Developmental Psychology
2008, Vol. 44, No. 5, 1225–1231

0012-1649/08/$12.00 DOI: 10.1037/a0013224

# Locomotor Experience Affects Self and Emotion

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Two studies investigated the role of locomotor experience on visual proprioception in 8-month-old infants. *Visual proprioception* refers to the sense of self-motion induced in a static person by patterns of optic flow. A moving room apparatus permitted displacement of an entire enclosure (except for the floor) or the side walls and ceiling. In Study 1, creeping infants and prelocomotor/walker infants showed significantly greater postural compensation and emotional responses to side wall movement than did same-age prelocomotor infants. Study 2 used true random assignment of prelocomotor infants to locomotor-training (via a powered-mobility device) and no-training conditions. Experimental infants showed powerful effects of locomotor training. These results imply that locomotor experience is playing a causal role in the ontogeny of visual proprioception.

*Keywords:* self-produced locomotion, visual proprioception, postural compensation, emotion, powered-mobility device

Herein we report experiments that markedly strengthen previous findings (Campos et al., 2000) showing that two very different seeming phenomena are closely linked. One is a relatively understudied but important perceptual phenomenon called *visual proprioception*. The second concerns a classic issue—the role of motoric factors in psychological development.

## Visual Proprioception: Its Definition and Importance

Visual proprioception is the awareness of one's own movement and resulting postural adjustments produced by patterns of optic flow (Gibson, 1979). Visual proprioception occurs even when vestibular and kinesthetic information specifies stasis. During locomotion, visual proprioception consists of (a) a radial expansion of the visual field emanating from the target of locomotion and (b) lamellar, nearly straight, layers of optic flow in the visual periphery (the limiting instance being the vertical walls to one's left and right in a corridor). Lamellar optic flow in the visual periphery is especially effective in producing perception of self-movement as well as postural compensation, even when there is no central, radial flow (for reviews, see Anderson, Campos, & Barbu-Roth, 2004; Dichgans & Brandt, 1978). When such flow goes from in front to behind a person, one perceives self-motion forward and shifts one's posture in the same direction as the optic flow; when the flow goes from behind to in front, one perceives oneself moving backward and shifts one's posture forward, again in the direction of optic flow. Everyone encounters this phenomenon and the power of peripheral optic flow when, sitting in a train, one feels oneself moving forward when an adjacent train starts to move backward. Far from a mere curiosity, visual proprioception is in fact crucial and adaptive in the maintenance and correction of posture with respect to the direction of self-movement.

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This research was supported by National Science Foundation Grant BCS-0002001, National Institutes of Health Grants HD-39925 and HD-50638, a France-Berkeley Fund Award, and National Center for Minority Health and Health Disparities Grant P20MD00262. Mika Ueno deserves special recognition for her exceptional work in carrying out the PMD study.

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## The Ontogeny of Visual Proprioception

Because it is as fundamental to perception as form, depth, and motion, visual proprioception has been thought to be both unlearned and thus possibly detectable even in the neonate—a prediction that has been confirmed at least for head movements (e.g., Jouen, 1988, 1990; Jouen, Lepecq, Gapenne, & Bertenthal, 2000), and by our own research linking neonatal air stepping to optic flow (Barbu-Roth, Anderson, Després, Provasi, & Campos, in press). However, the visual proprioceptive skills of the newborn, like other skills such as reaching, auditory localization, and face perception, must undergo further development. Jouen et al. (2000) and others (Bertenthal & Bai, 1989) have proposed that these subsequent developments may be tied to major developmental shifts in motoric skills of the infant that come online in the second half year of life pursuant to new postural control demands such as upright seating and locomotion.

Bertenthal and Bai (1989) bracketed such a developmental shift: 5-month-olds did not show postural compensation to peripheral flow, yet 9-month-olds did. A subsequent study by Higgins, Campos, and Kermoian (1996) replicated and extended Bertenthal and Bai's study, finding postural compensation to peripheral optic flow both in endogenously locomotor infants and also in prelocomotor infants with "artificial" locomotor experience in baby walker devices, by contrast with infants of the same age with no locomotor experience. Higgins et al. (1996) concluded that locomotor experience somehow "functionalized" peripheral optic flow for the control of posture. That is, locomotor experience led to (a) perceptual differentiation of peripheral from global optic flow and (b) changing peripheral optic flow from a noticeable but posturally ineffective visual event to one that systematically affects one's control of one's own movement.

