longitudinally, avoidance attenuated over weeks of crawling experience (Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). However, other studies showed the opposite effect: Infants with several weeks of crawling experience were more likely to avoid crossing the visual cliff than infants who had just begun crawling, even when age at testing was held constant in the experienced and novice groups (Bertenthal, Campos, & Barrett, 1984).

The generalizability of locomotor experience across developmental changes in posture is also controversial. Using a between-subjects design, some researchers found that crawling experience was such a potent predictor of adaptive responding on the visual cliff that it facilitated avoidance in newly walking infants (Witherington, Campos, Anderson, Lejeune, & Seah, 2005). At 12 months of age, both crawlers and walkers avoided an apparent 130-cm drop-off, crawlers in their experienced crawling posture and walkers in their unfamiliar upright posture, suggesting that experience transfers from the earlier to later developing posture.

However, other lines of evidence using within-subjects designs suggest that the beneficial effects of crawling experience do not transfer to an unfamiliar upright posture. For example, when crawling infants faced the visual cliff from a crawling position, they avoided crossing. But when tested in an upright position moments later in a mechanical baby walker, the same infants rolled right over the brink (Rader et al., 1980). Similarly, in studies where infants faced actual rather than illusory drop-offs, the beneficial effects of experience were posture specific. (In lieu of the safety glass, an experimenter rescued infants if they fell.) For example, when perched at the brink of an adjustable gap in an experienced sitting posture, 9-month-olds avoided the wider gap sizes beyond the limits of their abilities. When tested in an unfamiliar crawling

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posture, the same infants fell repeatedly into the same, impossibly large gaps (Adolph, 2000).

Likewise, longitudinal observations of infants descending slopes suggest that experience is posture specific (Adolph, 1997). In their first weeks of crawling, infants fell headlong down steep slopes. Over weeks of crawling, perceptual judgments geared in to the limits of infants' abilities; they crawled down safe slopes and slid down or avoided risky ones. Some experienced crawlers became so reticent to fall that they became overly cautious and avoided crawling down slopes that they had mastered in previous weeks. But, when these same infants faced the same slopes as new walkers, they showed no evidence of transfer over the developmental transition from crawling to walking. They attempted to walk down impossibly steep slopes on trial after trial. In fact, the beneficial effect of experience was so posture specific that infants alternated between adaptive avoidance responses and reckless falling when tested in their experienced crawling and novice walking postures on multiple, back-to-back trials at a risky 36° slope. Over weeks of walking, again perceptual judgments gradually geared in to infants' abilities.

Clearly, infants did not cross the visual cliff or fall over the edge of the gaps and slopes because they did not see the drop-off. Infants made visual contact with the obstacles and had adequate depth perception to see the size of the precipice. Why, then, might infants sometimes display fool-hearty judgments when faced with a novel, potentially risky situation? What factors might explain the discrepancies among previous studies?

An unexplored but potentially important methodological difference in previous studies was the social incentives for crossing over the precipice. In studies testing infants on slopes and gaps (e.g., Adolph 1997, 2000), social incentives were designed to bias infants to traverse the obstacles: Sessions started with warm-up trials to teach infants the game of crossing the walkway, and protocols began with a series of safe and easy increments. Trials were short (30–45 s), fun, and raucous. Caregivers and experimenters waited at the far side of the apparatus, exhorting infants to go, cheering their efforts, and offering toys and food as rewards. In contrast, in studies testing the role of locomotor experience in avoidance on the visual cliff (e.g., Witherington et al., 2005), social incentives were minimal. Infants did not receive warm-up trials on which they crossed the apparatus repeatedly, and they received test trials only on the small and large drop-offs. Trials were long (120–240 s), the experimenter stood quietly behind the infants, and caregivers gently showed a lure if infants did not begin crossing after 120 s (Rader et al., 1980).

There is reason to suppose that social incentives may play a significant role in infants' response to a precipice. When mothers posed fearful facial expressions, 12-month-old crawlers avoided crossing a 30-cm apparent drop-off on the visual cliff (Sorce, Emde, Campos, & Klinnert, 1985). When mothers posed joyful facial expressions, infants crossed. However, mothers were silent (to isolate the effect of their facial expressions), and many infants did not look toward them before approaching the drop-off. Possibly, the positive social incentives in the slopes and gaps paradigms persuaded infants in a novice posture to ignore the perceptual information for the precipice or otherwise made the perceptual information less salient. In experienced postures, infants ignored the hullabaloo.

Current Study: Experienced Crawlers and Novice Walkers Descending Slopes

We designed the current study to resolve some of the controversy raised in previous work concerning the role of locomotor experience in infants' perceptual judgments. Our experimental design capitalized on some of the strengths in the earlier studies while also examining the role of select methodological differences. In particular, we examined the role of social incentives in explaining the rash judgments of novice infants on risky increments.

We examined the link between locomotor experience and perceptual judgments by testing 12-month-old experienced crawlers and novice walkers on a walkway with an adjustable slope. Inspired by previous work on the visual cliff (Witherington et al., 2005), we held constant infants' age and the average duration of crawling experience in both locomotor groups. More adaptive responses in the crawlers would corroborate previous longitudinal work showing that learning is posture specific when perceiving possibilities for descending slopes (Adolph, 1997) and would provide a challenge for the findings of posture-general responses in 12-month-olds on the visual cliff. Our motivation for using a between- rather than within-subjects design was practical. After infants begin walking, they frequently refuse to crawl. In fact, although new walkers safely slid down steep slopes when they approached the brink on their hands and knees, they frequently stood themselves up and fell over the edge as if preferring to be hapless walkers rather than experienced crawlers (Adolph, 1997).

We tested infants on adjustable slopes rather than gaps or the visual cliff for several reasons. Like cliffs and gaps, slopes present a drop-off at the edge of a precipice. However, because the change in elevation is gradual rather than abrupt, infants can slide down when the going gets risky. Because infants can use alternative strategies to descend slopes, their affective responses to risk are not confounded with being frustrated at having to wait out the duration of the trial on the starting platform (Tamis-LeMonda et al., 2008). With a slope apparatus, slant covaries with the height of the drop-off, whereas with a gaps apparatus, the depth of the precipice is constant. Thus, like a cliff, riskier slopes are associated with more severe consequences of falling, providing a stronger test of infants' perception of risk.

