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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. Subsequently, such wariness becomes exceptionally strong over the life-span. Neither depth perception nor falling experiences explain this extraordinary developmental shift; 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. Pre-crawling infants randomly assigned to drive a powered-mobility-device (PMD), showed significantly greater visual proprioception, and significantly greater wariness of heights, than controls. More importantly, visual proprioception scores mediated the relation between wariness of heights and locomotor experience. In a separate study, visual proprioception predicted whether crawling infants would descend onto the deep side of a visual cliff, confirming the importance of visual proprioception in the development of wariness of heights.

Keywords

Emotional Development; Motor Processes

The Epigenesis of Wariness of Heights

The onset of wariness of heights in human infants is an enigma. Avoidance of drop-offs is so biologically adaptive 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. Gibson & Walk, 1960; Rosenblum & Cross, 1963), but that is not so with the human infant (Campos, Bertenthal, & Kermoian, 1992). Rather, babies go through a phase after locomotion begins when they will go over the edge of a bed, a changing table, or even the top of a staircase, followed by a second phase when infants intensely avoid heights. This unexpected and puzzling shift from non-avoidance to aversion of heights is witnessed almost without exception by mothers, and observed in laboratory studies using visual cliffs and risky slopes (Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978; Campos et al, 1992; Adolph, 1997).

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Authorship

J.C.C., D.I.A., D.C.W., I.U., and M. B.R. developed the study concept and designed the study. Testing and data collection were performed and supervised by J.C.C., I.U., M.U., L.P.-J. A.D. analyzed the data. A.D., J.C., and D.I. wrote the manuscript, and D.C.W., I.U., and M.B.R. provided critical revisions. All authors approved the final version of the paper for submission.

Explaining the emergence of wariness of heights is also enigmatic. Falls are not the explanation, nor is 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 visual placing response on the visual cliff at 6 months, 2–3 months before they show signs of wariness (Walters, 1980). Locomotor experience precedes the phase of wariness (Campos et al, 1978; Campos et al, 1992) 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 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 our physical motion, such as its direction and speed (J. Gibson, 1979). Peripheral lamellar optic flow (PLOF), as opposed to central radial optic flow (see Movie 1 in the Supplemental Material available online), is a particularly potent determinant of visual proprioception during linear motion (Stoffregen, 1985) – witness the perception of self-motion one experiences when looking 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 utilizing PLOF to control whole-body sway. Locomotor experience leads to the perceptual differentiation and utilization 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 object 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 upon 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/body sways 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 and/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, figure 1A) resulted in significant improvements in 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 adults provide 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 (Hüweler, Kandil, Alpers, & Gerlach, 2009) and show more postural sway when facing a drop-off (Davis, Campbell, Adkin, & Carpenter, 2009), than non-acrophobics.

We used two approaches to test the hypothesis that postural compensation to PLOF plays a role in the emergence of wariness of heights. One study examined locomotor infants; a second examined prelocomotor infants randomly assigned to PMD training or a control condition. More specifically, Study 1 tested for the relation between postural compensation to PLOF and avoidance of the deep side of a visual cliff in infants with six weeks of locomotor experience – a time when many infants do not yet avoid heights while others do. . Study 2 tested whether precrawling infants randomly assigned to PMD training show 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 importantly, we predicted that postural compensation to PLOF would mediate the relation between cardiac indications of wariness and experimental condition.

Study 1

Method

Study 1 tested 27 crawling infants (13 female, $M_{\text{age}} = 42.3$ weeks, $SD_{\text{age}} = 0.60$) in a *moving room* and on a *visual cliff* apparatus. The *moving room* is a 1.2 m×1.2 m×2.1 m rectangular enclosure with the back wall removed (figure 1B). 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 infant center of pressure COP and wall position at 50 Hz and only used data from the first 1.5 sec of wall movement (Figure 2).

The *visual cliff* is a large table covered by Herculite® glass divided into a *shallow* side and a *deep* side (figure 1C, Campos et al, 1978; Campos et al, 1992; Walk & E. 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. The transition between the shallow and deep sides created the perception of a drop-off and lighting underneath the tiles made the glass invisible to the baby. 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 or shallow side of the cliff. Maximum trial time was 120 sec.

Results

On the *deep* side trials, 11 out of 27 infants refused to cross on both trials, whereas no infants failed to cross on both shallow side trials, McNemar's test: $\chi^2(1) = 14.06, p < .001$. To assess the association between postural compensation to PLOF in the moving room and avoidance on the cliff, we fitted logistic regression models predicting infant crossing from

$r_{\max}$ (mean peak cross-correlation), crossing side (deep vs. shallow), and an $r_{\max} \times$ Side interaction, with subjects 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 (D), which approximates a χ^2 -distribution under the null hypothesis (Dobson, 2002).

As hypothesized, infants with higher postural compensation score ($r_{\max}$) were more likely to avoid the deep side, $b = -22.92$, $z = -2.38$, $p = .018$, but not the shallow side of the visual cliff, $b = 7.47$, $z = 1.01$, $p = .312$ (cliff side $\times r_{\max}$ interaction: $D(1) = 6.40$, $p = .011$, Figure 3A). In addition, infants were somewhat more likely to cross on the second trial than on the first, $b = 2.082$, $z = 1.040$, $p = .011$.

