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# Robust Coupling of Body Movement and Gaze in Young Infants

**ABSTRACT:** In the first few months after birth, rapid bursts of body movement precede and possibly facilitate shifts of gaze during free looking, with potential consequences for perception and cognition. Here we report that the characteristic features of movement–gaze coupling found during free looking are preserved when attention is perturbed by a salient change in the visual environment. Twenty-four 3-month-olds looked at two attractive 3-dimensional objects while body movement and corneal reflections of the objects were recorded. Lateral head movement was measured offline. After approximately 2 s of looking at one stimulus, the nonfixated stimulus either began to rotate back and forth (distracter events) or remained motionless (control events). In distracter events, the motion of the nonfixated stimulus triggered substantial motor quieting, shortened the duration of the look, and shortened the time to reorient gaze compared to control events. Abbreviated motor quieting and small increases in lateral head movement occurred during control events at the same time in the look as the protracted motor quieting and increased head movement in distracter events. Despite these perturbations, the characteristic bursts of body movement that precede shifts of gaze during free looking occurred in both distracter and control events. The results demonstrate the robust nature of early movement–gaze coupling, raise questions about the specific role of attention in the dynamic links between body movement and gaze, and highlight the potential short and long term functional significance of movement–gaze–attention coupling. © 2007 Wiley Periodicals, Inc. *Dev Psychobiol* 49: 208–215, 2007.

**Keywords:** movement; gaze; attention; coupling; infant

## INTRODUCTION

Spontaneous body movement and overt visual attention are tightly coupled under natural conditions of free looking during the first few months after birth (Robertson, Bacher, & Huntington, 2001b). When 1- and 3-month-old infants are allowed to look ad libitum at an array of identical, interesting objects, the shifts of gaze that punctuate overt attention are reliably preceded by bursts of general body movement. The phasic increases in motor

activity may facilitate shifts of attention by momentarily suppressing tonic inhibition of saccadic eye movements mediated by the basal ganglia (Hikosaka, Takikawa, & Kawagoe, 2000), inhibition that appears to be particularly strong and unregulated in the first 2 or 3 months after birth (Johnson, 1995).

The functional significance of this intrinsic coupling of body movement and gaze in young infants could range considerably. One possible benefit of unlocking gaze, especially in young infants whose visual fixation tends to be “sticky” (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Hood, 1995; Johnson, Posner, & Rothbart, 1991), is a broader distribution of attention to different sources of information in the environment. Although the associated shifts of attention might not be driven directly by perceptual or cognitive processes, automatic visual foraging driven by spontaneous motor activity would

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provide important input for those rapidly developing systems. In fact, dynamical models suggest that stochastic processes may play a central role in the organization of free looking by 1-month-olds (Robertson, Guckenheimer, Masnick, & Bacher, 2004), and spontaneous motor activity in the first 3 months has chaotic properties that make it a likely candidate for the biological instantiation of such a stochastic process (Robertson, Bacher, & Huntington, 2001a).

One possible adverse consequence of the intrinsic coupling of body movement and gaze is the untimely interruption of attention. If gaze is unlocked too early by fluctuations in spontaneous motor activity, important perceptual and cognitive processing of the information being extracted from the targets of attention would be cut short. In fact, recent evidence indicates that the extent to which 3-month-olds do not suppress ongoing body movement at the onset of each new look predicts parent-reported attention problems at 8 years of age (Friedman, Watamura, & Robertson, 2005). In addition, structural and functional neuroimaging in older children and adults has implicated the basal ganglia in the pathophysiology of attention deficit/hyperactivity disorder (Bush, Valera, & Seidman, 2005; Casey, Tottenham, & Fossella, 2002; Seidman, Valera, & Makris, 2005) and behavioral studies have revealed associated deficits in the control of visual fixation (Munoz, Armstrong, Hampton, & Moore, 2003; Sweeney, Takarae, Macmillan, Luna, & Minshew, 2004). Therefore, the likelihood that early movement–gaze coupling is mediated by the basal ganglia raises the possibility of a developmental link to more serious attention disorders in childhood.