Rather than using safety glass to protect infants from falling, an experimenter spotted infants to ensure their safety. Previous work showed that infants do not learn to rely on the experimenter for rescue over multiple trials (Adolph, 1997), but wariness decreases over repeated encounters with the safety glass on the visual cliff (Campos et al., 1978; Eppler, Satterwhite, Wendt, & Bruce, 1997). Moreover, the safety glass is more forgiving of small errors in judgment. On the visual cliff, infants might lean their weight onto the safety glass or take a step or two before retreating. On risky slopes, infants fall if they crawl or walk over the brink, providing a more conservative estimate of their perceptual judgments.

In contrast to the visual cliff, which provides only two extreme increments of depth (typically, 108 cm and 1.90 cm), the slope apparatus was finely adjustable (from 0° to 50° in 2° increments) so that infants' judgments could be compared across a range of safe and risky increments. Because skill levels vary widely within and between crawlers and walkers, we reasoned that the consequence of attempting to descend any particular slope could vary. A risky slope for a less skilled infant could be safe for a more proficient crawler or walker. Thus, we normalized risk level to the limits of each infant's ability using a psychophysical procedure to estimate the steepest slope infants could crawl or walk down (Adolph, 1997). In a subsequent test phase, we assessed infants' perceptual judgments at safe and risky increments. In addition, analogous to work with the visual cliff, we tested each infant at two extreme increments, 4° and 50°, where the corresponding drop-offs were 6.35 cm and 69.71 cm.

Most important, we varied social incentives so as to test the limits of experienced crawlers' prudent responses and novice walkers' rash responses. Mothers encouraged and discouraged infants' descent on blocks of trials. To ensure that infants would receive the social information, mothers' advice was unsolicited. Mothers began delivering their message at the start of each trial, using their faces, voices, and gestures in any way they chose. We reasoned that mothers' encouragement might lead novice walkers to discount perceptual information on risky slopes, and discouragement might lead them to weigh the perceptual information more heavily. Thus, by manipulating the social information, we could test the extent to which rash judgments on risky increments resulted from positive social incentives. For experienced crawlers who already avoid steep slopes even when positive incentives are strong, we asked whether discouragement would make them even more cautious.

Finally, as in previous work on slopes, gaps, and the visual cliff (Adolph, 1997, 2000; Rader et al., 1980; Sorce et al., 1985; Tamis-LeMonda et al., 2008; Witherington et al., 2005), we sought corroborating evidence for infants' perceptual judgments by reporting a variety of exploratory and affective behaviors. In addition to infants' attempts to descend, coders scored latency to leave the starting platform, position shifts, tactile exploration of the slope, and facial and vocal affect.

Method

Participants

Families were recruited from the New York City area through mailing lists, brochures, and referrals. Families received small souvenirs of their participation as remuneration. Twenty-six crawling infants (mean age = 12.23 months, SD = 0.34; 15 girls, 11 boys) and 25 walking infants (mean age = 12.30 months, SD = 0.38; 10 girls, 15 boys) and their mothers (mean age = 35.58 years, SD = 4.47) participated. All crawlers moved on hands and knees with their bellies off the floor. All infants were healthy and born at term. Most families were White, middle class, and well educated. All mothers spoke English as their primary language. With the help of baby books and calendars, mothers reported infants' locomotor experience during a structured interview (Adolph, Vereijken, & Shrout, 2003). Crawling and walking onset were defined as the dates when infants first crawled on hands and knees and walked independently a distance of 10 feet (3.05 m). Experience data were unavailable for 1 walker. As shown in Figure 1, crawling experience was comparable across the two locomotor groups (crawlers: M = 3.55 months, SD = 1.21; walkers: M = 3.04 months, SD = 1.20), $t(48) = 1.49$, $p > .10$. However, crawlers had more than twice as much crawling experience as walkers had walking experience (mean walking experience = 1.26 months, SD = 0.81), $t(48) = 7.81$, $p < .001$. Only 5 crawlers and 4 walkers had prior experience descending playground slides independently, so the sloping walkway was relatively novel for most infants. One crawler and 2 walkers had previously experienced a serious fall that required a physician's attention.

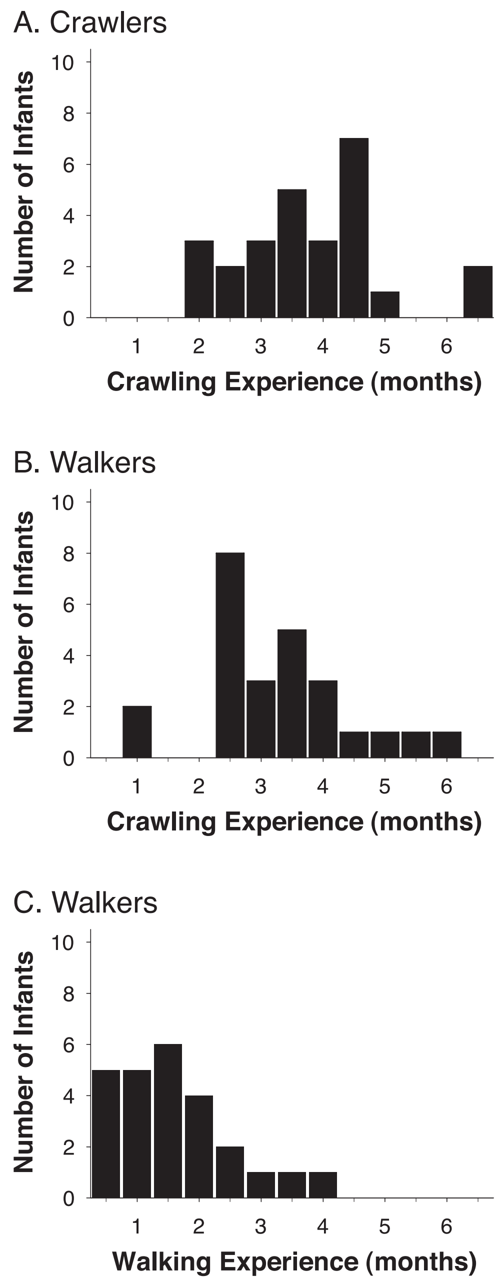

Figure 1. Distribution of locomotor experience. Duration of crawling experience in the group of crawlers (A) and walkers (B) as well as the duration of walking experience in the group of walkers (C).

A strict inclusion criterion was implemented so that only infants who completed both phases of the study (the initial psychophysical procedure and subsequent test trials) were included. Data from 26 additional infants (20 crawlers, 6 walkers) were excluded: 13 infants became fussy during the psychophysical procedure; 12 infants completed the psychophysical procedure but became fussy during test trials; data from 1 infant's test trials were not recorded.

