PSYCHOLOGICAL SCIENCE

Research Report

THE INTEGRATION OF BODY MOVEMENT AND ATTENTION IN YOUNG INFANTS

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Abstract—*The normal development of adaptive behavior in humans depends on the integration of visual attention and body movement, yet little is known about the initial state of movement-attention coupling at the beginning of postnatal life. We studied 1- and 3-month-old infants during extended periods of visual exploration and found that spontaneous shifts of gaze are preceded by rapid changes in general body movement. The results reveal a tight link between motor activation and overt attention on a time scale of seconds or less. This link undergoes substantial developmental change in the first few weeks after birth. During that time, phasic motor activation may play a key role in visual exploration by helping to unlock gaze when the environment is unchanging.*

Theory and research in a number of disciplines from philosophy to robotics have converged on the idea that a good science of the mind must include the body (Ballard, Hayhoe, Pook, & Rao, 1997; Chiel & Beer, 1997; Clark, 1999). From a developmental perspective, mechanisms that might constitute an early basis of embodied cognition, such as an intrinsic coupling between body movement and mental processes, are of special interest. Recent work has increased understanding of the early perceptual control of specific or goal-directed actions (e.g., prereaching; Bacher, Robertson, Gurmankin, Kunkel, & Weidhorn, 2000; von Hofsten, 1984), the role of motion-generated sensory input (e.g., posture; Bertenthal, Rose, & Bai, 1997), and the influence of advances in motor development on the sensitivity to perceptual information (e.g., manual coordination; Bushnell & Boudreau, 1993).

Very little is known, however, about the dynamic integration of general body movement and cognition in the first few months after birth. In particular, little is known about the possibility that spontaneous fluctuations in motor activation influence the second-by-second distribution of attention to the external world. There is some evidence (Bacher & Robertson, in press) that slow variations (on a scale of seconds to minutes) in overt visual attention at 3 months of age are linked to the spontaneous fluctuations in body movement that are ubiquitous early in development (Corner, 1977; Robertson, 1993; Robertson, Dierker, Sorokin, & Rosen, 1982). However, nothing is known about early movement-attention coupling at the shorter time scales (seconds or less) on which the neural integration of motor and mental activity occurs (Ballard et al., 1997).

Our aim in the present study, therefore, was to discover whether attention and general body movement are coupled on a short time scale during visual exploration of the environment, an activity of singular importance for the young infant, before the emergence of goal-directed actions such as skilled reaching or locomotion. We reasoned that spontaneous shifts of gaze in a stable visual environment would be critical events that might reveal important characteristics of an intrinsic coupling between attention and motor activity. We therefore measured 1-month-old infants' direction of gaze and general body movement continuously during extended periods of free looking at a fixed set of objects. Because visual attention and its neural substrate change rapidly during the first few months after birth (Johnson, 1990; Richards, 1998), we also studied 3-month-old infants under the same conditions. In both age groups, we looked for reliable patterns of motor activation or inhibition on a scale of seconds or less that might precede or coincide with spontaneous shifts of overt attention.

METHOD

Subjects

All the infants were healthy and born at full term with birth weights appropriate for their gestational ages. They had no known visual or motor abnormalities. Parents volunteered to participate in the study by responding to a letter given to all parents giving birth at the local hospital. Usable data from continuous awake periods at least 4 min long were obtained from 12 males and 12 females age 1 month (26–32 days), and from 10 males and 11 females age 3 months (82–89 days). The usable periods were longer for the 3-month-olds ($M \pm SEM = 10.7 \pm 0.7$ min) than the 1-month-olds (7.6 ± 0.6 min), $t(43) = 3.49$, $p = .001$. An additional 24 males and 20 females age 1 month and 5 males and 5 females age 3 months did not provide usable data because they were fussy ($n = 35$), were sleepy ($n = 14$), or did not look at the stimuli ($n = 5$).