Study 1 supported the hypothesized link between visual proprioception and wariness of heights. Yet, the correlational design cannot rule out that the association simply reflects some uncontrolled variable, like neurological maturation. There is currently no known technique for directly manipulating visual proprioception ability in infants, though, as noted, experience with self-controlled locomotion in a PMD increases postural compensation to PLOF (Uchiyama et al, 2008). Whereas Uchiyama et al. investigated the effect of PMD experience on a *single* phenomenon (responsiveness to PLOF), the present Study 2 was an experimental test of *the intrinsic link between two phenomena* expectedly affected by locomotor experience: responsiveness to PLOF and wariness of heights.

Study 2

Study 2 thus 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, heart rate (HR) was recorded while an experimenter lowered infants from 1 m above the cliff surface to either the deep or the shallow side of the cliff (figure 1D). HR *decelerates* in states of non-wary orienting and *accelerates* when an infant engages in vigilant wary attention (Campos, 1976). We predicted that infants in the PMD group would show greater postural compensation to PLOF and greater cardiac indications of wariness on the visual cliff, operationalized as mean HR acceleration on deep side trials minus mean HR change on shallow side trials (*HR differentiation*). Most importantly, we tested whether the effects of PMD experience on wariness of heights were mediated by postural compensation to PLOF. That is, would PMD experience be associated with increased wariness of heights primarily by bringing about changes in infant visual proprioception?

Twenty-three infants (14 female) were randomly assigned to an experimental PMD condition or a control condition (PMD: $N = 12$, $M_{\text{age}} = 28.93$ weeks, $SD_{\text{age}} = 0.99$. Control: $N = 11$, $M_{\text{age}} = 29.96$ weeks, $SD_{\text{age}} = 1.46$). Infants in the PMD condition received ten minutes of PMD training per day over fifteen days, pre- and post-testing on the moving room and post-testing on the visual cliff. The control group received the same pattern of testing as the PMD group, but no PMD training. The PMD training and the pre- and post-

testing took place in different rooms so as to minimize any effects of familiarity with the laboratory setting.

All infants received 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 received two trials on each side. HR was averaged during the three seconds of lowering and HR change upon lowering to each side was assessed relative to the mean of the three seconds just prior to the initiation of lowering.

Results

Consistent with prior work, infants in the PMD condition showed significant increases in postural compensation to PLOF from pre- to post-test (from $M_{r_max} = .356$ to $M_{r_max} = .456$, $t[11] = 2.738$, $p = .019$) whereas control infants did not ($M_{r_max} = .354$ to $M_{r_max} = .332$, $t[10] = -0.556$, $p = .295$. Condition $\times$ Time interaction: $F[1,21] = 5.197$, $p = .033$). In addition, PMD-trained infants showed significant HR differentiation in an acceleratory direction between lowering to the deep and shallow sides of the cliff ($M_{HR\text{differentiation}} = 3.107$ bpm, $t[11] = 2.378$, $p = .037$). In contrast, control infants did not ($M_{HR\text{differentiation}} = -2.101$ bpm, $t[10] = 1.596$, $p = .142$. PMD vs. Control group: $t[21] = 2.803$, $p = .011$).

As predicted, the effect of PMD experience on HR differentiation was mediated by postural compensation score (Indirect effect: 0.304, $CI_{95\%}$: 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 HR differentiation on its own, but not when controlling for r_{max} (Figure 3B). In contrast, postural compensation to PLOF remained a significant predictor of HR differentiation on the visual cliff when controlling for experimental condition, $b^* = 4.80$, $t(20) = 2.91$, $p = .009$. In both PMD and control groups, infants who had higher r_{max} also tended to show greater HR differentiation (PMD group: $b = 22.65$, $t[21] = 2.23$, $p = .018$. Control group: $b = 26.23$, $t[21] = 2.59$, $p = .008$).

Discussion

The findings from two different experimental paradigms and two different infant populations converge 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 in turn 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 non-locomotor experiential pathway, then she would also show wariness of heights. (There was a positive relation between r_{max} and HR differentiation among the control group infants in Study 2.) The present evidence has implications for the above-cited

work demonstrating wariness of heights in precocial animals: Is there a similar two-step link, 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 hypotheses deserve further attention.

One comment is in order about Study 2's control group participating in fewer visits to the laboratory than the experimental group. While a familiarity effect does not provide an obvious explanation for why the PMD infants showed greater HR differentiation on the visual cliff than did the control infants, 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 more movement strategies available when encountering novel situations. Paradoxically, a tendency to explore risky situations may be one of the driving forces behind skill development (Plumert, 1995).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
(A) The powered mobility device (PMD), (B) the moving room, (C) the crossing paradigm on the visual cliff (Study 1), (D) the lowering paradigm on the visual cliff (Study 2).

Figure 2.

Examples of infant (solid line) and wall (dashed line) position plotted against time. Figures show data from .75 seconds before to 1.5 seconds after start of wall-movement (time = 0, indicated with a dotted vertical line). Before plotting, infant and wall data were divided by their standard deviations and centered around their position at the time of recorded wall movement. (A) $r_{\max} = .89$. (B) $r_{\max} = .16$.

Predicted Crossing as a Function of $r_{\max}$ and Trial Side

Figure 3.

(A) Study 1: Estimated crossing behavior on the visual cliff as a function of moving room performance. The figure shows fitted probabilities of an infant crossing on the deep (solid line) and shallow (dashed line) side as a function of $r_{\max}$. (B) Study 2: Moving room performance mediates the relation between experimental condition and HR differentiation. Numbers represent standardized regression coefficients. * $p < .05$, ** $p < .01$.