Research Report

Psychological Science
24(7) 1361–1367

DOI: 10.1177/0956797613476047
pss.sagepub.com
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The Epigenesis of Wariness of Heights

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Abstract

Human infants with little or no crawling experience surprisingly show no wariness of heights, but such wariness becomes exceptionally strong over the life span. Neither depth perception nor falling experiences explain this extraordinary developmental shift; however, something about locomotor experience does. The crucial component of locomotor experience in this emotional change is developments in visual proprioception—the optically based perception of self-movement. Precrawling infants randomly assigned to drive a powered mobility device showed significantly greater visual proprioception, and significantly greater wariness of heights, than did controls. More important, visual proprioception mediated the relation between wariness of heights and locomotor experience. In a separate study, crawling infants' visual proprioception predicted whether they would descend onto the deep side of a visual cliff, a finding that confirms the importance of visual proprioception in the development of wariness of heights.

Keywords

emotional development, motor processes

Received 9/6/12; Revision accepted 11/28/12

The onset of wariness of heights in human infants is an enigma. Avoidance of drop-offs is so biologically adaptive that one would expect it to be present at the earliest testing opportunity. Indeed, that seems to be the case with many precocial infant animals, such as goats and rhesus monkeys (E. J. Gibson & Walk, 1960; Rosenblum & Cross, 1963), but not with human infants (Campos, Bertenthal, & Kermoian, 1992). Rather, after locomotion begins, human infants go through a phase during which they will go over the edge of a bed, a changing table, or even the top of a staircase, followed by a second phase during which they display an intense avoidance of heights. This unexpected and puzzling shift from non-avoidance to aversion of heights is witnessed almost without exception by mothers and has been observed in laboratory studies in which researchers used visual cliffs and risky slopes (Adolph, 1997; Campos et al., 1992; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978).

The explanation for the emergence of wariness of heights is also enigmatic. Falls cannot explain it, nor can the emergence of depth perception. The relation between falls and avoidance of heights or risky slopes is weak or nonexistent (Adolph, 1997; Campos et al., 1978; Walk, 1966). Contrary to widespread belief, depth perception is also not the explanation. Infants show stereopsis at 3.5 months (Fox, Aslin, Shea, & Dumais, 1980) and show a visual-placing response on the visual cliff at 6 months—that is, 2 to 3 months before they show signs of wariness (Walters, 1980). Locomotor experience precedes the phase of wariness (Campos et al., 1992; Campos et al., 1978), but by itself, it does not explain why or how wariness comes about.

Visual proprioception—the optically based perception of self-movement—may be the critical factor in the

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emergence of wariness of heights (Bertenthal & Campos, 1990). Visual proprioception plays a vital role in the control of balance and, like wariness of heights, undergoes a major developmental shift following locomotor experience (Higgins, Campos, & Kermoian, 1996). Movement of the head relative to the illuminated environment generates optic flow. Parameters of optic flow, such as its geometry and velocity, are related to parameters of physical motion, such as its direction and speed (J. J. Gibson, 1979). Peripheral lamellar optic flow (PLOF), as opposed to central radial optic flow (see Video S1–Optic Flow in the Supplemental Material available online for an illustration of the difference between PLOF and central radial optic flow), is a particularly potent determinant of visual proprioception during linear motion (Stoffregen, 1985)—witness the perception of self-motion experienced when one looks forward while seated in a train and the train on the adjacent track starts moving.

Two steps are involved in the explanation of how PLOF contributes to the emergence of wariness of heights. First, human infants are initially poor at using PLOF to control whole-body sway. Locomotor experience leads to the perceptual differentiation and use of PLOF, presumably because relegating control of posture during locomotion to the peripheral field of view frees the central field of view for steering and attending to objects and events in the environment (Anderson, Campos, & Barbu-Roth, 2003). The second step occurs when the infant who is perceptually attuned to PLOF encounters depth at an edge, leading to a loss of information on which the infant has come to depend. The texture ordinarily present relatively nearby in the periphery is now far away, such that even if the head and body sway considerably, the PLOF is minimal or absent. Once PLOF has become perceptually effective, this loss of information is the basis for wariness of heights, because of disparity between visual and somatosensory or vestibular information about self-movement or a decrease in postural stability.

