Published in final edited form as:
Dev Psychol. 2012 September ; 48(5): 1254–1261. doi:10.1037/a0027530.

What infants know and what they do: Perceiving possibilities for walking through openings

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Abstract

What infants decide to do does not necessarily reflect the extent of what they know. In the current study, 17-month-olds were encouraged to walk through openings of varying width under risk of entrapment. Infants erred by squeezing into openings that were too small and became stuck, suggesting that they did not accurately perceive whether they could fit. However, a second penalty condition revealed accurate action selection when errors resulted in falling, indicating that infants are indeed perceptually sensitive to fitting through openings. Furthermore, independent measures of perception were equivalent between the two penalty conditions, suggesting that differences in action selection resulted from different penalties, not lack of perceptual sensitivity.

Developmental researchers assess what infants know based on measures of what infants do. Typically, infants' perception, cognition, or affect are indexed by a single behavioral measure per experiment, such as how long infants look at possible versus impossible events (Baillargeon, Spelke, & Wasserman, 1985; Spelke, Breinlinger, Macomber, & Jacobson, 1992). However, distilling what infants know from what they do requires an inferential leap, especially when behavioral evidence is limited to a single measure.

In this paper, we explore a central problem associated with making that inferential leap. What is the appropriate interpretation of infants' failures? We use an example from perceptual-motor development: infants' perception of possible versus impossible actions. Here, infants made repeated errors as they decided whether to walk through openings of varying width; they repeatedly squeezed themselves into impossibly small openings. At first glance, infants' errors indicated that they did not know whether they could fit. Had infants' errors been the only measure, the results would suggest that infants failed to distinguish possible from impossible openings. However, independent measures of perception—gait modifications and approach behaviors—revealed accurate perceptual sensitivity to opening size relative to body size, and a second penalty condition that involved falling from a narrow ledge showed that low weighting of entrapment as a penalty for errors was responsible for maladaptive decisions.

What Infants Know

Knowing how to get around in the world requires more than learning to control body mechanics. Adaptive locomotion involves distinguishing possible from impossible actions and selecting actions accordingly. Possibilities for action depend on the fit between the physical characteristics of the body and the physical features of the environment. For

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Portions of this work were presented at the 2010 meeting of the International Society for Developmental Psychobiology, San Diego, CA and the 2011 meeting of the Society for Research in Child Development, Montreal, Canada.

example, walking through an opening is possible if the opening is large enough relative to the size of the infant's body.

Infants must learn to distinguish possible from impossible actions (Adolph & Berger, 2006). In their first weeks of walking, infants do not distinguish situations that allow walking from those that do not (Adolph, 2008). Novice walkers attempt to walk down impossibly steep slopes (Adolph, 1997; Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008) and over the brink of impossibly high cliffs (Kretch & Adolph, in press). Errors result in infants falling into the precipice (requiring rescue by the experimenter). Even when walking is possible, novice walkers do not systematically match gait patterns to the characteristics of the obstacle. They respond to challenging and easy slopes indiscriminately, sometimes using a "braking" strategy to curb their speed and sometimes running recklessly to the bottom (Gill, Adolph, & Vereijken, 2009).

Over months of walking experience, infants perceive possibilities for action more accurately. On impossible slopes and cliffs, experienced 18-month-old walkers avoid descent or choose alternative means of locomotion such as sliding down slopes and backing down cliffs (Adolph, 1997; Kretch & Adolph, in press). With practice, visual information about obstacles helps infants to modify their gait. Over weeks of testing, infants increasingly match their gait patterns to the degree of a slope by taking slower, smaller steeps on steeper slopes (Gill et al., 2009).

What Infants Do

Researchers' inferences about infants' perception are based on their actions—what infants do. However, action selection relies on, but is not identical to action perception. Selecting an action involves perception as well as decision-making. Although selecting actions adaptively implies accurate perception, the converse is not necessarily true.

These notions are well established in psychological and economic studies with adults. Theories of decision-making under risk address how people weigh potential rewards against penalties for error (Kahneman & Tversky, 1979)—typically studied in the context of winning or losing money (e.g., Smith, 1976). Adults are sensitive to how probabilities of different options relate to risks and rewards. In decision theory, this is referred to as a cost function. Cost functions characterize the risk and reward of each action based on the probability of success and the expected gain (Glimcher, 2003). In many motor tasks, adults select actions near the optimal points in a cost function (Körding & Wolpert, 2006; Trommershäuser, Maloney, & Landy, 2008). For example, they show sensitivity to the variability of their perceptual-motor systems by aiming hand movements to hit a target to earn money while avoiding penalty areas that result in losses (Trommershäuser et al., 2008).

Previous studies of infants approaching the brink of steep slopes and high cliffs indicate that infants can recognize penalties for error and use risk and reward to inform their decisions. Experienced walking infants refuse to walk at impossible increments that would result in falling into the precipice (Adolph, 1997; Kretch & Adolph, in press). But we do not know how infants weigh different penalties for error. Previous work varied possibilities for action (e.g., steepness of the slope, height of the cliff, or traction on the soles of infants' shoes) but not penalties for error (Adolph, 1997; Adolph, Karasik, & Tamis-LeMonda, 2010; Kretch & Adolph, in press; Tamis-LeMonda, Adolph, Lobo, Karasik, & Dimitropoulou, 2008): In all of these studies, the penalty for error was falling. Although infants may weigh their perception against penalties for errors, they might simply ignore penalties for error and select actions based solely on the probability of success. By varying possibilities for action and penalties in the same task, we can distinguish between these interpretations.