A balance between stability and interruptibility of visual attention has clear adaptive significance, and the available evidence suggests that the intrinsic coupling of body movement and gaze early in development may play an important role in the dynamic control of the balance. However, our knowledge of early movement–gaze coupling is limited to conditions of free looking during which the underlying mechanisms are largely unperturbed by extrinsic events. Therefore, the present study was designed to investigate the dynamic response of the coupled system of body movement and gaze when the environment changes in a way that commands attention. Comparisons between perturbed and unperturbed conditions are likely to reveal important features of the link between spontaneous motor activity and overt visual attention in young infants. Features that are present under both conditions may play a more central role in the early integration of action and perception. In particular, if phasic motor activation helps unlock gaze in young infants, thereby facilitating the redirection of attention, the motor activation should occur regardless of whether the redirection of attention is spontaneous or triggered by

an external event. Furthermore, the timing relation between bursts of body movement and shifts of gaze should be preserved.

## METHODS

### Subjects

Usable data were obtained from 24 (11 female) healthy 3-month-old infants with no known motor or sensory deficits. All infants were born after a full-term gestation (37–41 postmenstrual weeks, median 39 weeks) with birth weights between 2,743 and 4,914 g (median 3,514 g) and studied between 82 and 87 days (median 84 days) after birth. Parents had indicated their potential interest in participating in research at the time of their infant's birth. An additional 16 infants participated but did not provide usable data due to insufficient interest in the stimulus objects (4 female, 2 male), fussiness (2 female, 6 male), or technical problems with recording equipment (1 female, 1 male). The 24 infants who did and the 16 who did not provide usable data did not differ on birth weight, gestational age, postnatal age, or sex (all  $ps > .25$ ).

### Procedure

Sessions were scheduled at a time that parents indicated their infant was most likely to be alert and rested (actual times of study ranged from 8:30 am to 3:45 pm). After arrival in the lab and a brief adjustment period, infants were placed in a commercial infant car seat approximately 90 cm from the stimuli, which were mounted in front of a black cloth screen. Additional black cloth screens to the infants' left and right minimized visual distractions. Ambient light and sound levels were approximately 300 lx, and 50 dbA, respectively. Data collection began as soon as the infant was comfortable and continued until the infant lost interest or became fussy. For five infants, one or two additional data collection periods separated by brief rests provided usable data. The total period of data collection for each infant ranged from 5.7 to 22.5 min (median 11.8 min).

The stimuli were two identical objects (commercially available Big Bird toys with bright yellow head and body, orange feet, pink eyelids, blue eyelashes, and large black pupils) that subtended approximately 11 degrees of visual angle and were separated horizontally by approximately 22 degrees of visual angle. A small incandescent lamp (type 1815) covered with yellow tape was mounted on the front of each object to increase the brightness of the corneal reflections of the stimuli. The infant's face, including the corneal reflections of the stimuli, were recorded on videotape (Panasonic AG-7350) from a camera (Cohu 4910) located behind a hole in the screen midway between the stimuli.

During data collection, an observer watched the corneal reflections of the stimuli on a video monitor and operated a 3-position switch (center off) that indicated to the data acquisition software (Labview 5.1, National Instruments, Austin, TX) when the infant's gaze shifted to and from each stimulus. Observers were trained until their real-time performance met the following

criteria based on the resolved frame-by-frame coding (see below) of the video recorded corneal reflections: (1) Less than 2 percent of shifts on stimuli and 2 percent off were missed. (2) Less than 5 percent of recorded shifts on stimuli and 3 percent of shifts off were false. (3) Less than 10 percent of correctly identified shifts on stimuli and 3 percent of shifts off were anticipated, and the median anticipation for each was less than 150 ms. (4) The median reaction time for the remaining correctly identified shifts was less than 400 ms for shifts on stimuli and 300 ms for shifts off.

When the duration of looking at one of the stimuli reached 2 s, a *distracter* or *control* event was initiated by the data acquisition software. In distracter events, the other (non-fixed) stimulus began to rotate 45 degrees back and forth at 1.25 cycles/s (moving alternately clockwise and counter clockwise from the infant's perspective). The stimulus continued to rotate for 1 s after the infant looked at it or until 10 s elapsed. Control events were identical to distracter events except that the nonfixed stimulus was not activated. Distracter and control events were randomly mixed (2 of each in blocks of 4).