There are good theoretical grounds to expect a link between locomotor experience and visual proprioception. Gibson (1979) argued that the visual system must control three important tasks during locomotion: (a) detecting whether a surface can be traversed, (b) steering around obstacles, and (c) maintaining postural control. Steering and attending to the surface of locomotion as well as to objects in the environment can be accomplished effectively by the infant noticing information in the central visual field, if other portions of the visual field (such as the periphery) are used to maintain postural stability. The functionalization of peripheral flow for postural control pursuant to the onset of locomotion thus makes great adaptive sense.

## Rationale: Replication and Extension, by Means of Converging Research Operations

Conclusions about important issues are markedly strengthened when converging research operations are used to triangulate the same point. In the research reported here, two converging operations tap into the consequences of self-produced locomotor experience. Because we used a moving room apparatus (Higgins et al., 1996) as a crucial tool in both studies, and because we can be succinct if we couch hypotheses in terms of this apparatus, we first describe the moving room.

As its name implies, a moving room is a rectangular-solid enclosure (hereafter referred to as a *room*) with an open back but five other inner surfaces that have high levels of visual texture. Our room uses a deep navy blue ground with a field of white dots. The room moves horizontally fore and aft past a person who is stationary. As a result, the person receives optic flow specifying self-movement, while vestibular and kinesthetic inputs specify that the person is stationary. In our research, the infant sits in a chair providing back support. Each of the five surfaces of the room—(a) ceiling, (b) left and right sidewalls, (c) floor, and (d) front wall—can be moved or not independent of, or in conjunction with, other surfaces. In the present research, we use only two of the many possible configurations: whole room, in which ceiling, sidewalls and front wall (but not floor) move together in concert, and sidewall, in which ceiling and sidewalls (but neither front wall nor floor) move together in concert. In the whole room condition, infants receive both central/radial and peripheral/lamellar optic flow. In the sidewall condition, infants receive only peripheral/lamellar optic flow. Fore-and-aft trunk sway of the infant (compensatory and otherwise) is captured through four pressure sensors in the platform supporting the chair on which the infant is seated. The infant's emotional reaction is scored from videos continuously recorded from a camera mounted behind a small aperture in the front wall (toward which the infant is looking). For further technical specifications, see Higgins et al. (1996).

### *Emotion as a First Converging Research Operation*

From Day 1 throughout the lifespan, emotion functions to facilitate adaptive responding with respect to the concerns of the organism (Campos, Frankel, & Camras, 2004). The presence of emotion, especially in the nonverbal infant, is thus a marker for a concern of the infant. If we are correct in our reasoning about the functionalization of peripheral optic flow, then, once an infant is locomoting, the infant should be more likely to display emotion in response to a sudden burst of optic flow in a moving room for several reasons, any or all of which could be operating. (a) For one, the infant can respond to the perceptual disparity: The vestibular and kinesthetic systems signal stationary sitting, while, to the locomotor infant especially, the optic flow signals self-motion. Such disparities reliably elicit affect (Hebb, 1946; Witherington, Campos, & Hertenstein, 2002). (b) Such bursts of optic flow also reliably induce increases in fore-and-aft sway, which, in the infant with locomotor experience more than the prelocomotor, should elicit strong distress reactions, inasmuch as the instability commonly precedes an (emotionally) undesirable fall (see Blatz, 1925; Watson & Morgan, 1917). (c) The burst of optic flow also violates transitional probabilities to which the locomotor infant is sensitized: The infant knows that she/he did not move and that no other person moved her or him; thus, the optic flow in the moving room creates a loss of control that is of (emotional) concern, by virtue of being rare, unexpected and invoking the peril of a fall. Whatever their basis or bases, we predicted emotion to be a reaction to peripheral optic flow present only or primarily in babies with locomotor experience: only such infants, by our reasoning, have functionalized visual proprioception to put peripheral optic flow in the service of postural stability and not falling, and only such infants are sensitized to any or all of the problems posed by a sudden burst of optic flow.