To weigh possibilities for action against penalties for errors, infants must be able to integrate multiple sources of information. Indeed, experienced 18-month-old walkers can integrate perceptual information generated by their own exploratory activity (looking and touching) with social information provided by their caregivers (encouragement or discouragement) to decide whether to walk down possible, impossible, and uncertain slopes (Tamis-LeMonda et al., 2008). When slopes were clearly possible or impossible, infants ignored mothers' advice and selected the appropriate action. But when slopes were in the region of uncertainty between possible and impossible, infants gave more weight to mothers' advice—they walked when mothers said "go" and avoided when mothers said "no." While wearing slippery, Teflon-soled shoes that made formerly safe slopes impossible, infants relied on information from mothers in their new region of uncertainty (Adolph et al., 2010).

Falling and Entrapment

To test whether infants differentially weigh penalties for error when selecting actions, we must present them with penalties that are ecologically relevant. In adult research, penalties typically involve losing money. Infants are not financially motivated, but they might care about avoiding injury. We focused on falling and entrapment, two leading causes of accidental injury in infants and children (Doraiswamy, 1999; Drago & Dannenberg, 1999; Mathers & Weiss, 1998). Infants treat falling into a precipice as an aversive penalty, even when rescued by an experimenter. However, entrapment—becoming trapped in an opening—appears to follow a different developmental trajectory. Adults accurately judge whether openings are large enough to allow walking (Franchak, van der Zalm, & Adolph, 2010; Wagman & Taylor, 2005; Warren & Whang, 1987) and reaching (Ishak, Adolph, & Lin, 2008). But infants and children, from 16 months to 6 years of age, overestimate their abilities for reaching through apertures. They err by wedging their hands and fingers into impossibly small openings (Ishak, Franchak, & Adolph, 2011). Similarly, when given a forced choice between crawling through a 30-cm wide, low opening or walking through a 10-cm wide, tall opening, 18- to 26-month-olds frequently choose the impossible doorway (Brownell, Zerwas, & Ramani, 2007).

The findings on entrapment present a puzzle: Why might experienced 18-month-old walkers distinguish between possible and mpossible slopes and cliffs but not possible and impossible openings? Possibly, infants do perceive whether they can fit through openings, but attempt to walk through nonetheless because they discount entrapment as a penalty for errors. In contrast, they accurately distinguish between possible and impossible slopes and cliffs because those obstacles present a penalty for errors that they care about—falling.

Current study

The aim of the current study was to determine what infants know about fitting through openings—whether they distinguish possible and impossible openings. However, what infants do when confronted with different openings—attempting or refusing to walk through—might depend on both their perception as well as decision-making factors like risk and reward. Thus, to test whether infants' decisions reflect the penalty for errors, we designed a task that involved two penalties for error—falling and entrapment—for attempting to walk through impossibly small openings. In the falling condition, infants walked through openings of varying width along a ledge; decision errors resulted in falling off the side of the walkway. In the entrapment condition, infants walked through openings created between two walls and errors resulted in becoming trapped in the opening. Comparing infants' decisions in these tasks can help to resolve whether experienced walking infants do, in fact, know the difference between possible and impossible openings. We predicted that infants would treat entrapment as a less severe penalty and make larger errors compared to infants in the falling condition.

It is important to note that the penalty conditions differed with regard to their visual appearance: In the entrapment condition the opening was defined by the edges of the two walls and the floor (a “U” shape) but in the falling condition the opening was defined only by one wall and the floor (an “L” shape). If the absence of one of the defining edges made judging the opening more difficult, infants’ decisions should be less accurate in the falling condition—the opposite of what we predicted based on penalties for error.

In addition to comparing penalty conditions, we scored multiple measures of perception to disentangle perceptual sensitivity from decision-making factors. In addition to indexing infants’ decisions, that is, their attempts and refusals to walk through openings, we observed whether they modified their gait on possible openings by turning sideways to fit through smaller openings compared to walking straight through larger ones. Matching body orientation to opening size provided an independent measure of perceptual sensitivity when penalties for error are irrelevant (all openings were possible to walk through). We also measured infants’ approach behaviors on impossibly small openings—whether they approached the openings and touched them with hands and feet rather than avoiding approach.

Because possibilities for fitting through openings depend on body size relative to opening size, we measured attempts relative to infants’ actual abilities to control for differences in body size and walking skill. Thus, we presented each infant with possible and impossible openings tailored to their individual abilities. Moreover, testing infants across a range of trials from possible to impossible reveals whether behaviors are scaled to changes in opening size.

Method

Participants

Thirty-two walking infants (15 boys and 17 girls) participated in the study. Infants were 17 months old (± 14 days). An additional 3 infants were recruited but did not complete the study due to fussiness. Families were recruited through mailing lists, referrals, and hospitals from the greater NYC metropolitan area. Most infants were white and middle-class. Families received souvenirs (framed photograph and certificate) for their participation.

Infants were assigned in alternating order to the *entrapment* or *falling* condition; 16 infants participated in each with gender roughly balanced between conditions. In a structured interview, caregivers reported when their infants first walked 10 feet without falling; caregivers referred to calendars, baby books, or dated photographs to help provide accurate dates. Infants averaged $M = 4.4$ months ($SD = 1.6$) of walking experience on the date of testing. Walking experience was comparable between the two conditions and within the range of previous studies with “experienced” walkers who perceived action possibilities adaptively (Adolph, 1997; Kretch & Adolph, in press; Tamis-LeMonda et al., 2008).

Parents reported if and when infants’ hands (16 infants), heads (4 infants), or entire bodies (10 infants) had become wedged in an opening and required rescue. For example, one infant’s hand got trapped in a VCR and one unlucky boy got his head stuck in a training potty. In total, 22 of the 32 infants (68.8%) had experienced entrapment of some form. None of the entrapment episodes required medical attention. Parents of 13 of the 32 infants (40.6%) reported that their infants had experienced a serious fall from a drop-off that caused visible injury or required a call to a doctor. Most accidents involved falling from furniture, such as rolling off of a bed or a couch.