The first step in the explanation of the emergence of wariness of heights has been confirmed. Locomotor experience plays a causal role in producing responsiveness to PLOF. Random assignment of prelocomotor infants to 15 days of training with a self-controlled *powered mobility device* (PMD; a baby go-cart; see Fig. 1, top left panel) resulted in significant improvements in

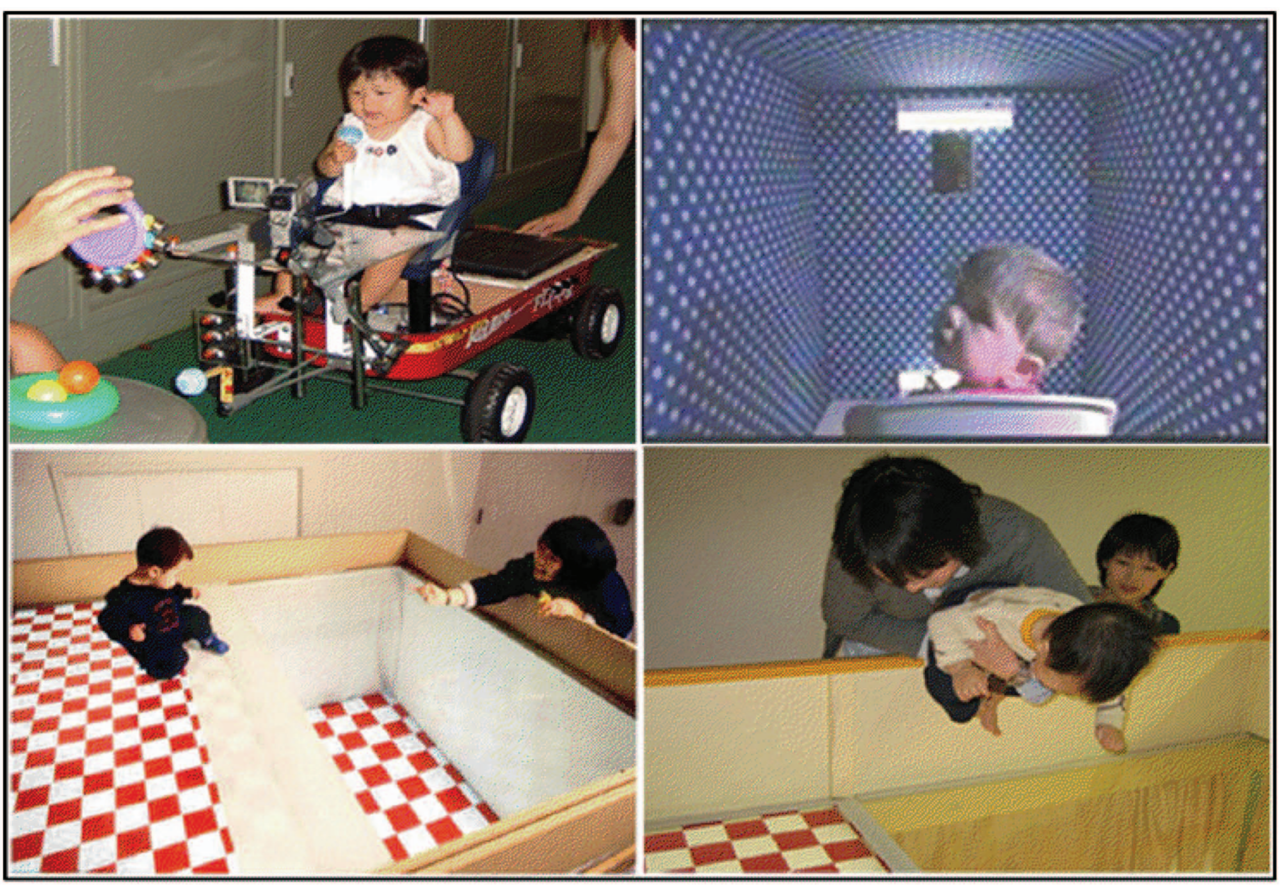

Fig. 1. Apparatus and procedure used in the crossing paradigm (Study 1) and the lowering paradigm (Study 2). The powered mobility device and the moving room are shown in the upper left panel and upper right panel, respectively. The lower left panel shows the visual cliff as used in the crossing paradigm. The lower right panel illustrates the lowering paradigm.

postural compensation to PLOF and greater emotional reactions to PLOF (Uchiyama et al., 2008). In line with our hypothesis, locomotor experience does not affect postural compensation to central radial optic flow (Higgins et al., 1996).

Studies with adult participants have provided indirect support for the second step in the explanation of the emergence of wariness of heights. The loss of visual proprioception is a potent determinant of height vertigo when peering over the edge of a building (Brandt, Arnold, Bles, & Kapteyn, 1980). Moreover, acrophobics are more reliant on optic flow for postural control than are nonacrophobics (Hüweler, Kandil, Alpers, & Gerlach, 2009), and fearful individuals show more postural sway when facing a drop-off (Davis, Campbell, Adkin, & Carpenter, 2009) than do nonfearful individuals.