Infant body movement was detected by two piezoelectric sensors (Radio Shack speaker elements 273-091), one in the back and one in the bottom of the infant seat. Sensor output was amplified (Coulbourn S75-01), band pass filtered (1–40 Hz; Coulbourn S75-34), and digitized (National Instruments AT-MIO-16H9) at 1/60 s intervals with 12-bit resolution. Analog to digital conversion was triggered at the beginning of each new video field by the camera recording the corneal reflections of the stimuli.

## Data Reduction and Analysis

Video recordings of the corneal reflections of the stimuli were used to determine the timing of gaze shifts on and off the stimuli to the nearest video field. Criterion looks (those identified online as lasting at least 2 s and therefore triggering a distracter or control event) were examined independently by two trained coders whose determination of the timing of shifts agreed to within two video fields (1/30 s) for more than 90 percent of shifts. Any differences between the coders were resolved. The event triggered by the criterion look was considered valid if the resolved coding confirmed that the look lasted at least 2 s and did not end until at least 120 ms after the event was triggered. The number of valid distracter events per infant was 5–25 (median 12) and the number of valid control events was 4–25 (median 11); the range was due variation in the length of time infants remained interested in the stimuli. The median number of distracter events that were invalid because the criterion look was shorter than 2 s or ended less than 120 ms after event onset was 2 for each reason. The median number of control events that were invalid was 3 and 1, respectively, for each reason.

Body movement sensor output was analyzed in 0.1 s bins time-locked to the onset of each event or to the subsequent gaze shift off the stimulus. The magnitude of sensor output that exceeded thresholds set to exclude electrical noise and activity caused by breathing movements was averaged within each bin. For each infant, the bin averages were normalized by subtracting

the mean and dividing by the standard deviation of all bin averages obtained for the infant.

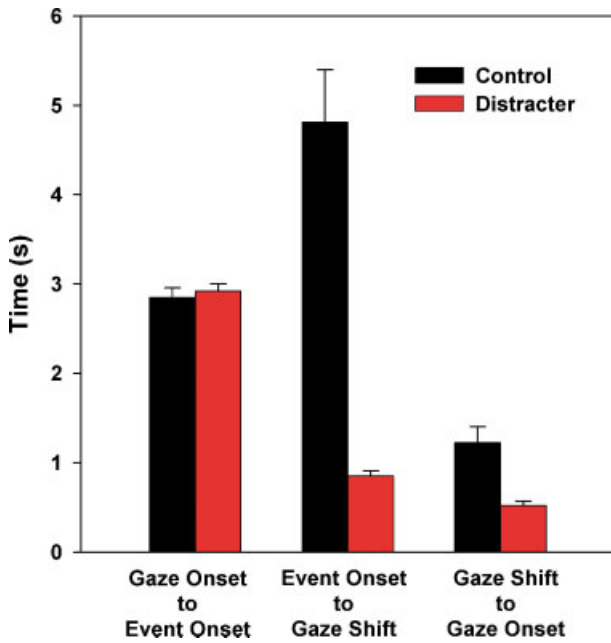
Head movement during each valid distracter and control event was measured from the video recording of corneal reflections for a random subset of 10 infants (6 female) with adequate image quality. A pattern-matching algorithm (National Instruments Vision 5.0) was used to track the change in position of a distinctive facial feature (e.g., the nostrils) at 0.1 s intervals, time-locked to the onset of each event or to the subsequent gaze shift off the stimulus. Based on 113 representative events, the median correlation between the head movement sequences obtained by two independent analyses by different individuals was .98 and the median difference across the bins within events was less than 0.1 cm, corresponding to approximately 0.7 degrees of rotational motion for an infant with a normal head shape (Hutchison, Hutchison, Thompson, & Mitchell, 2004) and median head circumference (Centers for Disease Control and Prevention, 2000). Lateral head movement as large as 1.0 cm/0.1 s did not itself produce detectable increases in the output of the body movement sensors with the sensor placement used in this study.

Normalized body movement and lateral head movement were averaged separately for bins time-locked to event onset and gaze shift and for distracter and control events. Body and head movement were analyzed using Event (distracter, control) by Time (16 0.1 s intervals) repeated measures analyses of variance. For analyses time-locked to event onset, the time interval boundaries were –0.3, –0.2, . . . , 1.3 s relative to event onset. For analyses time-locked to gaze shift, the time interval boundaries were –1.3, –1.2, . . . , 0.3 s relative to gaze shift. The time intervals were selected to exclude effects associated with the preceding and following looks. If there was a main effect of Time, or an Event  $\times$  Time interaction, monotonic increases or decreases over time intervals were evaluated further using *t*-tests of the corresponding slopes. Where relevant, the reported *p*-values reflect the Huynh–Feldt correction for nonsphericity.