Sloping Walkway

Infants encountered slopes of varying degrees on an adjustable walkway (see Figure 2). Flat starting and landing platforms flanked a middle sloping section (each 86 cm wide × 91 cm long). A push-button remote lowered the height of the landing platform from 116 cm to 45 cm causing the middle section to slant from 0° to 50° in 2° increments. Thus, on steeper slopes, infants had a longer distance to fall. Plush carpet cushioned the surface of the walkway and netting served as a barrier along the sides of the walkway.

Procedure

Each 90-min session began with a set of warm-up trials to verify infants' locomotor status, teach them the game of crossing the walkway to their mothers, and acclimate them to the height of the walkway. The experimenter placed infants on the flat walkway and encouraged them to cross increasingly longer distances until they crawled or walked over the entire walkway four times consecutively. Next, we used a modified psychophysical procedure (Adolph, 1995, 1997; Mondschein, Adolph, & Tamis-LeMonda, 2000; Tamis-LeMonda et al., 2008) to estimate each infant's ability to crawl or walk down slopes. To encourage infants to demonstrate the limits of their abilities, mothers stood beside a research assistant at the end of the landing platform and both adults encouraged infants to descend by crawling or walking while applauding their efforts and offering toys and dry cereal as additional incentives. During a subsequent test phase, based on the individualized estimates of risk levels, infants received a series of test trials on safe, risky, and borderline slopes while mothers encouraged and discouraged descent. During test trials, mothers sat on a raised platform, positioned at infants' eye level but out of arms' reach. Researchers did not speak to infants during test trials, large window shades were pulled down to screen infants' view of toy shelves, and toys and food were removed so that mothers provided the sole incentive to descend. On all trials, the experimenter followed alongside infants to ensure their safety. All trials lasted 30 s or until infants initiated descent, whichever occurred first.

An assistant videotaped infants from the side of the walkway to record their locomotor and exploratory movements. A second assistant videotaped infants from the bottom of the walkway to record a close-up, frontal view of their faces. A third camera at the top of the walkway was operated remotely to record mothers' faces and torsos. A shotgun microphone directly above the walkway enhanced the recording quality of infants' vocalizations. The camera views and sound signals were mixed online onto a single audio/video stream for later coding.

Psychophysical procedure. On average, infants received 33.02 trials (SD = 9.76) during the initial psychophysical procedure. As in previous work (e.g., Adolph, 1997), each trial was coded online as a success (crawled or walked safely), failure (attempted to crawl or walk but fell), or refusal (used alternative sliding positions or avoided descent). For the purpose of determining the limits of infants' abilities, failures and refusals were treated as equivalent, unsuccessful trials. Although the wealth of incentives to descend and easy baseline slopes interspersed throughout the protocols were designed to motivate infants to attempt slopes beyond their abilities, the procedure underestimated the limits of infants' abilities if they never fell. As is customary with adaptive psychophysical procedures, the outcome of the previous trial determined the difficulty of the increment on the following trial (e.g., Cornsweet, 1962). Protocols began with an easy baseline slope at 4°. After successful trials, the experimenter increased slant by 6°. After two consecutive, unsuccessful trials, the experimenter decreased slant by 4°. The process continued until meeting a stopping criterion in which infants succeeded on ≥ 2 out of 3 trials at a borderline slope (i.e., the steepest slope for which infants demonstrated success) and failed or refused on ≥ 2 out of 3 trials at the next 2°, 4°, and

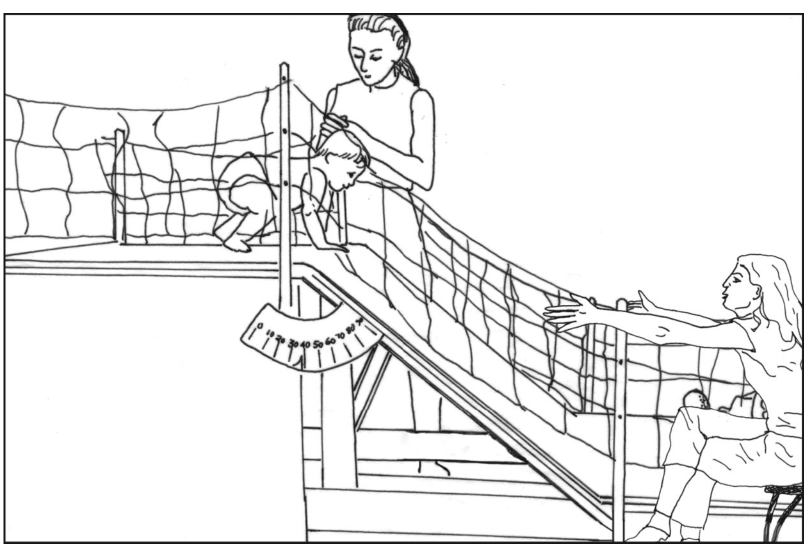

Figure 2. Walkway with adjustable slope. Infants began in either a prone or upright position on the flat starting platform. The middle section of the walkway adjusted in 2° increments from 0° to 90°. An experimenter followed alongside infants to ensure their safety. During the test phase, mothers sat on a raised platform adjacent to the flat landing platform. From "How Mothers Encourage and Discourage Infants' Motor Actions," by L. B. Karasik, C. S. Tamis-LeMonda, K. E. Adolph, and K. A. Dimitropoulou, 2008, *Infancy, 13,* p. 372. Copyright 2008 by Taylor & Francis.

6° increments. Safe slopes were shallower and risky slopes were steeper than the borderline slope.

Test trials. In the test phase, infants encountered trials at 5 risk levels blocked into two social incentive conditions, with condition order counterbalanced across sex. Five slope increments were presented in 4 quasi-random orders for a total of 11 trials in each condition: 3 trials at the borderline increment, 2 trials on safe slopes 10° shallower than the borderline increment (labeled −10°), 2 trials on risky slopes 10° steeper than the borderline (labeled +10°), and 2 trials at 4° and 2 trials at 50° slopes. In addition, infants received a 4° baseline trial (always with mothers encouraging) at the end of each condition to maintain their interest and verify their motivation to descend. Thus, infants received 2 more encouraging than discouraging trials. Half of the children received the full battery of 24 trials; the others received slightly fewer, but all infants received at least one trial at each risk increment in each condition; overall the average number of test trials was 20.57 ($SD = 3.83$). There were no differences in the number of infants who received fewer than 24 trials between locomotor groups, social incentive conditions, or risk levels. There was no correlation between trial number and latency at 4°, indicating that infants did not become more likely to hesitate over the course of the session.