Procedure

The infants were seated in a commercial infant seat and allowed to look *ad libitum* at a square array of four identical toy animals mounted on a black cloth screen 100 cm in front of them. We used four stimuli to maintain the infants' interest and maximize the number of shifts of attention available for analysis. The specific locations (in the stimulus array) of the stimuli for individual gaze shifts were not analyzed. Each stimulus subtended visual angles of 7° in the horizontal direction and 9° in the vertical direction, and was separated from adjacent stimuli by 21°. The ambient light level was approximately 300 lx, and the ambient sound level was approximately 50 dBA (white noise).

Body movement was detected by piezoelectric sensors (Radio Shack speaker elements 273-091) mounted in the infant seat. Direction of gaze was determined from corneal reflections of the stimuli recorded on videotape by a camera (Cohu 4810) mounted behind the screen in the center of the stimulus array. The vertical trigger pulse from the video camera was used to synchronize the acquisition of gaze and body-movement data at 30 samples/s. The output of the movement sensors was amplified (Coulbourn S75-01) and band-pass filtered (1–40 Hz, Coulbourn S75-34) before being digitized (National Instruments AT-MIO-16H9). Positive and negative thresholds were set to exclude sensor activity due to respiration and electrical noise.

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Data Reduction and Analysis

Inspections of any stimulus that lasted 4 s or more were included in the analyses. To reduce the influence of changes in movement associated with the previous onset of gaze, we did not use looks shorter than 4 s. There were 19 ± 2 (6–41) looks lasting 4 s or longer per infant in the 1-month-old group and 25 ± 3 (8–60) looks lasting 4 s or longer per infant in the 3-month-old group, $t(43) = 1.77$, $p = .08$. The average duration of these looks was 15.2 ± 1.0 s (7.4–30.4 s) among the 1-month-olds and 12.3 ± 1.2 s (6.8–23.6 s) among the 3-month-olds, $t(43) = 1.88$, $p = .07$; maximum duration was 44.2 ± 3.0 s (11.8–77.1 s) for the 1-month-olds and 40.7 ± 5.3 s (14.7–109.8 s) for the 3-month-olds, $t(43) = 0.59$, $p = .56$. Independent scorers determined 1,046 looking onsets and offsets from 12 infants; there was 93% agreement that an onset or offset occurred, and the timing difference was less than 50 ms in 84% of the judgments.

Suprathreshold movement-sensor activity was rectified and integrated in 200-ms bins preceding and following the offset (to the nearest video frame) of all looks at least 4 s in duration. The binned movement data were averaged across looks for each infant. The average binned data for each infant were then normalized using the overall mean and standard deviation for that infant. Group analyses were done on the normalized data. The same procedure was followed for the analysis of movement-attention coupling at the onsets of the same looks. The insets in Figures 1 and 2 show examples of the rectified and integrated movement signals for single looks.

RESULTS

We found reliable patterns of motor activation were associated with shifts of overt visual attention at both ages. An Age (1 or 3 months) × Second (−4 to 1 s relative to gaze offset) analysis of variance of normalized body-movement data yielded a main effect of age, $F(1, 43) = 11.96$, $p = .001$; a main effect of second, $F(24, 1032) = 16.21$, $p < .001$; and an age-by-second interaction, $F(24, 1032) = 1.99$, $p = .003$.

The pattern of activation was more complex and protracted among the 1-month-olds than among the 3-month-olds. The younger infants showed three distinct changes in general body movement preceding the disengagement of overt attention (Fig. 1): First, approximately 2.5 s before gaze shifted away from a stimulus, body movement rapidly increased from below baseline to baseline levels, where it stabilized briefly. Second, approximately 1.5 s before gaze shifted, there was another rapid increase in body movement to above baseline levels, where it remained. Third, immediately before gaze shifted, a final wave of motor activation began.

In contrast to the younger infants, 3-month-olds showed a single, rapid increase in general body movement immediately preceding the disengagement of overt attention (Fig. 1). Body movement increased in a continuous manner from below baseline to above baseline levels during the 600 ms before infants looked away from a stimulus.