## RESULTS

### Interruption of Overt Attention

The interval between look onset and event onset was the same for distracter ( $2.92 \pm 0.08$  s, mean  $\pm$  SEM) and control ( $2.85 \pm 0.11$  s) events,  $t(23) = .57$ ,  $p > .50$ . See Figure 1. However, the interval between the onset of the event and the following gaze shift off the stimulus was shorter for distracter events ( $0.85 \pm 0.06$  s) than for control events ( $4.81 \pm 0.59$  s),  $t(23) = 7.10$ ,  $p < .001$ . Similarly, infants were more likely to look at the other stimulus within 10 s for distracter events ( $99.7 \pm 0.3$  percent of events) than for control events ( $65.0 \pm 4.7$  percent of events),  $t(23) = 7.59$ ,  $p < .001$ . Finally, when infants looked at the other stimulus within 10 s, the time between the gaze shift off the first stimulus and the gaze shift on the other stimulus was shorter for distracter events ( $0.52 \pm 0.05$  s) than for control events



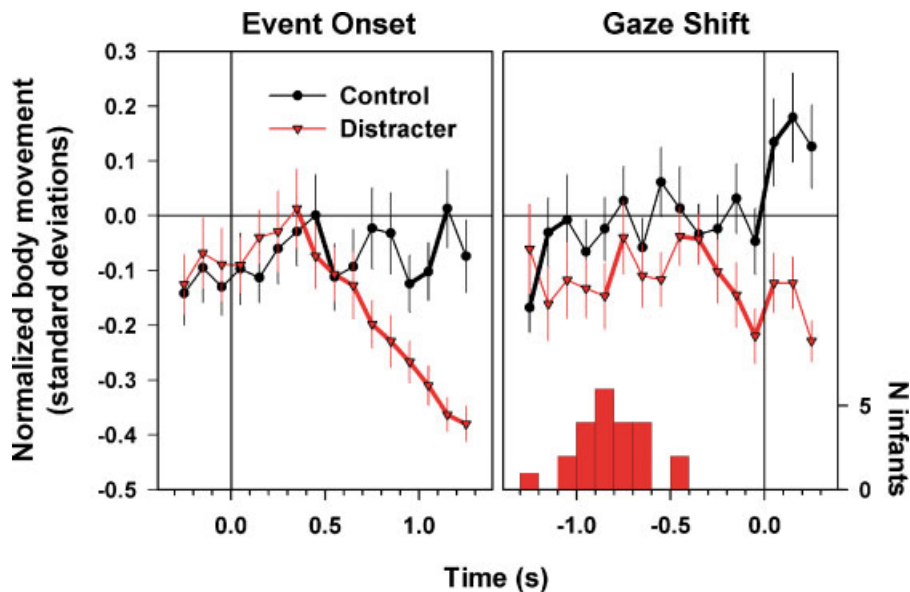
**FIGURE 1** Times (mean  $\pm$  SEM) between gaze onset to the first stimulus object, event onset, gaze shift from the first stimulus object, and gaze onset to the second stimulus object in distracter and control events for 24 infants.

( $1.22 \pm 0.18$  s),  $t(23) = 4.24$ ,  $p < .001$ . These results confirm that the rotational motion of the second stimulus interrupted infants' overt attention to the first stimulus and facilitated reorienting to the second stimulus.

### Body Movement around Event Onset

The time course of body movement immediately before and following event onset was different for distracter and control events, as indicated by an Event  $\times$  Time interaction,  $F(15, 345) = 4.08$ ,  $p < .001$ . There was also a main effect of Time,  $F(15, 345) = 3.41$ ,  $p = .001$ , but not Event,  $F(1, 23) = 2.53$ ,  $p = .13$ . There was substantial motor quieting beginning approximately 0.5 s after the onset of distracter events, evident in the monotonic decrease in body movement across the remaining time intervals,  $t(23) = 5.18$ ,  $p < .001$ . See Figure 2.