An assistant instructed mothers to communicate encouragement and discouragement using their voices, faces, and gestures in whatever way seemed most natural. In the encouraging condition, mothers were instructed to "get their infants to try to crawl/walk down the slopes;" they should "treat the situation as if they were encouraging their infants to tackle a new challenge such as taking their first walking steps or jumping into a caregivers' arms at the swimming pool." In the discouraging condition, the assistant told mothers to "prevent their infants from trying to crawl/walk down the slopes;" they should "treat the slope as if it were a sheet of ice that would jeopardize infants' safety." To ensure that mothers' communications were consistent across varying degrees of slant, we instructed mothers to disregard the steepness of the slopes when delivering their messages. Previous coding verified that mothers' behaviors varied by condition but did not vary by slant (Karasik, Tamis-LeMonda, Adolph, & Dimitropoulou, 2008).

At the beginning of each test trial, an experimenter held infants on the starting platform. After infants faced their mothers, an assistant rang a bell to signal mothers to begin encouraging or discouraging. The experimenter released the infant onto the starting platform after 2 s.

Data Coding

A primary coder scored all of the data from videotapes using a computerized video coding system, MacSHAPA (Sanderson et al., 1994; www.openshapa.org), that records the frequencies and durations of behaviors. A secondary coder scored 25% of each infant's data to determine interrater reliability. The coders scored trials from the psychophysical procedure and test trials as successes, failures, or refusals as described above. Coders agreed on 98.4% of the trials ($\kappa = .98$). On test trials scored as refusals, coders determined whether infants slid down (head first prone, feet first backing, or sitting) or avoided descent ($\kappa = .98$). They also determined the number of times infants shifted positions on the starting platform ($\kappa = .92$). Latency to descend was scored from the start of the trial until infants initiated descent. Latency included the time that infants explored slopes by looking and touching, and the time that infants tested alternative descent methods while still on the starting platform. The time required for infants to get into their final descent position was subtracted. Latency could range from 0 s (immediate decision) to 30 s (maximum trial length). The correlation between coders' scores was $r(960) = .99$, $p < .001$. Tactile exploration included rubbing the hands or feet against the slope, rocking back and forth with hands/feet straddling the brink, or taking tiny steps with hands/feet at the edge of the slope ($\kappa = .84$). Coders scored negative vocalizations as whining, whimpering, and crying ($\kappa = .84$), and negative facial expressions as downward curls of the mouth, frowns, and scrunched eyebrows ($\kappa = .83$). All other vocalizations and facial expressions were scored as positive/neutral ($\kappa = .92$ and $\kappa = .52$, respectively).

Results

The initial psychophysical procedure yielded a wide range in borderline slopes within and across locomotor groups, confirming the need to normalize risk level to each infant's ability. Crawlers' borderline slopes ranged from 10° to 34° ($M = 20.31°$, $SD = 5.21°$), walkers' borderline slopes ranged from 4° to 24° ($M = 11.92°$, $SD = 5.87°$), and crawlers could descend steeper slopes than walkers, $t(49) = 5.40$, $p < .001$. Walking infants with more days of walking experience had steeper borderline slopes, $r(24) = .74$, $p < .001$, providing independent corroboration of the estimates derived from the psychophysical procedure. However, crawling experience was not related to crawlers' borderline slopes.

Each behavioral measure collected during the test trials was subjected to a 2 (locomotor groups: crawlers vs. walkers) × 5 (risk levels: 4° and 50° slopes, and the 3 slopes normalized to infants' abilities, −10°, borderline, and +10°) × 2 (social incentives: encourage vs. discourage conditions) repeated measures analysis of variance (ANOVA). Follow-up, pair-wise comparisons used a Bonferroni-adjusted alpha level to control for experiment-wise error rates (overall $p = .05$). Preliminary analyses showed no effects for condition order, slope presentation order, or sex, so data were collapsed across these factors in further analyses.

Perceptual Judgments

The frequency of infants' attempts to crawl and walk down slopes on the test trials (see Figure 3A) provided an index of their perceptual judgments. For both locomotor groups, attempts decreased as risk increased, and attempts were higher in the encourage than discourage condition. But, walkers showed higher attempt rates than crawlers at every risk level in both social incentive conditions. The difference was especially striking on the risky +10° and 50° slopes: Crawlers attempted only 15% of trials at the +10° slope; walkers attempted 75% of trials. Crawlers' attempts dropped to 2% at the 50° slope, but walkers' attempt rate was 58%. Additional evidence for the role of experience emerged for the walkers. Correlations showed that walkers with more walking experience displayed lower attempt rates on risky slopes (+10° and 50°) in both the encourage, $r(24) = –.51$, and discourage, $r(24) = –.66$, conditions ($ps < .02$). (Similar correlations for the crawlers were not significant because most infants refused to crawl down the risky slopes).