Apparatus

Infants walked over a raised walkway (4.9 m long × 1 m wide × 0.65 m high) with a sliding doorway that was adjusted in 1-cm increments to create openings ranging from 0 to 75 cm in width (Figures 1A-1B). The experimenter placed infants 3.5 m away from the opening at the start of each trial. The sliding doorway was 1 m high, requiring infants to fit their entire bodies, from head to toe, through the opening. In the entrapment condition, a fixed wall (1 m high × 0.6 m wide) was attached to the walkway, perpendicular to the sliding door, to create a bounded opening (Figure 1A). The fixed wall was removed in the falling condition—infants walked through unbounded openings between the sliding wall and the edge of the walkway (Figure 1B). The height of the drop-off in the falling condition was 0.65 m—too large for infants to safely step down.

An assistant panned a camera from the side to record infants as they approached the opening (the view shown in Figures 1C-1D). A second camera, placed above the apparatus, provided a view of infants' body orientation as they walked through. A third camera, mounted to the sliding doorway, projected calibration markings from a tape measure to allow accurate adjustment of the doorway. The video feeds from the three cameras were mixed into a single video file and captured digitally at 30 frames/s.

Procedure

Infants began each trial at the starting line. Caregivers sat at the end of the walkway and offered toys and dry cereal to coax infants to walk through the opening. An experimenter walked alongside infants to ensure their safety. Each trial lasted 30-s or until the infant crossed to the other side of the walkway, became wedged in the opening (entrapment condition), or fell off the side of the walkway (falling condition).

At the start of the session, infants completed 4 warm-up trials at the largest opening width (75 cm). Afterwards, trials were presented according to a modified staircase procedure (Adolph, 1997) to determine each infant's success threshold—the smallest opening the infant could successfully walk through on ≥ 67% of trials (Figure 2). Success rate was calculated as the proportion of successful walks out of the total number of successes and failures at each opening size, ignoring trials that resulted in infants refusing to walk through. The staircase procedure started at a baseline width of 40 cm, an opening size that infants could easily navigate facing forward in both conditions. After successful trials (walked through the opening without falling or becoming wedged), the experimenter decreased the opening size by 3 cm for the subsequent trial. After failures (fell or became entrapped when walking through the opening) on two consecutive trials, the experimenter increased the opening by 2 cm. In the entrapment condition, trials in which infants put their torsos into the doorway and became stuck counted as failures (Figure 1C). In the falling condition, only trials in which infants fell off the walkway counted as failures. Thus, failures in each condition corresponded to the penalty for errors, either entrapment or falling. The experimenter provided large, baseline trials at 40 cm as needed to prevent infants from becoming frustrated. Trials were presented following this procedure until the success threshold was determined: Infants succeeded on at least 2 of 3 trials at the threshold width and failed on at least 2 of 3 trials at each of the 3 smaller opening widths. Five infants in the falling condition never failed, so we determined their thresholds based on successes and refusals.

After determining the success threshold, the experimenter presented probe trials to assess infants' decisions when faced with possible and impossible openings. Infants completed at least two trials at ± 1 cm, ± 3 cm, ± 6 cm, and ± 9 cm relative to their individual success thresholds (Figure 2, bottom axis). In total, infants completed $M = 43$ trials, ranging from 28 to 61 trials, depending on how many trials were needed to find threshold. At the end of the session, the experimenter measured infants' nude weight (kg), recumbent height (cm), and head circumference (cm). Sessions lasted approximately 45 to 60-min.

Data Coding

A primary coder scored each trial using a computerized video coding software, OpenSHAPA (www.openshapa.org). A second coder independently scored 25% of trials; coders agreed on ≥ 91.2% of trials (*kappas* ≥ .83) for each code. All disagreements were resolved through discussion.

Coders determined if infants successfully walked through the opening, attempted but failed to walk through, or refused to attempt passage. Success thresholds calculated from video matched those determined online for all but 2 infants. In addition, for each attempt, coders scored *prospective turning*—whether infants turned their shoulders ≥ 45° as they approached the opening rather than facing straight forward. Coders also scored *approaching* the opening based on whether infants walked up to the opening and either touched the edges of the doorway or poked their hands or feet in the opening without attempting to fit through.

Results

Success Thresholds

Across conditions, success thresholds ranged from 6 cm to 17 cm ($M = 12.5$ cm). As shown in Figure 3, average thresholds were similar for the entrapment ($M = 12.4$; $SD = 0.8$) and falling conditions ($M = 12.5$; $SD = 3.1$). Thresholds in the entrapment condition occupied a narrow range, varying only from 11 cm to 14 cm, because infants' body dimensions constrained thresholds for fitting through the doorway and infants did not vary greatly in size: Body-mass index, a measure of body proportion that takes both height and weight into account, correlated with threshold opening width in the entrapment condition, $r(13) = .66$, $p = .008$), but not in the falling condition, $r(12) = -.04$, $p = .99$. Presumably, thresholds in the falling condition depended more on walking skill than body dimensions. Indeed, 3 infants managed to navigate openings less than 10 cm in width by holding onto the moving wall with their hands to keep balance. Infants with earlier walking onsets tended to navigate smaller openings, however, the correlation did not reach significance in the small sample of infants tested, $r(14) = -.44$, $p = .09$. Walking onset was unrelated to success thresholds in the entrapment condition, $r(14) = -.02$, $p = .95$.

Attempt Rates

At the individual level, more infants erred in the entrapment condition than in the falling condition. Every infant in the entrapment condition became wedged in the opening on at least one trial; however, only 9 of 16 infants in the falling condition erred by falling off the walkway. Prior experiences with falling or entrapment did not predict attempt rates in either condition.