We used two approaches to test the hypothesis that postural compensation to PLOF plays a role in the emergence of wariness of heights. In one study, we examined locomotor infants; in a second study, we examined prelocomotor infants randomly assigned to a PMD-training condition or a control condition. More specifically, in Study 1, we tested for the relation between postural compensation to PLOF and avoidance of the deep side of a visual cliff in infants with 6 weeks of locomotor experience—a time when many infants do not yet avoid heights, whereas other infants do. In Study 2, we tested whether precrawling infants randomly assigned to PMD training showed greater postural compensation to PLOF and greater cardiac indications of wariness on the visual cliff—cardiac accelerations and behavioral avoidance on the visual cliff cohere in indicating wariness (see Ueno, Uchiyama, Campos, Dahl, & Anderson, 2012.) More important, we predicted that postural compensation to PLOF would mediate the relation between cardiac indications of wariness and experimental condition.

Study 1

Method

In Study 1, we tested 27 crawling infants (13 female, 14 male; mean age = 42.3 weeks, SD = 0.60) in a *moving room* and on a visual-cliff apparatus. The moving room is a 1.20-m × 1.2-m × 2.1-m rectangular enclosure with the back wall removed (see Fig. 1, top right panel). We assessed responsiveness to PLOF by moving the side walls of the enclosure toward the infant. The index of postural compensation to PLOF was the peak cross-correlation (r_{max}) between infant sway and wall movement averaged across four trials (Higgins et al., 1996; Uchiyama et al., 2008). We sampled infants' center of pressure and wall position at 50 Hz and used data from the first 1.5 s of wall movement only (see Fig. 2).

The visual cliff was a large platform with a shallow side and a deep side, covered with a sheet of Herculite