Because general body movement was significantly below baseline levels before the motor activation that preceded disengagement, we conducted another analysis locked to the onset of gaze in the same set of looks in order to detect any reliable patterns of motor quieting that might be associated with the engagement of attention. An Age (1 or 3 months) × Second (−1 to 4 s relative to gaze onset) analysis of variance of normalized body-movement data yielded a main effect of second, $F(24, 1032) = 22.48$, $p < .001$. There was no main effect of age, $F(1, 43) = 0.22$, $p = .64$, and no age-by-second interaction, $F(24, 1032) = 0.89$, $p = .62$. Among infants of both ages, general body movement decreased after the onset of looking at an object, reaching a level signifi-

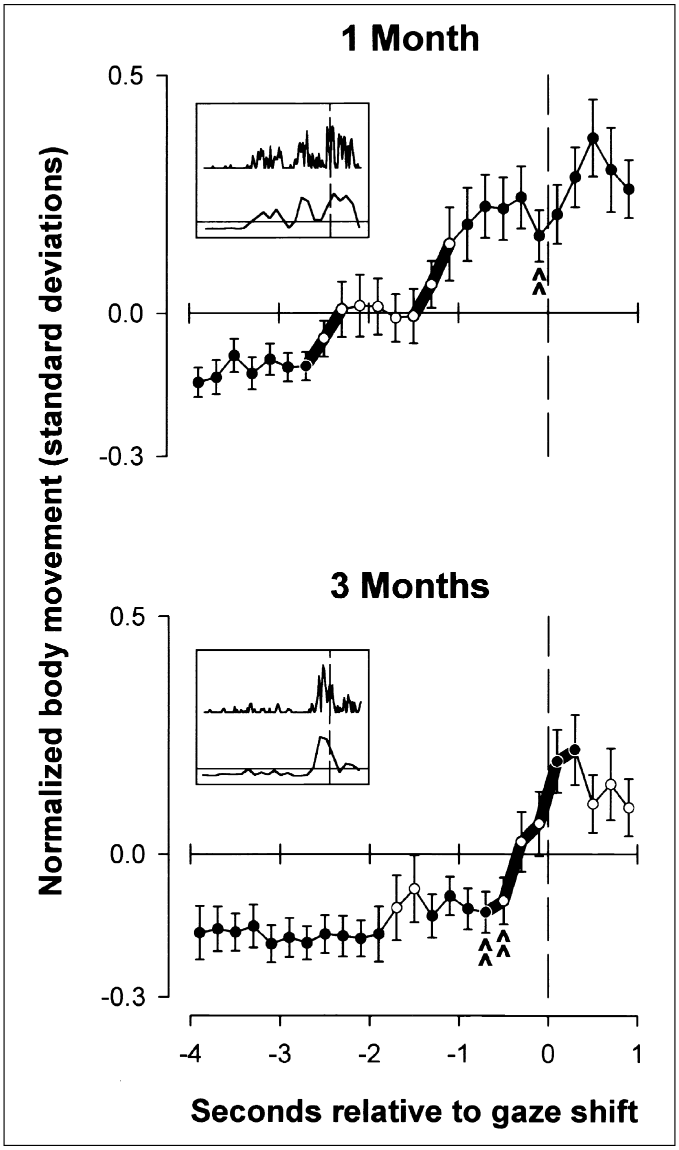

Fig. 1. Normalized body movement (mean ± SEM) near shifts of overt attention during free looking at 1 month (top) and 3 months (bottom) after birth. Filled circles indicate group means that differ from zero ($p < .05$ by t test). Thick lines connecting data points indicate that normalized body movement was increasing or decreasing at a rate that differed from zero ($p < .05$ by t test). The double-hat symbols indicate points at which the rate of change in normalized body movement increased significantly ($p < .05$ by t test). The insets show examples of the movement data from individual infants beginning 4 s before and ending 1 s after a single gaze shift. In each inset, the top trace is the rectified movement-sensor output, the bottom trace is the sensor output integrated in 200-ms bins, and the horizontal line is the overall mean of the integrated movement data for the infant. In all panels, the vertical dashed lines mark the instant of gaze shift (to the nearest video frame).