To determine infants' sensitivity to changes in opening size, we analyzed attempt rates relative to infants' individual success thresholds to determine whether their decisions reflected the probability of success. Because thresholds varied widely, the same absolute opening size could be possible or impossible depending on infants' abilities—a 12-cm aperture was easy for an infant with a 6-cm threshold but impossible for an infant with a 17-

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cm threshold. To compare action selection across infants, we clustered trials into 7 opening sizes based on opening width relative to threshold. Each size group spanned 3 cm (i.e., the 0-cm group included responses from −1 cm to +1 cm around threshold, the +3-cm group included responses from +2 cm to +4 cm, etc.). Thus, the 7 opening sizes divided trials into impossible (−9 cm, −6 cm, −3 cm), uncertain (0 cm), and possible openings (+9 cm, +6 cm, +3 cm).

For each opening size, infants' attempt rates were calculated as the proportion of trials at which they attempted to walk through the opening (successes and failures) divided by the total number of trials for that opening size (successes, failures, and refusals). As shown in Figure 4A, attempts decreased on impossible openings, but more so for the falling condition. A 7 (opening size) × 2 (penalty condition) repeated-measures ANOVA on attempt rate confirmed a main effect of opening size, $F(6, 174) = 141.25$, $p < .001$, partial η2 = .83, a main effect of condition, $F(1, 29) = 39.96$, $p < .001$, *partial*-$\eta^2 = .58$, and a condition × opening size interaction, $F(6, 174) = 13.05$, $p < .001$, partial η2 = 31. Sidak-corrected pairwise comparisons revealed that infants in the entrapment condition attempted significantly more often at the −3 cm, 0 cm, and +3 cm openings (*p*s < .01). At −3 cm, where passage was impossible, infants in the entrapment condition erred by attempting and becoming entrapped on $M = 81.2\%$ ($SD = 23.4$) of trials, compared to infants in the falling condition who erred on only $M = 20.9\%$ ($SD = 20.2$) of trials.

Prospective Turning

To determine whether errors in the entrapment condition reflected a deficit in perception or merely a difference in decision-making, we examined infants' behaviors when the penalty for errors was not a factor. Considering only possible openings (the opening was large enough to pass through), we analyzed whether infants oriented their bodies to match the spatial requirements of the opening. Correctly orienting the body in advance of reaching the opening would provide evidence that infants accurately perceived the possibilities for action.

Similar to attempt rate, we clustered trials into 4 opening size groups, but used clusters twice as large (6 cm) to ensure that enough trials fell within each cluster and to capture differences in infants' prospective turning across a larger range of opening sizes. The opening size groups were centered on +3 cm, +9 cm, +15 cm, and +21 cm relative to each infant's threshold. Infants turn rate was scaled to opening size, and visual guidance of body orientation was scaled similarly between the two conditions (Figure 4B). A 4 (opening size) × 2 (penalty condition) repeated-measures ANOVA yielded a significant main effect of opening size, $F(3, 90) = 79.3$, $p < .001$, *partial*-$\eta^2 = .73$, but neither the main effect of penalty condition nor the condition × opening size interaction reached significance. A linear trend contrast on opening size, $F(1, 30) = 325.1$, $p < .001$, *partial*-$\eta^2 = .92$, showed that infants walked straight through larger apertures but turned their shoulders to fit through smaller ones.

Approach

Prospective turning suggested that infants' perceptual guidance was similar when opening sizes were larger than threshold. However, it is possible that infants' perception differed on the impossible openings for which infants in the entrapment condition made more errors. We could not use prospective turning to assess infants' perception for impossible openings because infants in the falling condition rarely attempted to walk through. Instead, we measured infants' rate of approach to determine what behaviors preceded infants' decisions when openings were impossibly small—did infants approach the openings before refusing, or did they avoid the opening altogether?

We calculated the proportion of trials where infants approached the opening for the 3 smallest opening size groups that were used to calculate attempt rates (−9 cm, −6 cm, and −3 cm). Similar to turn rate, approach rate scaled to opening size but did not vary according to penalty condition (Figure 4C). A 3 (opening size) × 2 (penalty condition) repeated-measures ANOVA confirmed a main effect of opening size, $F(2, 52) = 4.97$, $p = .011$, *partial-η2* = .16, but revealed no effect of penalty condition or interaction between opening size × penalty condition. Infants approached the opening more often on trials near threshold, as confirmed by a significant linear trend of opening size, $F(1, 26) = 7.91$, $p = .009$, *partial-*$\eta^2 = .23$. On openings nearer to threshold (−3 cm), infants approached on $M = 88.3\%$ of trials (SD = 21.1) compared to $M = 69.4\%$ ($SD = 38.6$) on the smallest openings (−9 cm). Thus, even when the opening was clearly impossible, infants in both conditions still approached and touched the opening on the majority of trials. Infants in the falling condition approached the opening, but ultimately refused to try to walk through. In contrast, infants in the entrapment condition approached, put their hands and feet in the opening, but then pushed their bodies into the opening and became stuck.

Discussion

The current study examined what infants know about possible and impossible actions. Infants were encouraged to walk through large and small openings under one of two penalties for error—falling or entrapment. In the falling condition, infants scaled decisions to opening size by attempting possible openings and refusing to walk through impossible ones. In the entrapment condition, infants erred by attempting to squeeze through impossibly small openings. Although decisions differed between penalty conditions, gait modifications and approach behaviors were identical: In both conditions, infants adjusted their bodies to match the spatial requirements of possible openings and they approached impossible openings and touched them with their hands and feet.