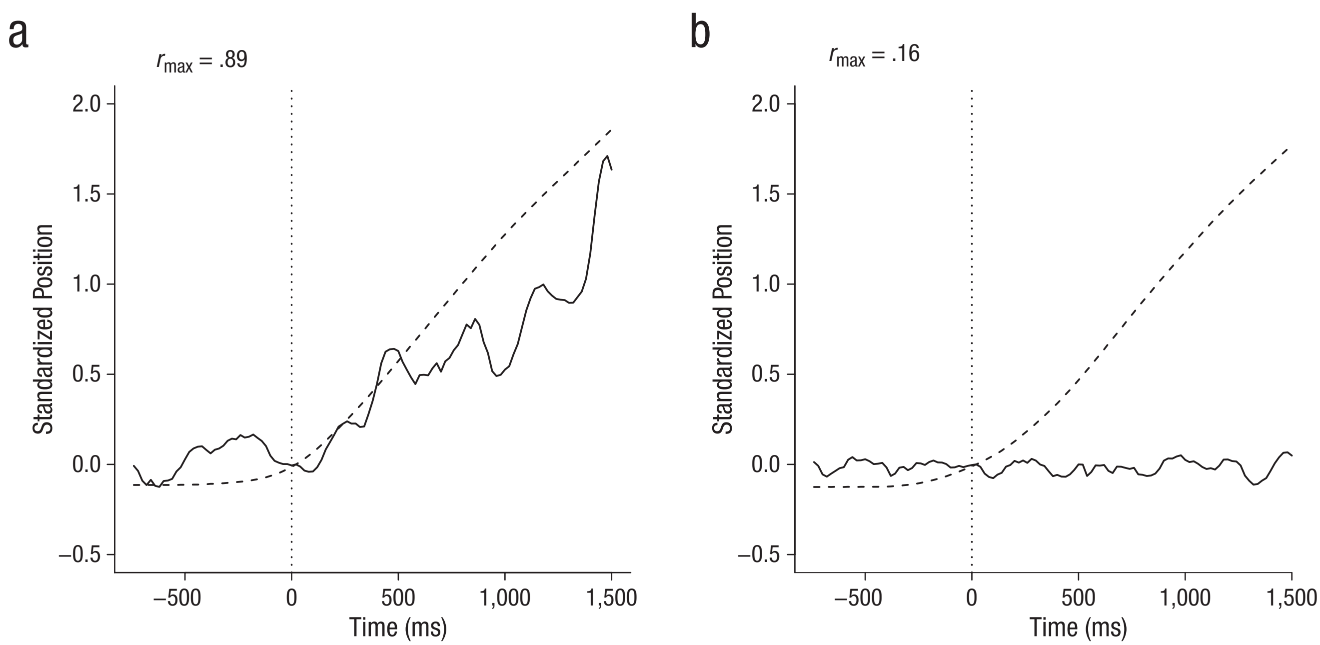

Fig. 2. Two examples of infant (solid line) and wall (dashed line) positions plotted against time. The graphs show data from 0.75 s before to 1.5 s after the onset of wall movement (indicated by the dotted vertical line). Before being plotted, infant- and wall-position data were divided by their standard deviations and centered on their position at the time of recorded wall movement. The graph in (a) shows data from one trial with a relatively strong response (r_{max} = .89), and the graph in (b) shows data from one trial with a relatively weak response (r_{max} = .16).

glass (Campos et al., 1992; Campos et al., 1978; Walk & Gibson, 1966). Immediately beneath the glass on the shallow side of the table and 1.1 m beneath the glass on the deep side was a checkerboard pattern of red and white tiles (see Fig. 1, bottom left panel). The transition between the shallow and deep sides created the illusion of a drop-off, and lighting underneath the tiles made the glass invisible to the infant. On each trial, an experimenter placed the infant on the center of the table and the mother called the infant to cross either the deep side or the shallow side of the cliff. The maximum trial time was 120 s.

Results

Of the 27 infants, 11 refused to cross on both deep-side trials, whereas no infants refused to cross on both shallow-side trials—McNemar's test: $\chi^2(1, N = 11) = 11.00$, $p < .001$. To assess the association between postural compensation to PLOF in the moving room and avoidance on the visual cliff, we fitted logistic regression models predicting infant crossing from mean peak cross-correlation, crossing side (deep vs. shallow), and a Mean Peak Cross-Correlation × Side interaction, with subjects entered as a random effect. Trial number (1 vs. 2) was included as a control variable. Preliminary analyses revealed no significant interactions between trial and either side or r_{max} (ps > .30). Models were compared using the difference in their −2 log likelihood (ΔD), which is approximated by a chi-squared distribution under the null hypothesis (Dobson, 2002).