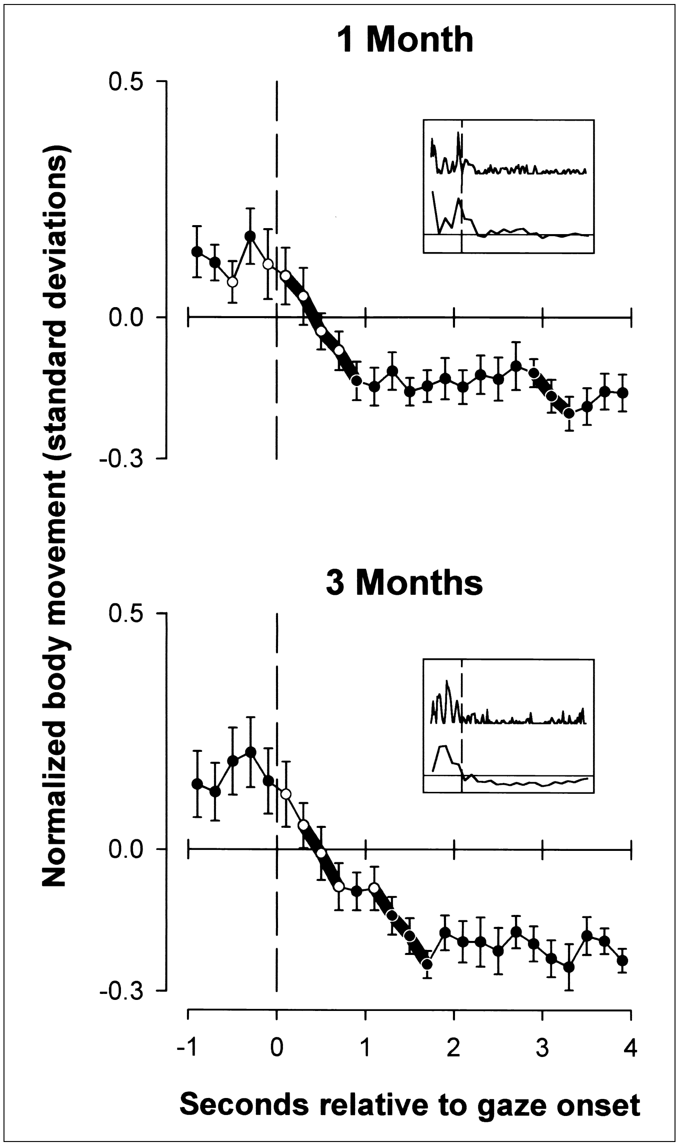

Fig. 2. Normalized body movement (mean ± SEM) at gaze onset during free looking at 1 month (top) and 3 months (bottom) after birth. Filled circles indicate group means that differ from zero ($p < .05$ by t test). Thick lines connecting data points indicate that normalized body movement was increasing or decreasing at a rate that differed from zero ($p < .05$ by t test). The insets show examples of the movement data from individual infants beginning 1 s before and ending 4 s after a single gaze onset. In each inset, the top trace is the rectified movement-sensor output, the bottom trace is the sensor output integrated in 200-ms bins, and the horizontal line is the overall mean of the integrated movement data for the infant. In all panels, the vertical dashed lines mark the instant of gaze onset (to the nearest video frame).

cantly below baseline by 900 ms (Fig. 2). There also appeared to be a second, later wave of motor inhibition during inspection of the stimulus. General body movement began decreasing again approximately 3 s after the onset of looking in 1-month-olds and approximately 1.2 s after the onset of looking in 3-month-olds.

DISCUSSION

General motor activation and shifts in overt attention are coupled on a time scale of seconds or less during spontaneous visual exploration of the environment 1 and 3 months after birth. Increases in body movement reliably precede looking away, suggesting that general motor activation might play a role in redirecting gaze at these ages. Covert disengagement of attention (Posner & Petersen, 1990) may be more closely associated in time (or coincide) with the beginning of the motor activation preceding the look away than with the gaze shift. If so, the results indicate a greater temporal dissociation between these covert and overt aspects of visual attention at age 1 month than at age 3 months. Similarly, the second wave of motor inhibition after the onset of looking may indicate further attentional engagement or processing of the stimulus that begins later at age 1 month than at age 3 months.