What infants know about possibilities for walking through openings

Can infants perceive whether openings are possible to walk through? Considered alone, high error rates in the entrapment condition suggest that infants cannot distinguish possible from impossible openings. However, low error rates in the falling condition point to highly adaptive action selection: Infants' error rates in the falling condition (20% error rate on openings 3 cm too small to allow passage) are comparable to those of adults (15%–20% error rate on openings 2–3 cm too small to allow passage), suggesting that infants in the falling condition may be close to ceiling performance (Franchak, van der Zalm, Hartzler, & Adolph, 2009).

Could squeezing into impossibly small openings be a form of perceptual-motor exploration that is not displayed by adults? Certainly, every motor action generates perceptual information and in that sense failed attempts serve an exploratory function. However, the evidence from multiple measures suggests a different interpretation. Infants showed no improvement over trials; they repeatedly attempted the -3-cm opening and became wedged over and over. Moreover, at the same impossible openings where decisions differed between penalty conditions, approach behaviors were equivalent. Possibly, infants in both conditions approached impossible openings to gather more information when they were uncertain, but how they acted on that information differed. In the falling condition, infants decided it was too risky to attempt and retreated from the opening, but in the entrapment condition, infants kept going and got stuck. Regardless of whether failed attempts were exploratory in intent, the decision was maladaptive and required us to rescue the infants.

Might differences in the falling and entrapment conditions have resulted from differences in the visual information for the openings? In the falling condition, infants viewed an L-shaped passage with a wall on one side—essentially, a ledge, and in the entrapment condition, they were presented with a U-shaped passage with walls on both sides—a doorway. These visual differences could have affected infants' decisions. However, if perceptual sensitivity differed between the two conditions, infants should have displayed differences in prospective gait modifications and approach behaviors as well as attempts. But they did not.

Indeed, independent measures of infants' perceptual sensitivity to changes in action possibilities—prospective turning and approach behaviors—suggest that perception was equally accurate in the two conditions. On possible openings, infants in both conditions modified gait to match opening size in advance, demonstrating that they perceived the spatial requirements of the opening before they reached it. We found similar evidence of prospective control in studies of infants reaching through openings: Although infants' decisions were inaccurate and they erred by wedging their hands into impossibly small openings, they hesitated longer and touched the opening less frequently with decreases in opening size (Ishak et al., 2011). In the current study, infants approached openings on most of the impossible trials. The high rate of approach in the falling condition rules out the possibility that refusals were merely due to general avoidance or fear of falling: Infants walked up to the ledge and touched the wall or poked a foot into the opening before attempting or refusing to walk through the opening. In both conditions, approach behaviors revealed sensitivity to opening size—they approached more frequently for openings near threshold and avoided more frequently on the narrowest openings.

What infants decide to do depends on probability and risk

If perceptual sensitivity was equivalent in entrapment and falling conditions, then differences in attempt rates reflect different weightings of penalties for error. In other words, the difference between the conditions was the point at which infants transitioned from attempting to refusing—reminiscent of different cost functions for the two tasks. Both groups made errors, but differed in what type of errors they were willing to make. On impossible, -3 cm openings, infants in the entrapment condition erred by being overly liberal; they attempted to walk through openings that were too small. But on possible, +3 cm openings, infants in the falling condition erred by being overly conservative; they refused to walk through openings that they could fit through. In both conditions, infants performed equivalently on the ±6 and ±9 cm openings, suggesting that they used information about penalties selectively. They ignored penalties for error when the action was clearly possible or impossible because they knew what to do. Weighing information sources selectively is consistent with previous work showing that 18-month-olds ignore mothers' advice on clearly possible and impossible slopes but take social information into account when possibilities for action are uncertain (Tamis-LeMonda et al., 2008).

Infants treated falling as a more serious penalty than entrapment. The fact that infants are motivated by some penalties more than others has implications for how researchers might interpret infants' failures. Specifically, our data suggest that infants may not demonstrate the extent of their perceptual knowledge unless faced with a penalty that they care about. Literature on the development of reaching and locomotion is consistent with this suggestion: Studies of infants attempting to fit their hands through openings and their bodies through doorways do not find evidence of accurate perception (Brownell et al., 2007; Ishak et al., 2011), but studies of infants falling off cliffs and down slopes do (Adolph, 1997; Kretch & Adolph, in press).

Our findings call into question claims that 18-month-olds lack "body awareness" based on failed attempts to walk through an impossibly narrow 10-cm opening (Brownell et al., 2007). A 10-cm opening (roughly corresponding to our -3-cm opening size group) is just smaller than threshold for most 17-month-olds in our study and, presumably, many 18-

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month-olds. We found, in agreement with Brownell and colleagues (2007), that infants persistently try to fit through openings approximately 3 cm too small if the penalty is entrapment. However, when the penalty is falling, infants' decisions showed adult-like performance at the same opening size. If infants lacked body knowledge, they would not be able to demonstrate accurate perception in the falling condition.

Our findings also have practical implications for ensuring infants' safety. Falling and entrapment are two of the leading causes of accidental injury in infants. The results suggest that even though experienced walking infants can perceive risks of falling and entrapment accurately, they may discount the potential danger of ntrapment. Their willingness to squeeze themselves into impossibly small openings may contribute to the prevalence of entrapment injuries.

Conclusion

Determining what infants know based on what they do requires an inferential leap. In perceptual-motor tasks, action selection reflects both perceptual sensitivity and decision-making. Infants' failures in a task might be a failure of perception, overly liberal decision-making, or both. We offer two suggestions for constraining researchers' inferences about what infants know. First, varying both possibilities for action and penalties allowed us to assess what infants know in terms of perceptual sensitivity and decision-making. Measuring behaviors across the range of action possibilities showed that infants used penalty information selectively depending on perceptual certainty; future research should vary penalties for error quantitatively to determine how optimally infants weigh risk and reward. Second, convergent measures help to elucidate the underlying causes of infants' actions. Collecting multiple measures of infants' perception across the range of action possibilities revealed body-scaled gait modifications and approach behaviors in both conditions. We conclude that with sufficient experience, walkers know when they can walk and when they cannot, regardless of whether the action involves falling or entrapment. But what infants decide to do depends on other factors, including penalties for error, social information, and motivation.