As hypothesized, infants with higher postural-compensation scores were more likely to avoid the deep side of the visual cliff, $b = -22.92$, $z = -2.38$, $p = .018$, but not the shallow side, $b = 7.47$, $z = 1.01$, $p = .312$—Cliff Side × Mean Peak Cross-Correlation interaction: $\Delta D(1) = 6.40$, $p = .011$ (see Fig. 3a for estimated crossing behavior on the visual cliff as a function of moving-room performance). In addition, infants were somewhat more likely to cross on the second trial than on the first, $b = 2.082$, $z = 1.040$, $p = .011$.

The results of Study 1 supported the hypothesized link between visual proprioception and wariness of heights. Yet the correlational design could not rule out that the association simply reflected some uncontrolled variable, such as neurological maturation. There is currently no known technique for directly manipulating visual proprioception in infants, although, as noted, experience with self-controlled locomotion in a PMD increases postural compensation to PLOF (Uchiyama et al., 2008). However, Uchiyama et al. (2008) investigated the effect of PMD experience on a single phenomenon (responsiveness to PLOF), whereas Study 2 was an experimental test of the intrinsic link between two phenomena we expected to be affected by locomotor experience: responsiveness to PLOF and wariness of heights.

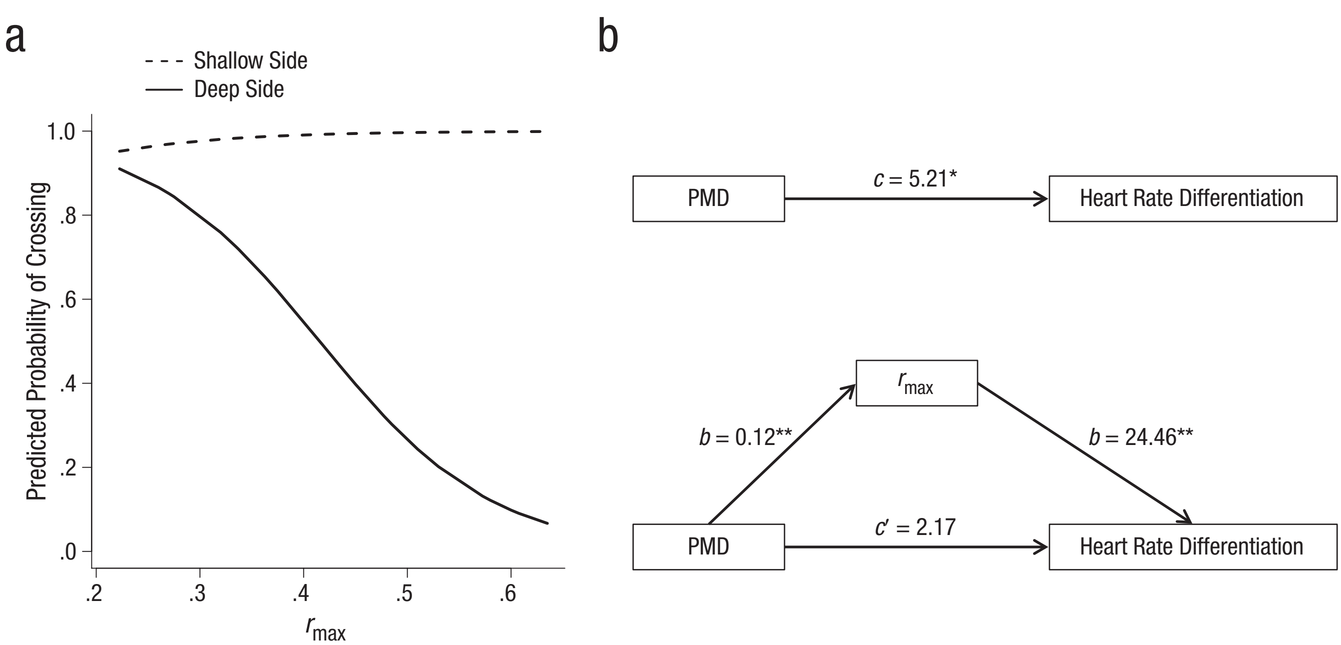

Fig. 3. Predicted probability of crossing the visual cliff as a function of moving-room performance in (a) Study 1 and mediation of the relation between powered-mobility-device (PMD) training and heart rate differentiation by moving-room performance in (b) Study 2. The graph in (a) shows fitted probabilities of an infant crossing on the deep side (solid line) and the shallow side (dashed line) as a function of mean peak cross-correlation (r_{max}). Asterisks indicate significant coefficients (*p < .05, **p < .01).

Study 2

Method

In Study 2, we used random assignment of prelocomotor infants to PMD or no-PMD training conditions. To test for wariness of heights in prelocomotor infants, in whom crawling could not be used to assess wariness, infants' heart rate was recorded while an experimenter lowered them from 1 m above the surface of the cliff to either the deep side or the shallow side of the cliff (see Fig. 1, bottom right panel). Heart rate decelerates in states of nonwary orientation and accelerates when an infant engages vigilant, wary attention (Campos, 1976). We predicted that infants in the PMD group would show increased postural compensation to PLOF and increased cardiac indications of wariness