### *A Powered-Mobility Device as a Second Converging Research Operation*

In the second study reported here, we not only used emotion as a dependent variable convergent with postural compensation, but we also employed a new paradigm to manipulate locomotor experience—a powered-mobility device (PMD), the forward movements of which prelocomotor infants can control by means of a joystick. The PMD thus can provide self-produced locomotor experience to a prelocomotor infant. The use of a PMD also permits the random assignment of participants to conditions, enabling us to infer that it is something about self-produced locomotor experience that is bringing about a psychological change. In addition to the basic scientific value of affording random assignment and a true experimental intervention that can identify a causal role for something about locomotor experience, the PMD offers possible clinical interventions for infants and toddlers with motoric impairments. Preliminary work has begun in this regard (Takashio, Kumode, Uchiyama, Campos, & Anderson, 2007).

## Study 1: Visual Proprioception as a Function of Locomotor Status

In Study 1, we used a quasiexperimental design holding age constant across conditions at 8.5 months. The data of two experimental groups (one locomotor, one prelocomotor with walker experience) were contrasted with that of a third comparison group of infants having no locomotor experience of any sort. In contrast to previous work, Study 1 included formal observation of emotional expressions in addition to postural compensation on moving room trials. The predictions for this study were that (a) both hands-and-knees creeping infants and prelocomotor infants with walker experience would show significantly higher levels of postural compensation to peripheral optic flow than would prelocomotors, and (b) both groups having locomotor experience would display more emotional expressions than same-age prelocomotors.

### *Method*

#### *Participants*

All participants were healthy, full-term 8.5-month-old infants. They were recruited from a list of parents who volunteered to bring their infants for testing and represented the many ethnicities residing in the San Francisco Bay Area. They were 65% Caucasian, 20% Asian, 10% Hispanic, and the remainder of mixed ethnicity; all were middle class, on the basis of education level (at least some college education) and place of residence. Three groups of infants were tested: (a) prelocomotors (5 boys, 6 girls, mean age = 35.7 weeks), (b) prelocomotor infants with walker experience (5 boys, 6 girls, mean age = 35.3 weeks), and (c) creeping (hands-and-knees locomotor) infants (5 boys, 7 girls, mean age = 35.5 weeks). All ages were ±2.5 weeks. Walker infants had an average of 5.8 weeks or 34 min/day exposure to the walker, by parental report. Creeping infants had a minimum of 4 weeks of hands-and-knees locomotor experience. Data from 2 infants (1 from the prelocomotor, 1 from the walker group) could not be scored for emotion due to inadequate video records, though their postural data were acceptable.

#### *Procedure*

The infant was seated in the moving room. One tester monitored each infant through a window on the front wall of the room or viewed the infant's activity on a video screen; that tester also had the task of inducing the infant to look straight ahead. Each trial began once the tester had gained the infant's attention toward the front wall window and the infant was still. The tester then signaled a second tester to move the walls of the moving room 35.5 cm in 2 s, alternating fore to aft (hereafter *forward*) and aft to fore (hereafter *backward*) movement for each successive trial. If the infant looked away from the front wall or grabbed the sides of the chair prior to room movement, the trial was redone.

All infants completed 12 experimental trials plus 2 pseudomovement trials (1 prior to the first experimental trial 1 one after the last). Half the trials involved exposure to whole room movement, and half involved only side wall movement. The presentation order of whole room and side wall conditions was counterbalanced across infants.

After the completion of moving room testing, as in Higgins et al. (1996), we assessed each infant's locomotor status in a large room with a 3.1-m runway, to confirm the parent's report of the infant's current locomotor abilities.

#### *Quantification of Postural Compensation*

Postural compensation was operationalized as the peak of the cross-correlation between the time series for infant postural sway and room movement during the first 0.7 s of room movement. Though the wall movement lasted 2 s, the last 1.3 s were discarded to avoid contaminating the analysis with any countermovement that restored the infant's equilibrium after the initial perturbation (see Higgins et al., 1996).