There was also a transient decrease in body movement after the onset of *control* events beginning at approximately the same time as the motor quieting in distracter events,  $t(23) = 2.56$ ,  $p = .017$ . However, in control events body movement quickly returned to baseline approximately 0.5 s later,  $t(23) = 2.30$ ,  $p = .04$ . The transient decrease in body movement in the last two control events ( $-0.34 \pm 0.19$ ) did not differ from the slight increase in the first two control events ( $0.09 \pm 0.13$ ),  $t(23) = 1.73$ ,  $p = .098$ .



**FIGURE 2** Normalized body movement (mean  $\pm$  SEM) around event onset (**left panel**) and gaze shift (**right panel**) in distracter and control events for 24 infants. Thick lines indicate that the corresponding monotonic increase or decrease in normalized body movement was different than zero. The histogram shows the distribution of average distracter event onset times (one infant at  $-1.95$  s is not shown).

## Body Movement around Gaze Shift

The time course of body movement before and immediately after gaze shift was different for distracter and control events, as indicated by an Event  $\times$  Time interaction,  $F(15, 345) = 2.88, p = .003$ . There was also a main effect of Event,  $F(1, 23) = 4.52, p = .044$ , but not Time,  $F(15, 345) = 1.71, p = .099$ . See Figure 2.

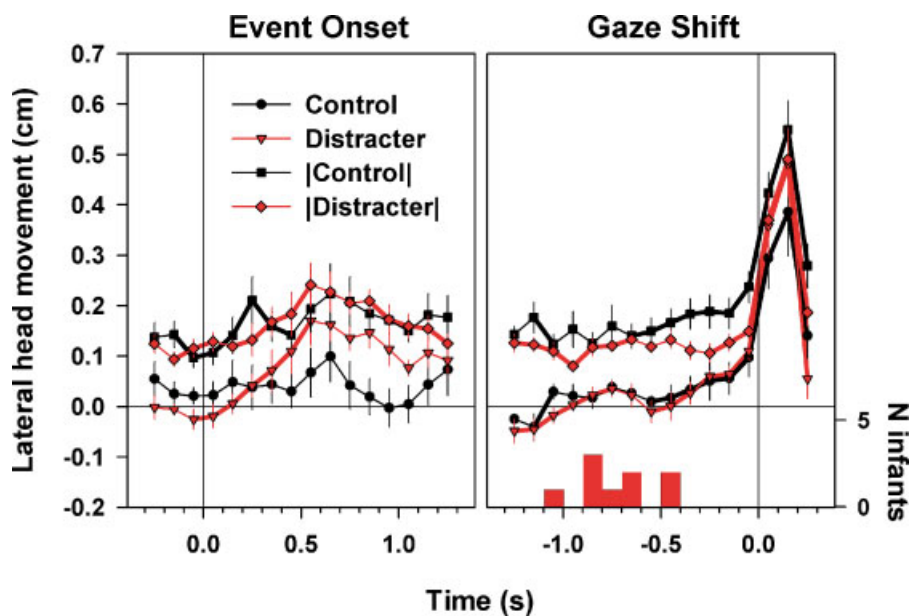
For both distracter and control events, there was a rapid, transient increase in body movement toward baseline approximately 1 s before gaze shift [ $t(23) = 2.49, p = .02$  for distracter events, and  $t(23) = 2.84, p = .009$  for control events]. In addition, there was a second increase in body movement at the moment of gaze shift for both types of events. For control events, the increase [ $t(23) = 3.29, p = .003$ ] took body movement above baseline. For distracter events, the increase [ $t(23) = 2.62, p = .015$ ] was toward baseline, but was superimposed on the more protracted decrease [ $t(23) = 3.47, p = .002$ ] that began approximately 0.5 s after distracter onset and continued [ $t(23) = 2.48, p = .021$ ] after the transient increase associated with gaze shift.

## Head Movement around Event Onset

*Directional* head movement toward the nonfixated stimulus increased more following the onset of distracter events than control events, as indicated by an

Event  $\times$  Time interaction,  $F(15, 135) = 2.23, p = .04$ . The increase persisted [ $t(9) = 3.66, p = .005$ ] until approximately 0.5 s after event onset. The increase in directional head movement in distracter events was also reflected in a main effect of Time,  $F(15, 135) = 2.53, p = .033$ . There was no main effect of Event,  $F(1, 9) = 3.51, p = .094$ . See Figure 3.