Acknowledgments

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

We gratefully acknowledge Angela Char, Bridget Hartzler, Arhanti Sadanand, and the members of the NYU Infant Action Lab for their help collecting data and for providing comments on the manuscript. We thank Samira Iravani for her beautiful illustrations.

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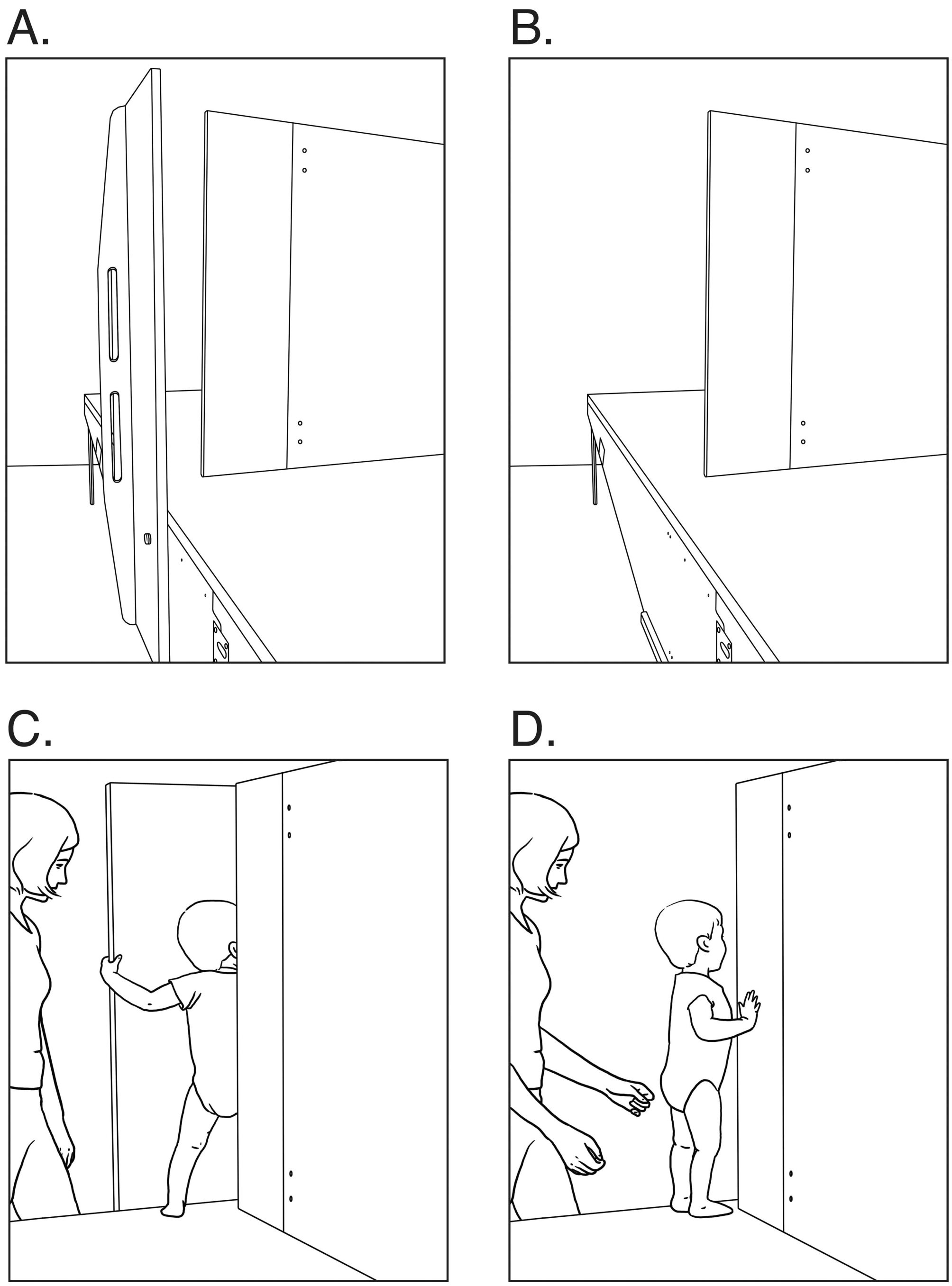

Figure 1.
Adjustable opening apparatus in (A) entrapment and (B) falling conditions. In entrapment, infants walked through bounded openings (C). In falling, infants walked along a ledge between the moving wall and a precipice (D).