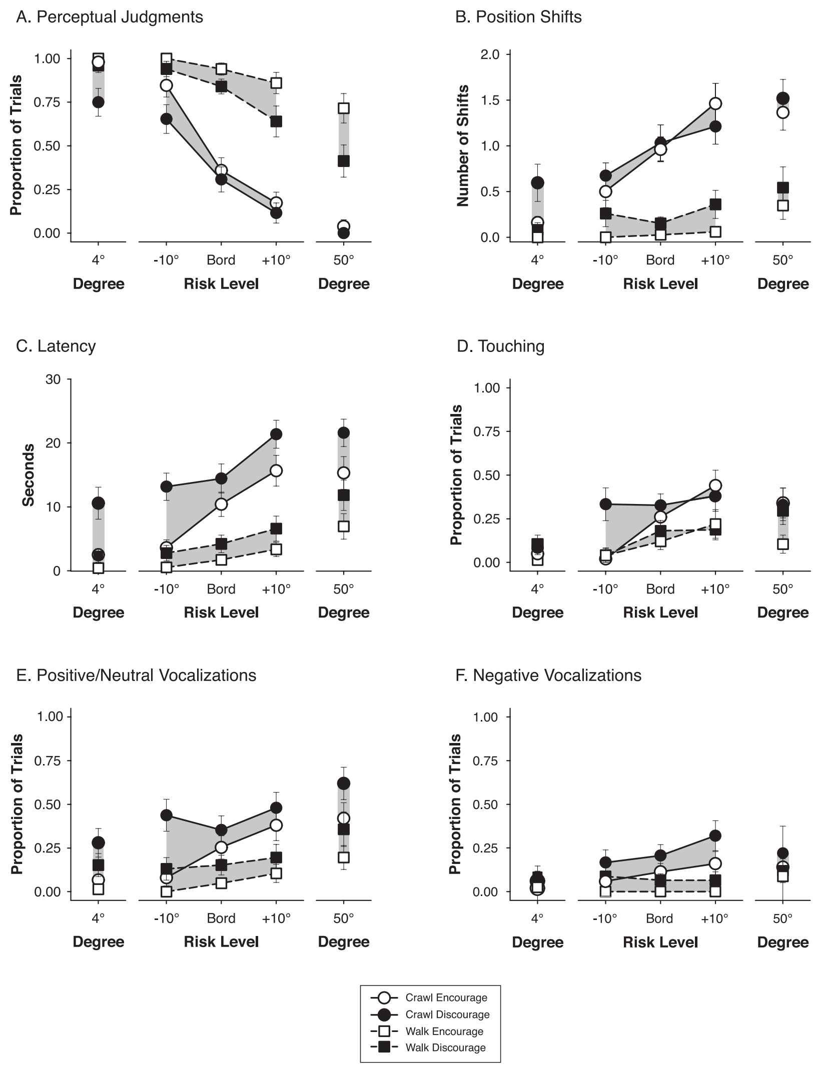

Figure 3. Perceptual judgments, exploratory, and affective behaviors. A: Proportion of trials in which infants attempted to crawl or walk down slopes. B: Number of discrete shifts in position on the starting platform prior to descent. C: Latency to begin descent. D: Proportion of trials in which infants touched the sloping section of the walkway with either hands or feet. E: Proportion of trials in which infants emitted positive/neutral vocalizations. F: Proportion of trials in which infants emitted negative vocalizations. The *x*-axis is labeled with the five slope increments in order of increasing risk: 4° (absolute degree of slope), –10° (10° shallower than infants' borderline slopes), borderline slope, +10° (10° steeper than infants' borderline slopes), and 50° (absolute degree of slope). Shading represents the difference between encourage and discourage conditions at each risk increment for crawlers and walkers. The error bars represent standard errors.

Social incentives differentially affected perceptual judgments of crawlers and walkers, depending on risk. For crawlers, the most powerful effect of social incentives was observed at the safe 4° and –10° slopes. For walkers, social incentives affected judgments on the risky +10° and 50° slopes. These differential effects are evidenced by the gray band between the curves in Figure 3A. An unexpected finding concerned the power of mothers' encouraging messages. Although the encourage condition incited higher attempt rates than the discourage condition, mothers' encouraging social messages appeared less potent for crawlers than social incentives offered during the psychophysical procedure (where both mother and experimenter encouraged infants with toys and food). Attempt rates in the encourage condition at the borderline slopes were lower during test trials (*M*s = .36 and .94, for crawlers and walkers, respectively) than in the psychophysical procedure (*M*s = .93 and 1.00, for crawlers and walkers, respectively).

The ANOVA confirmed main effects for locomotor group, $F(1, 47) = 96.17$, $p < .001$, partial $\eta^2 = .67$, risk level, $F(4, 188) = 74.97$, $p < .001$, partial $\eta^2 = .62$, and social incentive, $F(1, 47) = 22.38$, $p < .001$, partial $\eta^2 = .32$, and interactions between locomotor group and risk level, $F(4, 188) = 13.71$, $p < .001$, partial $\eta^2 = .23$, and between all three factors, $F(4, 188) = 4.21$, $p < .05$, partial $\eta^2 = .08$. Collapsed over social incentive, the difference between crawlers and walkers was greater at the borderline (Ms = .33 and .89, respectively), +10° (Ms = .15 and .75, respectively), and 50° (Ms = .02 and .58, respectively) increments compared with the 4° (Ms = .92 and .99, respectively) and –10° (Ms = .75 and .97, respectively) increments (all ps $< .001$). Post hoc comparisons revealed differences between social incentives for crawlers at 4° and walkers at +10° and 50° (all ps $< .01$).

On refusal trials, variety of means was the norm. Infants in both locomotor groups used a variety of refusal strategies including avoiding descent and several sliding positions—sitting, backing feet first, sliding head first prone, kneeling, walking upright gripping onto the experimenter, and crawling on hands and knees (for walkers). Although crawlers avoided descent on 52.6% of their refusal trials and walkers on 43.4%, only 1 crawler and 5 walkers limited themselves to avoidance on every refusal trial. Nearly all (96.2%) crawlers and 43.4% of walkers used two or more refusal strategies. Three crawlers and 1 walker used four different refusal strategies. Correlations showed that walkers with more walking experience slid down on a greater number of refusal trials than less experienced walkers, $r(23) = .49$, $p < .02$, but walking experience was not related to avoiding. Crawling experience was not related to frequency of sliding or avoiding for the crawlers.

Infants also exhibited a variety of postural and locomotor positions on the starting platform prior to descent. They sat, kneeled, crawled, and squatted; they laid down in backing, prone, and supine positions; and they pulled to a stand using the support posts. They shifted one time on 18.5% of trials and more than once on 12.2%. The maximum number of shifts was five for crawlers and four for walkers; 96% of crawlers and 40% of walkers displayed multiple shifts. For both locomotor groups, position shifts increased with risk level, especially at the steepest +10° and 50° increments where the average number of shifts exceeded one for crawlers (see Figure 3B). Discouragement led to slightly more position shifts in both groups. After a single shift, infants slid down on 70.6% of trials, but after multiple shifts, they slid down on only 42.2%, suggesting that the variety of positions on the starting platform may reflect infants' descent position, a search for alternative means of descent or a more advantageous way to explore, or displacement activity while waiting out the trial. The ANOVA confirmed main effects for locomotor group, $F(1, 47) = 45.12$, $p < .001$, partial $\eta^2 = .69$, risk level, $F(4, 188) = 20.47$, $p < .001$, partial $\eta^2 = .30$, and social incentive, $F(1, 47) = 4.72$, $p < .05$, partial $\eta^2 = .09$, and an interaction between locomotor group and risk level, $F(4, 188) = 6.73$, $p < .001$, partial $\eta^2 = .13$. Collapsed over social incentives, differences between crawlers and walkers were greater at the borderline (Ms = 1.01 and 0.09, respectively), +10° (Ms = 1.33 and 0.21, respectively), and 50° (Ms = 1.41 and 0.43, respectively) increments compared with the 4° (Ms = 0.28 and 0.02, respectively) and –10° (Ms = 0.59 and 0.14, respectively) increments (all ps $< .01$).