#### *Emotion Coding Procedure*

Three coders blind to the locomotor status of the infants simultaneously coded six behavioral categories from each infant, of which only the three that occurred with sufficient frequencies are reported here. These coders also judged the locomotor status of each infant after the first pseudomovement trial. These judgments were uncorrelated with infants' actual locomotor status, confirming that the coders could not discern to which group each infant belonged. Emotion codes observed with sufficient frequency were: brow movement, eye widening, and the combination of these two expressions. Codes were assigned only to responses that occurred during the 2 s of wall movement for each trial. Operational definition of these three expressive reactions were as follows: Brow movement was based on a 3-point scale rating the degree of eyebrow movement detected in the infant's face (a score of 1 was defined as no brow movement, 2 was defined as brows either raised or brought down and together, and 3 was defined as brows raised or brought down/together while simultaneously furrowed). Eye widening was coded when the infant's eyelids appeared to move farther apart during a trial. Due to necessarily muted lighting in the moving room, these expressions proved difficult to code.

Each of three coders scored each trial simultaneously, with trial presentations repeated if requested by a coder. Codes were entered independently. After the coding of each trial was completed by all three coders, they shared their codes to identify where there was agreement and disagreement. If all three coders agreed on a code, that code was entered into a final data sheet as an agreement. If two coders agreed and one coder disagreed, that code was also entered into the final data sheet; however, it was entered as a disagreement resolved by consensus. If all three coders disagreed, the video of the trial was reviewed until a consensus was reached. That code was then entered into the final data sheet also as a disagreement resolved by consensus.

Intercoder agreement, prior to sharing and reconciling codes, averaged 81%, yielding kappas of 0.61. Although the kappas were low, statistical analyses were conducted on the data from each coder separately. These analyses yielded significant conclusions, regardless of which coder's scores were used, increasing our confidence in the validity of the emotion codes.

### Data Analysis

To determine whether locomotor experience (either through creeping or walker use) facilitated postural compensation on the side wall trials, were conducted planned comparisons to contrast the data from: (a) the single creeper group versus the single prelocomotor group and (b) the single prelocomotor/walker group against the single prelocomotor group. Analyses are restricted to the forward trials, which mimic the optic flow that the infant experiences when locomoting toward a goal. One set dealt with side wall forward trials only, while the second set dealt with whole room forward trials. We used the identical analytic strategy to analyze emotion codes.

## Results

### Locomotor Experience and Postural Compensation

In Study 1, we tested two propositions. The first was that locomotor experience produces significantly higher levels of postural compensation to peripheral optic flow (side wall movement in the moving room). The second was that locomotor experience is associated with greater emotional expressions, again to peripheral optic flow.

*Side wall movement: Creeping versus prelocomotor infants.* Consistent with prediction, the creeping infants' cross-correlation in the side wall condition (+0.47) was significantly higher than the +0.25 for the prelocomotors, $F(1, 21) = 6.90$, $p < .02$, partial $\eta^2 = .12$.

*Side wall movement: Prelocomotor/walker versus prelocomotor infants.* Also somewhat consistent with prediction, the prelocomotor infants who had walker experience showed a trend toward significantly higher cross-correlations (+0.39) than did the prelocomotors, $F(1, 20) = 2.90$, $p < .09$, partial $\eta^2 = .05$.

*Whole room movement.* For whole room movement, the mean cross-correlations were much higher for all three groups than for the side wall conditions. Contrasts involving locomotor experience were not significant. The cross-correlations in the whole room condition were as follows: prelocomotors, +0.50; prelocomotor/walkers, +0.61; and creepers, +0.59.

### Locomotor Experience and Emotional Reactions

*Side wall emotion: Creeper versus prelocomotor infants.* The comparisons of the data of creepers and the prelocomotor infants were significant for brow and also for brow and eyes taken together. For the locomotor group, the emotion code means for brow, eyes, and both, respectively, were 1.61, 1.32, and 1.40 compared to 1.15, 1.20, and 1.20 for the prelocomotor infants: For brows, $F(1, 19) = 7.4$, $p = .01$, partial $\eta^2 = .12$; for brow and eye, $F(1, 19) = 5.1$, $p < .03$, partial $\eta^2 = .092$.

*Side wall emotion: Prelocomotor/walker versus prelocomotor infants.* The walker infant means for brow, eye widening, and eye/brow combination, respectively, were 1.60, 1.46 and 1.67 compared to 1.15, 1.20, and 1.20 for prelocomotor infants. All between-groups comparisons were significant: for brow, $F(1, 18) = 5.2$, $p < .03$, partial $\eta^2 = .096$; for eye widening, $F(1, 18) = 5.70$, $p < .02$, partial $\eta^2 = .10$; and for eye/brow, $F(1, 18) = 17.3$, $p < .001$, partial $\eta^2 = .25$.