on the visual cliff, which were operationalized as mean heart rate acceleration on deep-side trials minus mean change in heart rate on shallow-side trials (*heart rate differentiation*). Most important, we tested whether the effects of PMD experience on wariness of heights were mediated by postural compensation to PLOF. That is, we asked whether PMD experience would be associated with increased wariness of heights primarily by bringing about changes in infant visual proprioception.

Twenty-three infants (14 female, 9 male) were randomly assigned to an experimental PMD condition or a control condition—PMD condition: n = 12, mean age = 28.93 weeks, SD = 0.99; control condition: n = 11, mean age = 29.96 weeks, SD = 1.46. Infants in the PMD condition received 10 min of PMD training per day over a 15-day period and were tested on the moving room before and after this training and were tested on the visual cliff after the training only. The control group received the same pattern of testing as the PMD group but no PMD training. The PMD training and the pretraining and posttraining testing took place in different rooms so as to minimize any effects of familiarity with the laboratory setting.

All infants completed two side-wall-forward trials in the moving room on each testing occasion. We administered the visual-cliff assessment only at the end of the study to prevent any effects of repeated exposure to the solid surface of the cliff. Infants completed two trials on each side of the cliff. Heart rate was averaged during the 3 s of lowering, and change in heart rate on lowering to each side was assessed in relation to the mean heart rate in the 3 s just prior to the initiation of lowering.

Results

As in prior work, infants in the PMD condition showed significant increases in postural compensation to PLOF from before the training period to after the training period (from mean r_{max} = .356 to mean r_{max} = .456), $t(11)$ = 2.738, p = .019, whereas infants in the control condition did not, from mean r_{max} = .354 to mean r_{max} = .332, $t(10)$ = −0.556, p = .295—Condition × Time interaction: $F(1, 21)$ = 5.197, p = .033. In addition, PMD-trained infants showed significant heart rate differentiation in an acceleratory direction between lowering to the deep and shallow sides of the cliff (mean heart rate differentiation = 3.107 beats per minute), $t(11)$ = 2.378, p = .037. In contrast, infants in the control condition did not (mean heart rate differentiation = −2.101 beats per minute), $t(10)$ = 1.596, p = .142—PMD condition versus control condition: $t(21)$ = 2.803, p = .011.