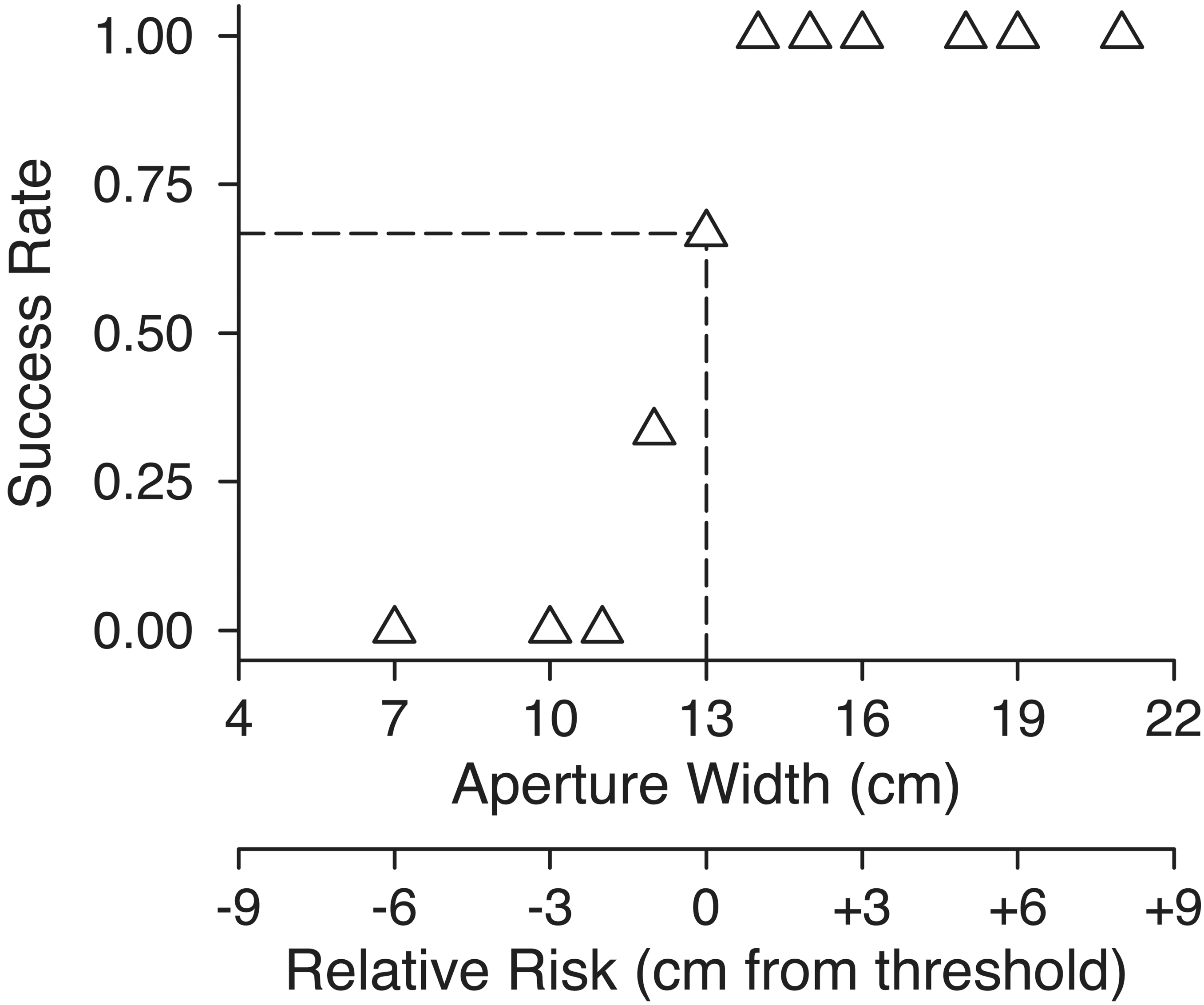

Figure 2.
Example of success rate data at each aperture width for one infant. Dashed lines mark the 67% success threshold. The bottom x-axis shows relative risk in centimeters: opening size normalized to the success threshold.

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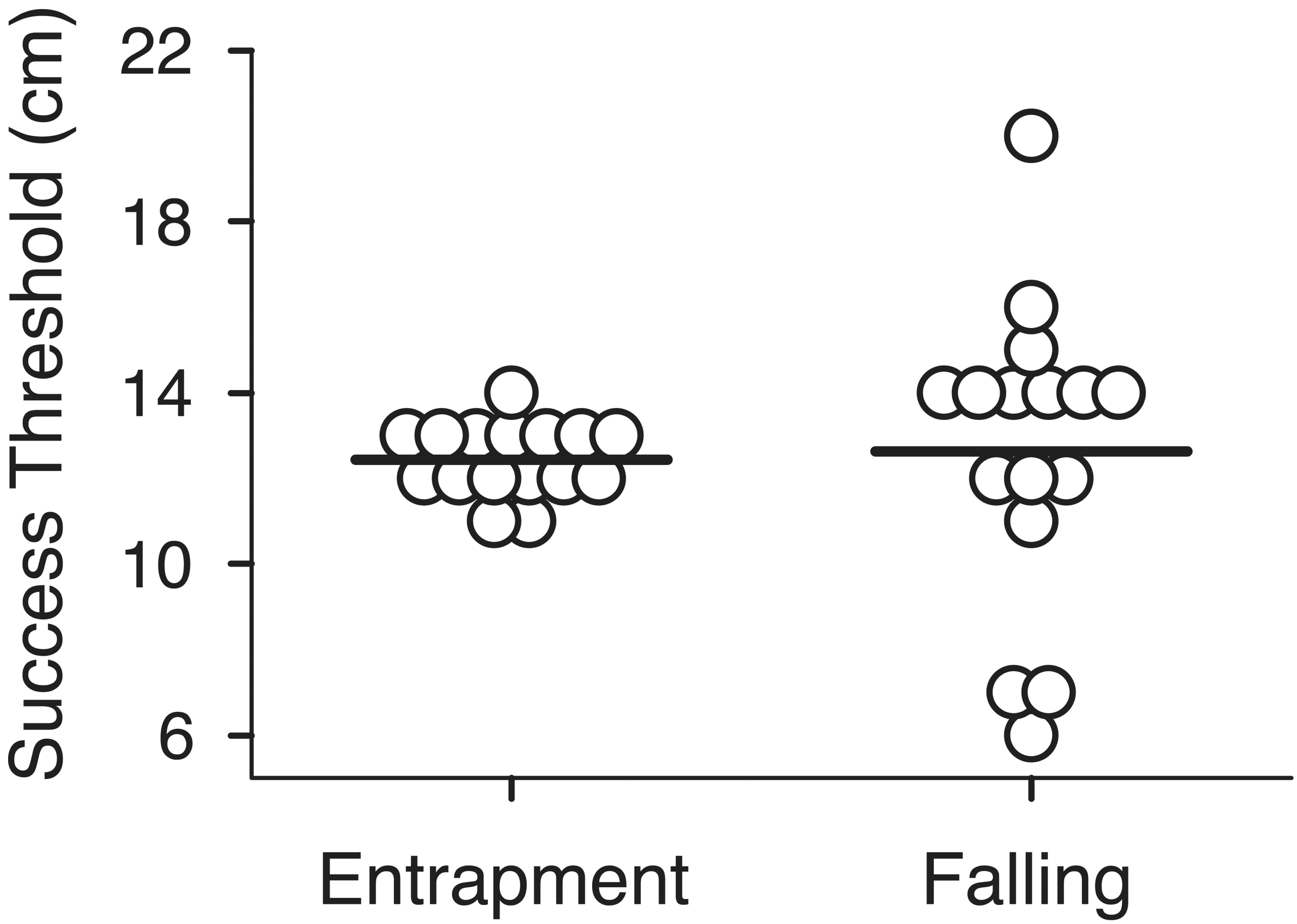