Exploratory Activity

Overall, latencies were short. Crawlers started down slopes immediately (i.e., latency = 0 s) on 42.9% of trials and walkers did so on 68.5% of trials. For both crawlers and walkers, latency to descend increased with risk level (see Figure 3C). However, at each risk level, crawlers showed higher latencies than walkers. Increased latency did not merely reflect avoidance, even in the more cautious crawlers. On 54.9% of trials where crawlers hesitated (latency > 0), they eventually crawled or slid down. On 81.5% of trials where walkers hesitated, they eventually walked or slid down. Discouraging social incentives resulted in higher latencies in both locomotor groups, but the effect was more pronounced for crawlers, especially at the safest increments. The effect of mothers' discouragement was to hold infants for a few seconds longer at the brink of the slope, even at increments where infants decided to descend.

The ANOVA confirmed main effects for locomotor group, $F(1, 42) = 26.23$, $p < .001$, partial $\eta^2 = .38$, risk level, $F(4, 168) = 22.72$, $p < .001$, partial $\eta^2 = .35$, and social incentive, $F(1, 42) = 35.46$, $p < .001$, partial $\eta^2 = .46$, and interactions between locomotor group and risk level, $F(4, 168) = 2.94$, $p < .05$, partial $\eta^2 = .07$, and locomotor group and social incentive, $F(1, 42) = 6.13$, $p < .05$, partial $\eta^2 = .13$. Collapsed over social incentives, differences between crawlers and walkers were greater at the borderline (Ms = 12.00 s and 2.88 s, respectively), +10° (Ms = 18.25 s and 5.00 s, respectively), and 50° (Ms = 18.81 s and 8.80 s, respectively) increments compared with the 4° (Ms = 4.63 s and 0.93 s, respectively) and –10° (Ms = 8.27 s and 1.68 s, respectively) increments (all ps $< .01$). Collapsed over risk levels, the difference between crawlers and walkers was greater in the discourage (Ms = 16.12 s and 5.11 s, respectively) than encourage (Ms = 8.10 s and 2.01 s, respectively) condition (all ps $< .001$).

Infants explored slopes by touching on 17.8% of trials. Crawlers touched primarily with their hands (93.3% of touch trials) and walkers with their feet (95.0% of touch trials). Occasionally, crawlers explored slopes with their feet by pulling to a stand while gripping onto a support post and straddling their feet over the brink, and walkers explored slopes with their hands by squatting down to rub their hand over the surface. Most infants touched on at least one trial (96.2% of crawlers, 72% of walkers). In both locomotor groups, touching increased with risk level (see Figure 3D). However, crawlers showed slightly higher levels of touching than walkers, especially at safer increments. For crawlers, discouraging social incentives effected higher rates of touching at the −10° increment, and for walkers discouraging social incentives led to higher rates of touching at the 50° increment. After touching, infants were more likely to avoid descent or choose an alternative sliding position (64.8% of touch trials) compared with trials where they did not touch (26.2% of no-touch trials). The ANOVA confirmed main effects for locomotor group, $F(1, 42) = 6.25$, $p < .05$, partial $\eta^2 = .13$, risk level, $F(4, 168) = 10.63$, $p < .001$, partial $\eta^2 = .20$, and social incentive, $F(1, 42) = 4.12$, $p < .05$, partial $\eta^2 = .09$), and a three-way interaction, $F(4, 168) = 3.99$, $p < .05$, partial $\eta^2 = .09$.

Affective Behaviors

Infants exhibited positive/neutral facial expressions on nearly every trial (93.0% of trials), but negative facial expressions were infrequent (5.9% of trials). There were no differences in the frequency of positive/neutral facial expressions between locomotor groups, social incentive conditions, or risk levels. For negative facial expressions, the ANOVA showed only a main effect for risk level, $F(4, 168) = 5.39$, $p < .001$, partial $\eta^2 = .11$, increasing to 15% of trials at 50°.

Infants emitted positive/neutral vocalizations on 21.6% of trials. Positive/neutral vocalizations increased with risk (see Figure 3E).

Crawlers vocalized more than walkers at every risk level. An unexpected finding was that infants in both groups emitted more positive/neutral vocalizations when mothers discouraged (M = .31, SD = .29) than when they encouraged (M = .13, SD = .17). The ANOVA confirmed main effects for locomotor group, $F(1, 42) = 10.67$, $p < .05$, partial $\eta^2 = .20$, risk level, $F(4, 168) = 9.82$, $p < .001$, partial $\eta^2 = .19$, and social incentive, $F(1, 42) = 16.11$, $p < .001$, partial $\eta^2 = .28$.

Infants emitted negative vocalizations on only 7.9% of trials. The frequency of negative vocalizations increased with risk, especially for crawlers at the +10° slope (see Figure 3F). Similar to the effects for positive/neutral vocalizations, the discourage condition (M = .14, SD = .23) led to more negative vocalizations than the encourage condition (M = .05, SD = .11). The ANOVA confirmed main effects for risk level, $F(4, 168) = 2.51$, $p < .05$, partial $\eta^2 = .06$, and social incentive, $F(1, 42) = 5.78$, $p < .05$, partial $\eta^2 = .12$, and an interaction between locomotor group and risk levels, $F(4, 168) = 2.69$, $p < .05$, partial $\eta^2 = .06$. Collapsed over social incentive, crawlers emitted more negative vocalizations than walkers at the borderline (Ms = .15 and .03, respectively) and +10° increment (Ms = .25 and .02, respectively; $p < .01$) compared with the other risk increments (overall Ms = .12 and .06, respectively; all ps > .10). On trials where infants emitted negative vocalizations, they typically displayed negative facial expressions (71.8% of negative-voice trials). But, they also displayed positive/neutral facial expressions (89.7%) and sometimes positive/neutral vocalizations (43.6%). If infants displayed negative affect in either face or voice, they typically avoided descent (78.7% of negative trials).