As predicted, the effect of PMD experience on heart rate differentiation was mediated by mean peak cross-correlation, indirect effect = 0.304, 95% confidence interval = [0.06, 0.64], p < .05, as estimated by the distribution of the product procedure (MacKinnon, Fritz, Williams, & Lockwood, 2007). Experimental condition was a significant predictor of heart rate differentiation on its own but not when controlling for mean peak cross-correlation (see Fig. 3b). In contrast, postural compensation to PLOF remained a significant predictor of heart rate differentiation on the visual cliff when controlling for experimental condition, b = 24.46, $t(20)$ = 2.91, p = .009. In both conditions, infants who had a higher mean peak cross-correlation also tended to show greater heart rate differentiation—PMD condition: b = 22.65, $t(20)$ = 1.90, p = .072; control condition: b = 26.23, $t(20)$ = 2.22, p = .038.

Discussion

The findings from studies using two different experimental paradigms and two different infant populations converged to support the hypothesis that visual proprioception contributes to the ontogeny of wariness of heights. In Study 1, postural compensation to PLOF significantly predicted whether newly crawling infants would cross the deep side of the visual cliff. In Study 2, the effects of PMD training on cardiac indications of wariness in precrawling infants were mediated by postural compensation to PLOF.

These findings help explain a major epigenetic event in infancy (Gottlieb, 2007): Wariness of heights comes about through a shift in infant visual proprioception, which typically results from experience with self-produced locomotion. However, we also predict that if a prelocomotor infant comes to rely sufficiently on PLOF for postural control through an alternative nonlocomotor experiential pathway, then she or he should also show wariness of heights. (There was a positive relation between mean peak cross-correlation and heart rate differentiation among infants in the control condition in Study 2.) The present evidence has implications for the work of E. J. Gibson and Walk (1960) and Rosenblum and Cross (1963) demonstrating wariness of heights in precocial animals: Is there a similar two-step process, involving experience-driven changes in visual proprioception, taking place very rapidly in these animals? Or is the relation between visual proprioception and wariness of heights evident from the start? These questions deserve further attention.

One comment is in order about the Study 2 control group's participating in fewer visits to the laboratory than the experimental group. Although a familiarity effect does not provide an obvious explanation for why the infants in the PMD condition showed greater heart rate differentiation on the visual cliff than did the infants in the control condition, it would be desirable to bring the control group to the laboratory for alternative training in future studies.

An important question arises from these findings: Why is there such a delay between the onset of locomotion—which is the setting event for encounters with life-threatening events, such as falls—and avoidance of heights? One major benefit of such a delay is that infants are more prone to explore their environment and the movement possibilities afforded by that environment when they are less concerned about the consequences of their actions. The result is better attunement to what the environment affords and the availability of more movement strategies in novel situations. Paradoxically, a tendency to explore risky situations may be one of the driving forces behind skill development (Plumert, 1995).

Author Contributions

J. J. Campos, D. I. Anderson, D. C. Witherington, I. Uchiyama, and M. Barbu-Roth developed the study concept and designed the study. Testing and data collection were performed and supervised by J. J. Campos, I. Uchiyama, M. Ueno, and L. Poutrain-Lejeune. A. Dahl analyzed the data. A. Dahl., J. J. Campos., and D. I. Anderson wrote the manuscript, and D. C. Witherington, I. Uchiyama, and M. Barbu-Roth provided critical revisions. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

This research was supported by grants from the Japanese Society for the Promotion of Science (Grant KAKENHI-22330191), the John D. and Catherine T. MacArthur Foundation, the National Institutes of Health (Grants HD-07181, HD-07323, HD-25066, HD-36795, and HD-39925), and the National Science Foundation (Grants SBR-9 1 16 15 1, BCS-0002001, and BSC-0958241), by a fellowship from the Center for Advanced Study in the Behavioral Sciences, and by a Research Infrastructure in Minority Institutions award from the National Institute on Minority Health and Health Disparities (Award No. P20 MD00262).

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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