*Emotion in whole room condition: Creeper versus prelocomotor infants.* The means for expression for the locomotor group were 1.47, 1.22, and 1.44 for brow, eye, and eye/brow, respectively, while for the prelocomotor group these means were 1.33, 1.04 and 1.14. Of these emotion signs, the difference in brow raise was not significant. However, the eye widen trended strongly toward significance, $F(1, 19) = 3.8$, $p < .056$, partial $\eta^2 = .061$, and the eye/brow combination was significantly different, $F(1, 19) = 6.8$, $p < .011$, partial $\eta^2 = .10$.

*Emotion in whole room condition: Prelocomotor/walker versus prelocomotor infants.* As with the sidewall-only condition, the emotion displays in the walker group were stronger than for the creeper group. The means for expression for the walker group were 1.60, 1.26, and 1.43 for brow, eye, and eye/brow, respectively. All differences were significant: for brow, $F(1, 18) = 4.2$, $p < .05$, partial $\eta^2 = .069$; for eye, $F(1, 18) = 5.2$, $p < .026$, partial $\eta^2 = .087$; and for eye/brow, $F(1, 18) = 6.9$, $p < .02$, partial $\eta^2 = .11$.

In sum, these sets of analyses confirmed a link between locomotor experience and emotional expression, when the infant confronts a marked burst of peripheral lamellar optic flow, both with and without central radial expansion.

## Discussion

These findings are methodologically and theoretically important. The high correlations obtained for pre- and postlocomotor groups to global flow suggest that infants in all groups were physically capable of posturally responding to optic flow, but only infants with locomotor experience, whether through walkers or through creeping, showed postural compensation to peripheral optic flow. These results support a perceptual differentiation interpretation of developmental changes in responsiveness to optic flow, as put forward by Higgins et al. (1996).

The emotion data provided convergence with the postural compensation data. Both creeping and walker experiences were associated with higher levels of emotional expression than absence of locomotor experience. The optic flow events in both configurations of wall movement in the moving room were thus of greater concern to infants with both endogenous and artificial walker locomotor experience, by contrast with fully prelocomotor infants—again, because the locomotor infants are sensitized to and concerned with (a) the visual/vestibular disparity, and/or (b) their increased sway with its concomitant increased likelihood of a fall, and/or (c) the unfamiliar, unexpected and (seemingly to the infant) uncontrolled nature of the optic flow event.

In two distinct ways, locomotor infants are responding more adaptively than prelocomotor infants: (a) in differentiating and utilizing the peripheral optic flow (b) and in responding with emotional concern to all optic flow events in the context of the moving room.

## Study 2: Effects of Randomly Assigned Powered Mobility Training on Posture and Emotion

In Study 2, self-produced locomotion is afforded to randomly assigned prelocomotor infants by means of the PMD previously described. The objective of Study 2 was to determine whether visual proprioception is affected by random assignment of infants to a PMD active condition versus a condition with no locomotor training of any sort. Study 2 included assessments of both postural compensation and emotional display.

### *Method*

#### *Participants*

This study was conducted in Kyoto, Japan, at the Center for Human Development of Doshisha University. Mothers, all of whom were Japanese and middle class, were recruited during visits to well-baby pediatric clinics when their infants were between 29 and 32 weeks of age. Except for employed mothers who could not make repeated lab visits, all mothers contacted agreed to participate and consented to random assignment of their infants to the experimental or control condition. Random assignment yielded 11 experimental and 12 control babies of identical age. Experimentals were given daily in the lab, 10 min periods of PMD training for 15 days over 3 weeks. During training, infants in the experimental (PMD) group could operate the PMD forward by pulling on a joystick; controls were given no testing during the same time period. There was no attrition in this study, although the data from an additional experimental infant could not be used because he began to crawl. Both groups were assessed on the moving room on Day 1 (pretraining) and Day 15 (posttraining).

#### *Procedure*

The moving room apparatus differed from that of Study 1 in using a seat with no back. The testing procedure differed from that of Study 1 in administering only eight trials, four side wall only (two forward, two backward) and four whole room only trials (two forward, two backward). Order of side wall and whole room trials was counterbalanced. As in Study 1, a pseudotrial preceded Trial 1, and another followed the last trial.