Discussion

Findings from the current study provide new evidence that infants' locomotor experience plays an important role in adaptive responding to a precipice. In this case, the precipice was an adjustable slope. All infants were 12 months of age, so individual differences could not be attributed to age-related changes. Half were experienced crawlers and half were novice walkers, replicating the between-subjects design used for testing infants on the visual cliff (Witherington et al., 2005). On safe slopes within their ability (4°, –10°, and the borderline slope), crawlers occasionally refused to crawl, but walkers always attempted to walk. On risky slopes beyond their ability (+10° and 50°), crawlers refused to crawl, but walkers stepped blithely over the brink. The difference in attempt rates on risky slopes was striking—averaging 8% versus 67% of risky trials for crawlers and walkers, respectively. In addition, experience varied within each locomotor group, so that experience could also be analyzed as a continuous measure. When we pooled the data across walkers and crawlers, the duration of infants' experience in their posture at test predicted lower attempt rates, longer latencies, and higher rates of touching on both safe and risky slopes; correlation coefficients for safe and risky slopes, respectively, were $r(50) = –.48$ and –.67 for attempts, .36 and .46 for latency, and .31 and .37 for touching (all ps < .03).

An important innovation in this study was the manipulation of social incentives: On some trials, mothers encouraged infants to descend, and on other trials, mothers discouraged them. The positive social incentive condition was meant to replicate the social conditions used in previous work with infants on slopes and gaps (e.g., Adolph, 1997, 2000), while serving as a contrast to the negative social incentive condition. To our surprise, mothers' encouragement resulted in lower attempt rates by the crawlers at the borderline slope during test trials compared with the psychophysical procedure, and lower attempt rates at borderline and risky slopes compared with earlier work (e.g., Mondschein et al., 2000). Apparently, mothers' sole encouragement was only a pale facsimile of the positive social incentives provided by both caregivers and experimenters offering toys and food in previous work. Thus, walkers' high attempt rates on test trials on risky slopes were even more remarkable. Possibly, situating mothers in a sitting position to the side of the landing platform during the test trials, rather than standing at the bottom of the slope as in the psychophysical procedure, contributed to the depressed attempt rates at the borderline slope.

The critical question concerned the effect of negative social incentives: Would discouragement prevent novice infants from falling into the precipice? Indeed, the negative social incentive condition resulted in lower attempt rates by walkers on risky slopes, resulting in a 29% decrease in attempts to walk between social incentive conditions at the 50° slope. However, walkers still showed poor perceptual judgments: They attempted to walk down 48% of trials at the 50° increment, a frequency comparable with that shown by infants in novice postures on impossibly large gaps and steep slopes in previous work. Discouragement also resulted in a lower attempt rate by crawlers on safe slopes. At the 4° slope—demonstrably easy for every crawler—they showed a 23% decrease in attempts between social incentive conditions, from 98% when mothers encouraged to 75% when they discouraged.

Posture-Specific Learning

A central controversy in previous work is whether the beneficial effects of experience are specific to the posture that infants use for balance and locomotion. The current study corroborates the posture-specific learning found in Adolph's (1997, 2000) earlier work with infants on slopes and gaps and Rader et al.'s (1980) work with infants on the visual cliff but presents a challenge to Witherington et al.'s (2005) finding of posture-general responding on the visual cliff. In the current study, regardless of the social incentive condition, infants in an experienced crawling posture displayed fewer errors in perceptual judgments (falls) on risky slopes compared with infants in a novice walking posture. Crawlers also showed more position shifts, longer latencies, more touching, and more vocalizations than walkers.

In fact, crawlers' responses to risky increments may have been overly cautious; that is, crawlers may have refused to crawl down challenging slopes that were within their ability. During the psychophysical procedure, many crawlers (65%) but few walkers (36%) showed sporadic successes on slopes 2° to 6° steeper than the estimated borderline increment. Thus, the psychophysical procedure may have slightly underestimated crawlers' borderline slopes, and as a consequence, increments designated as borderline and +10° would have been relatively less challenging for crawlers compared with walkers. (Note, however, no infant succeeded at +10°). In this event, low attempt rates by crawlers during test trials at those increments would provide further evidence of extreme reticence to fall. Similarly, in Adolph's (1997) longitudinal study, some experienced crawlers became overly cautious and slid down or avoided steep slopes that they had descended successfully by crawling in earlier sessions.

In contrast, in Witherington et al.'s (2005) study, experienced crawlers showed higher crossing rates and shorter latencies on the deep side of the cliff compared with novice walkers, suggesting that experienced crawlers were actually less, not more, wary of the precipice. Several factors may explain the discrepancy between the current findings and those of Witherington and colleagues. One possible explanation for the differences between infants' behavior on slopes and the visual cliff is the perceptual information for the drop-off. In the current slope study, the drop-off was gradual and measured only 69.71 cm at 50°. In the gap studies, the drop-off was abrupt, but the height of the drop-off was only 76 cm. On the visual cliff, the apparent drop-off was abrupt and the distance to fall was 130 cm (Witherington et al., 2005). Possibly, novice walkers respond more judiciously to a larger vertical distance to the floor and/or visual information for a more abrupt drop-off. We are currently testing this possibility using the methods described here with an adjustable cliff.

A second potential explanation for the discrepant findings concerns differences in how infants' behaviors were scored. In the slope task, infants could generate a wide range of descent strategies, including sitting, backing down feet first, kneeling, and so forth. Because the focus was on whether infants could effectively judge slopes as safe or risky, these strategies were scored as refusals. In contrast in the visual cliff task, only a few infants could devise alternative ways of crossing such as scooting backward or holding the edge of the apparatus because the visual cliff was covered in Plexiglas. However, these alternative strategies were still scored as crossing (Witherington et al., 2005). Moreover, many crawling infants explored possibilities for locomotion on the visual cliff and slopes before leaving the starting platform. On slopes, infants typically kept two knees on the starting platform while placing both hands on the slope and rocking back and forth. These movements generate torque around the wrists and shearing force between the hands and surface—perceptual information that may have dissuaded them from attempting slants that were too steep to keep balance and prevent slipping. On the visual cliff, crawlers felt a solid surface beneath their hands—information that may have prompted them to go.

Finally, in the slope and gap studies, attempts were coded even if infants fell at the brink. Thus, on slopes, crawling infants could shift their weight forward onto the slope without falling and then retreat back to the starting platform. Walkers did not enjoy this luxury. If they shifted their weight forward, they fell. In contrast, Witherington and colleagues (2005) required infants to place all of their limbs onto the surface before scoring the trial as an attempt. If the safety glass was absent, walking infants would have fallen as soon as they shifted their weight over the drop-off.