Visual attention has been described as “obligatory” or “sticky” between 1 and 3 months after birth because of long latencies to look away from a source of stimulation when a new one is presented (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Hood, 1995; Johnson, Posner, & Rothbart, 1991). The stickiness has been attributed in part to immature cortical inputs to the basal ganglia, resulting in ineffective suppression of the tonic inhibition of saccadic eye movements by the substantia nigra, an output nucleus of the basal ganglia (Johnson, 1995). Magnetic resonance imaging studies of infants with perinatal brain damage have confirmed that lesions in the basal ganglia are strongly associated with difficulty in looking away from a target of visual attention (Mercuri et al., 1997). Taken together, these findings and the present results suggest that phasic activation of basal ganglia motor circuits may help unlock gaze by momentarily suppressing nigral inhibition of saccadic eye movements. The shorter period of motor activation preceding looking away at age 3 months than at age 1 month may reflect the changing balance of excitatory and inhibitory influences on eye movements during this period of development.

A striking characteristic of 1-month-olds’ increase in body movement before looking away is that it occurs in three distinct steps (the return to baseline, the subsequent increase above baseline, and the final increase immediately before gaze shifts), each separated from the preceding one by about a second. The regular bursts in motor activation responsible for this stepwise increase in body movement may be linked to intrinsic oscillations in the basal ganglia (Beurrier, Congar, Bioulac, & Hammond, 1999; Plenz & Kital, 1999). In any case, the key development in the first few postnatal months appears to be the integration of the first two waves of activation evident at age 1 month (the return to baseline and the subsequent increase above baseline) into a single burst by age 3 months. The rapid, uninterrupted surge in motor activation may be more effective at suppressing the inhibition of saccadic eye movements so that a further wave of activation, which occurs reliably at age 1 month, is unnecessary by age 3 months.

The inhibition of general motor activity during looking is likely to help maintain individual bouts of attention by reducing the probability that gaze will be redirected, whereas the general activation of motor circuits when gaze shifts provides opportunities for the development of adaptive coordination of attention and movement. Furthermore, if general motor activation helps unlock gaze as attention wanes, it could have additional functional benefits for the young infant, particularly in the 1st and 2nd months after birth, when fixation appears to be stickiest. Timely redirection of gaze to different regions of the visual environment would facilitate the integration of information obtained from successive inspections and increase exposure to new information as well, perhaps with secondary benefits for early perceptual and cognitive development. Presumably, the limited periods of nonfussy awakeness typical at these ages would further increase the value of more efficient visual exploration resulting from movement-attention coupling.

However, if spontaneous bursts of general motor activity unlock gaze prematurely, before adequate processing of the visual input has been achieved, then the coupling of attention and body movement could be an adaptive liability for the infant. Frequent interruption of overt attention would likely compromise early visual exploration and thereby limit some of the cognitive benefits of alert periods in the first few months after birth. In the extreme, abnormal coupling of visual attention and body movement early in life might predict some later cases of attention-deficit/hyperactivity disorder (ADHD), one category of which is characterized by inattention with impulsivity and overactivity. The possible role of the basal ganglia in movement-attention coupling in the first 3 months after birth is consistent with recent structural and functional imaging studies of older children implicating the same structures in the pathophysiology of ADHD (Berger & Posner, 2000; Swanson, Castellanos, Murias, LaHoste, & Kennedy, 1998; Teicher et al., 2000).

The present results show that attention and body movement are bound together under natural conditions of visual exploration soon after birth, and therefore may provide one useful starting point for an embodied account of early cognitive development. At the very least, researchers should examine how emerging cognitive activity is supported or constrained by the rapidly changing physical system in which it occurs. We should also consider adopting a theoretical stance in which traditional distinctions between mind and body are deemphasized or dispensed with altogether in favor of a set of more fundamental concepts (Clark, 1999; Smith, Thelen, Titzer, & McLin, 1999; Thelen, Schöner, Scheier, & Smith, in press; van Gelder, 1998).

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