The PMD training involved pulling a joystick, which, when activated, caused the PMD to move forward in a linear trajectory at the rate of 15 cm/s (the typical speed of crawling). When joystick pulls ended, the PMD stopped. The movement track was 5 m in length. When the infant reached the end of the track, a tester moved the PMD and the baby back to the starting point. The visual periphery of the path was occupied by shelving, books, a wooden parquet floor, filing cabinets, and closet doors. The mother called to the infant from the end of the path traversable by the PMD. Infants' control over the movement of the PMD increased significantly, $F(14, 140) = 1.94$, $p < .03$, partial $\eta^2 = .16$, from 9% of time in the PMD on Day 1 to a peak of 26% on Day 13.

#### *Data Coding and Analysis*

Cross-correlations and emotional expression coding were computed as in Study 1.

However, statistical analyses consisted of two-factor mixed-model analyses of variance (ANOVAs), with pretraining/posttraining as a within subjects factor with two levels, and training condition as a between-subjects factor also with two levels (experimental vs. control). For the emotion data, units in this study consisted, for each individual, of the number of trials (from 0 to 2) in which an infant showed (a) brows drawn down, (b) mouth open with lips drawn back or drawn down, or (c) both of these codes in the same 2-s period. These scores were converted into proportions of the two trials in which an emotion code was observed. The facial codes were presumed to reflect negative emotion. As in Study 1, we present only the data most relevant to our hypothesis, the forward movement trials.

### *Results*

#### *Postural Compensation*

*Side wall forward condition.* PMD training resulted in a significant increase in postural compensation to the side wall condition, from a pretraining cross-correlation of +0.39 to a posttraining cross-correlation of +0.52. By contrast, the cross-correlation decreased slightly in the control group from +0.39 pretraining to +0.33 posttraining. The ANOVA revealed a significant interaction between pretraining/posttraining and groups, $F(1.21) = 5.90$, $p < .03$, partial $\eta^2 = .22$. Fisher's least significant difference post hoc comparisons revealed a significant increase from pretraining to posttraining for the PMD group, as well as a significant difference on posttraining trials between the PMD and control groups.

*Whole room forward condition.* There were no significant effects for group, session, or their interaction.

#### *Emotional Expression*

*Side forward condition.* These data revealed a strong effect for locomotor training. There were no facial movements observed at all in the pretraining trials for either group, but the PMD group reacted emotionally on 50% of trials on the posttraining assessment, while the controls reacted on only 18% of the trials. The ANOVA yielded significant effects for training group, $F(1, 21) = 10.92$, $p < .005$, partial $\eta^2 = .34$, pretraining versus posttraining session, $F(1, 21) = 15.1$, $p < .001$, partial $\eta^2 = .42$, and their interaction $F(1, 21) = 15.1$, $p < .001$, partial $\eta^2 = .42$. Post hoc Fisher's tests showed that the training group had a significant improvement from pretraining to posttraining, while the controls did not. In addition, the training group showed significantly higher posttraining scores than did the control group.

*Whole room forward condition.* This analysis yielded significant changes in emotional reactions for the training group, which showed minimal facial responding on the pretraining trials but responding on over 50% of posttraining trials. There was a modest change from 0% to 18% of trials in the control condition. The ANOVA yielded significant effects for training group, $F(1, 21) = 6.71$, $p < .02$, partial $\eta^2 = .24$, pretraining versus posttraining session, $F(1, 21) = 26.7$, $p < .001$, partial $\eta^2 = .56$, and their interaction $F(1, 21) = 13.8$, $p < .001$, partial $\eta^2 = .40$.

### *Discussion*

The results of this study provided unequivocal evidence that locomotor training significantly affected both postural compensation and emotional expression to peripheral optic flow. The PMD training also powerfully affected emotional reactions to global flow, resulting in emotional responses very much like both the endogenously creeping infants and the infants with walker experience in Study 1. Because the PMD condition involved random assignment of participants to conditions, locomotor experience must be more than an antecedent of changes in visual proprioception; some feature of PMD training caused a change in visual proprioception.

## General Discussion

The research reported here leads to two general conclusions. First, something about self-produced locomotion is materially affecting an important psychological development. Second, visual proprioception, albeit evident in the newborn, continues developing: When infants acquire locomotor experience, visual proprioception to peripheral optic flow markedly improves.