The Role of Social Incentives

In the current study, we examined the role of locomotor experience and posture in infants' use of social information. The most frequently cited study of infants' use of social information to guide motor action is Sorce et al.'s (1985) research with 12-month-old crawlers on the visual cliff. Sorce and colleagues focused only on 12-month-old crawlers, whereas in the current study we compared experienced 12-month-old crawlers and novice 12-month-old walkers. In addition, we expanded on Sorce et al.'s study by offering infants a more rich and varied source of social information. The previous work showed that infants' attempts to cross the apparent drop-off were related to mothers' static facial expressions of joy, fear, interest, and anger. However, silent, frozen facial expressions are not representative of everyday interactions. In the current study, mothers provided more natural, multimodal social messages (Karasik et al., 2008), varying their facial expressions, voices, verbal content, manual gestures, and body language. With this richer, more variable social input, infants responded differentially to encouragement and discouragement. Moreover, we used a within- rather than between-subjects design, showing that infants respond differentially to varying messages across multiple trials.

In the current study, we also addressed several methodological limitations in the previous work. In the Sorce et al. (1985) study, mothers' communications relied on infants' spontaneous looks to mothers' faces. However, with the 30-cm apparent drop-off, 21% of infants never referenced their mothers, and on a small 8.2-cm apparent drop-off, 74% of infants never referenced their mothers. In the current study, all infants received social information from their mothers on every trial. Social messages were unsolicited, mimicking everyday situations when mothers tell their infants what to do: Mothers began delivering their message before infants were released on the starting platform and continued to encourage or discourage until the end of the trial. In the Sorce et al. study, the height of the ambiguous drop-off was fixed at 30 cm. The authors settled on this increment because pilot data showed that some infants crossed and some did not. In the current study, the apparatus was adjustable, so that safe, borderline, and risky increments were individualized to each infant's locomotor skill rather than predetermined for the group.

The effects of the social manipulation were posture specific for attempts, exploratory activity, and social expressions. Overall latencies were greater in the discourage trials, meaning that both crawlers and walkers had similar opportunities to receive the negative social incentives. However, negative social incentives affected walkers only at the risky increments and crawlers only at the safe increments. Finally, negative social incentives resulted in longer latencies for walkers on risky slopes and more touching and positive/neutral vocalizations for crawlers on safe slopes.

Thus, the social manipulation illuminates the effects of locomotor experience by providing new evidence about the malleability of infants' perceptual judgments. For infants in a novice posture, the first inkling that some situations are beyond their abilities arises on the most extreme, risky increments. Perceptual judgments gradually gear in to infants' abilities. This gearing-in pattern appears to be general across crawling and walking postures and slope, gap, and visual cliff paradigms (Adolph, 1997, 2000; Campos & Bertenthal, 1984). In contrast, for infants in an experienced crawling posture, perceptual judgments are malleable at safe increments, demonstrably within their abilities. Overly cautious responding on safe slopes was also observed longitudinally in crawlers (Adolph, 1997). However, cautious perceptual judgments may be specific to younger infants or to crawlers. A recent study showed that 18-month-old experienced walkers deferred to mothers' discouragement only at the borderline slope, where perceptual information was most ambiguous (Tamis-LeMonda et al., 2008). Therefore, cautious responding to risk might transition to a more accurate appraisal to risk across development.

Posture-General Learning

Three sets of findings were not specific to crawling and walking postures. First, infants in both locomotor groups had a variety of means for coping with slopes. They knew several sliding positions and ways of shifting position on the starting platform, could touch slopes with hands and/or feet, and could inhibit descent by hesitating. The problem for walkers was not that they had forgotten safer ways to descend or that they lacked the means of obtaining perceptual information from tactile exploration. The problem was that they did not recognize that steep slopes were risky as they walked toward the brink. The visual information was not sufficient to elicit tactile exploration, shifts in position, or alternative strategies.

A second set of posture-general findings concerns the relationship between exploration and perceptual judgments. If infants hesitated and/or touched slopes, they were less likely to attempt their typical crawling/walking method. For infants in both groups, attempt rate was negatively correlated with latency and touching on both safe and risky slopes; correlation coefficients for safe and risky slopes, respectively, were $r(51) = -.73$ and $-.68$ for latency and $r(51) = -.47$ and $-.32$ for touching (all $ps < .02$). Latency and touching were also correlated; correlation coefficients for safe and risky slopes, respectively, were $r(51) = .44$ and $.46$ (all $ps < .01$).

A third set of posture-general findings concerns infants' facial expressions and vocalizations. For infants in both groups, positive/neutral displays were common, and negative displays were rare. Infants displayed positive affect on trials when they crawled or walked down and on trials when they used an alternative sliding strategy. When infants displayed negative affect, they most frequently avoided descent, suggesting that alternative means for descent may mitigate infants' frustration on risky increments. Rather than waiting out the duration of the trial on the starting platform, where 30 s seems interminably long, infants can take a reasonable course of action. The possibility of alternative means makes the slope paradigm a valuable tool for observing infants' affective responses to potential risk.

Additionally, infants emitted more positive/neutral than negative vocalizations when mothers discouraged than when they encouraged. One possibility for this unexpected finding is that longer latencies during discouraging trials resulted in more vocalizations overall, which was reflected in the increased positive/neutral vocalizations of infants. Moreover, although mothers displayed differential messages in the two conditions, they were generally positive even when discouraging (Karasik et al., 2008). Thus, mothers found a way to communicate the risk of the situation without evoking negative affect in their infants. As a result, infants' vocalizations might have reflected interest rather than distress. Finally, previous research has shown that infants remain positive in their affect even when mothers pose fearful facial expressions (Sorce et al., 1985).

Conclusions: Why Infants Sometimes Plunge Over the Edge of a Precipice

In summary, infants sometimes plunge over the edge of an impossibly steep slope because they lack the locomotor experience to recognize the potential risk. Infants may have some inkling that extreme increments pose a potential threat in their novice posture, but they cannot yet scale their perceptual judgments to the limits of their own abilities. Manipulating social incentives provided new insight into the malleability of infants' perceptual judgments. At the most extreme increments, positive social incentives may lead novices to discount the visual information for the drop-off, resulting in rash attempts at impossible increments. Negative incentives may help to make the perceptual information more salient, occasionally swaying novices to think twice.

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