Figure 3.
Infants' success thresholds in the entrapment and falling conditions. Each circle shows data for one infant. Horizontal bars indicate means.

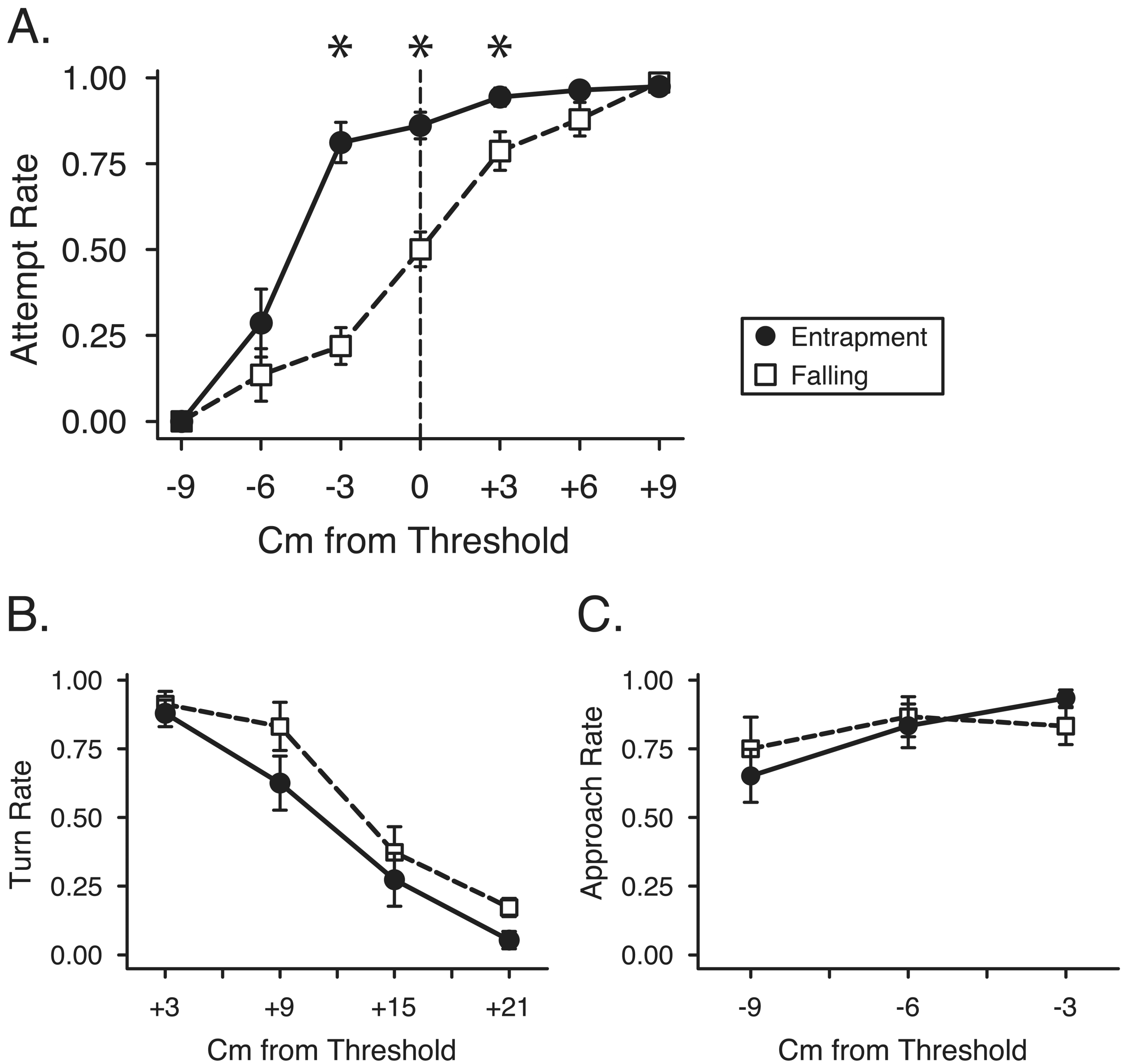

Figure 4.

Infants' rates of (A) attempts, (B) prospective turning, and (C) approaching in entrapment (filled circles) and falling (open squares) conditions. Vertical dashed line in (A) represents each infant's success threshold. Negative numbers on the x-axis denote impossible openings; positive numbers indicate possible openings.