Both these conclusions need clarification and expansion to avoid misunderstanding of the findings in this report. The evidence for the causal role of self-produced locomotion seems to us persuasive but should be generalized cautiously. We are not precluding the role of maturation in visual proprioception. All developmental acquisitions, including that of visual proprioception, likely involve the intercoordination of many skills. The present research shows that locomotor experience organizes one or more of a set of these unknown skills, but such experience may leave others unaffected. Hence, we cannot, and do not, argue here that our results disprove any role for maturation in the ontogeny of visual proprioception (Bushnell, 2000). At the same time, maturation cannot give an entire account of the development of visual proprioception; indeed, in the final analysis, it might not account for any of it. Those who favor a maturational explanation need to propose crisp definitions of what maturation is, and how that process, as defined, operates in the coordination of skills. The work presented here in a sense initiates, rather than brings to a climax, the study of developmental transitions in visual proprioception.

The findings presented here raise the question of the role of locomotor experience on both very young infants and those suffering extreme delays in locomotion onset. If locomotor experience is provided at too early an age, the other skills required to effect a developmental reorganization may not yet be in place. If so, locomotor experience will appear ineffectual. If locomotor experience is absent at relatively late ages, a different issue arises—that of alternative developmental pathways for the organization of a skill. Notice that we are proposing two important hypotheses. We are reaffirming the importance of locomotor experience on psychological development because it operates consistently, effectively, and in a causal manner at the age when almost all infants become developmentally ready for such experience. We are also saying that the role of locomotor experience may apply robustly at normative ages of infant development, but not at extremely young ages, and possibly not at extremely advanced ages either. Both of these propositions are testable.

What is it about locomotor experience that we believe enables it to play such a powerful role in visual proprioception? We favor Gibson's (1979) notions about the "education of attention" as one likely factor that underlies both (a) the functional relation between locomotor experience and psychological developments and (b) the apparent exceptions to that functional relation. Education of attention consists in deployment of strategies to notice and use information in the service of specific goals or tasks. Locomotion, and later locomotion to someplace, are the actions of the infant that yield developmental change in visual proprioception. However, such action may have its developmental consequences through the recruitment and targeted deployment of attentional resources, consequences that could transfer to other tasks requiring refined deployment of attentional resources. Longitudinal test of this possibility is essential.

### *From Neonate to Crawler: Tracing the Development of Visual Proprioception*

Taken together, a puzzle is proffered by the findings reported here on 8- and 9-month-olds, those reported by Jouen (e.g., Jouen et al, 2000), and those reported by Bertenthal and Bai (1989) and Higgins et al. (1996). Often, researchers focus on the origins in the newborn of perceptual, cognitive, and affective phenomena (e.g., size and shape constancy, imitation, reaching, intersubjectivity) but do not link to later development the neonatal competencies discovered in these studies. This problem applies to visual proprioception. We do not yet know why there is responsiveness to peripheral flow in the newborn, then apparent reduction in responsiveness at 5–9 months of age, followed by elevation of responsiveness after locomotor experience. A longitudinal study spanning the first months of life may begin to clarify the precise ways in which neonatal and 9-month-olds' responses to peripheral optic flow are similar, and in what ways they are different. As Jones (2007) proposed for the development of imitation, it may be that neonatal skills result from processes that are not the same as later ones.

Emotion was a valuable converging response in connection with the development of visual proprioception. Both studies reported here revealed a link between locomotor experience and emotional expressiveness, with both studies yielding strong and strikingly similar patterns of findings. Infants with experience of self-produced locomotion—powered mobility device, baby-walker device, or creeping—are more likely to respond emotionally to wall movement in the moving room. However, the present studies were not designed to tease apart the extent to which emotional responding occurs pursuant to the disparity between vestibular and visual inputs when the walls are moving versus the extent to which the infant experiences as an incipient undesirable fall, due to increased fore-and-aft sway. That the infant with self-produced locomotor experience is more likely to display emotion in a moving room is clear. Further work is underway (Frankel, Campos, & Anderson, 2008) to understand why this emotional response occurs.

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Received August 19, 2007
Revision received April 18, 2008
Accepted April 29, 2008 ■