In contrast to directional head movement, the *magnitude* of lateral head movement (without regard to direction) increased following the onset of *both* distracter and control events, as indicated by a main effect of Time,  $F(15, 135) = 3.72, p = .010$ . There was no main effect of Event,  $F(1, 9) = 0.08, p = .79$ , and no Event  $\times$  Time interaction,  $F(15, 135) = 1.09, p = .38$ . In distracter events, the increase paralleled the increase in directional head movement, persisting [ $t(9) = 2.37, p = .042$ ] until approximately 0.5 s after event onset. Shortly thereafter, the magnitude of lateral head movement decreased slowly,  $t(9) = 2.32, p = .046$ . In control events, the increase following event onset [ $t(9) = 2.65, p = .027$ ] was shorter and was immediately followed by a decrease [ $t(9) = 2.29, p = .048$ ]. In addition, in the 200 ms before event onset the magnitude of lateral head movement decreased slightly before increasing in control events,  $t(9) = 3.73, p = .005$ . In distracter events, the transient decrease was marginal,  $t(9) = 2.05, p = .071$ .



**FIGURE 3** Lateral head movement (mean  $\pm$  SEM) toward (head movement  $> 0$ ) and away from (head movement  $< 0$ ) the nonfixated stimulus object around event onset (**left panel**) and gaze shift (**right panel**) in distracter and control events for 10 infants. |Control| and |Distracter| indicate the magnitude of head movement without regard to direction. Thick lines indicate that the corresponding monotonic increase or decrease in head movement was different than zero. The histogram shows the distribution of average distracter event onset times (one infant at  $-1.95$  s is not shown).

## Head Movement around Gaze Shift

*Directional* head movement toward the nonfixated stimulus around gaze shift increased in a nearly identical manner during both distracter and control events, as indicated by a main effect of Time,  $F(15, 135) = 24.92$ ,  $p < .001$ , with no Event  $\times$  Time interaction,  $F(15, 135) = 1.18$ ,  $p = .33$ , or main effect of Event,  $F(1, 9) = .02$ ,  $p = .90$ . During both types of events, small increases occurred approximately 1 s before gaze shift [distracter,  $t(9) = 3.29$ ,  $p = .009$ ; control,  $t(9) = 2.73$ ,  $p = .023$ ]. The large increases that peaked immediately following gaze shift [distracter,  $t(9) = 7.84$ ,  $p < .001$ ; control,  $t(9) = 4.28$ ,  $p = .002$ ] began slowly approximately 0.5 s before gaze shift and stopped abruptly [distracter,  $t(9) = 8.55$ ,  $p < .001$ ; control,  $t(9) = 5.46$ ,  $p < .001$ ] by 0.3 s after gaze shift. See Figure 3.

In contrast to directional head movement, the *magnitude* of lateral head movement around gaze shift was greater during control events than during distracter events, as indicated by a main effect of Event,  $F(1, 9) = 8.55$ ,  $p = .017$ , in addition to the main effect of Time,  $F(15, 135) = 39.02$ ,  $p < .001$ . There was no Event  $\times$  Time interaction,  $F(15, 135) = 1.12$ ,  $p = .37$ . For both distracter and control events, the large increases in the magnitude of lateral head movement [distracter,  $t(9) = 6.55$ ,  $p < .001$ ; control,  $t(9) = 6.51$ ,  $p < .001$ ] peaked immediately after gaze shift and ended abruptly [distracter,  $t(9) = 7.48$ ,  $p < .001$ ; control,  $t(9) = 7.67$ ,  $p < .001$ ].

There were also small *decreases* in the magnitude of head movement just before the average time of event onset. For distracter events, the small decrease [ $t(9) = 3.38$ ,  $p = .008$ ] occurred over 0.3 s and was followed by a similar increase [ $t(9) = 4.32$ ,  $p = .002$ ]. For control events, the small decrease [ $t(9) = 2.49$ ,  $p = .034$ ] was brief and was followed by unstable changes until the gradual increase before gaze shift began.

## DISCUSSION

A salient change in the visual environment had substantial effects on infants' spontaneous body movement and overt attention but left the characteristic features of the intrinsic coupling between them intact. Rotational motion of a nearby non-fixated object interrupted overt attention to the fixated object, shortening the duration of looking by more than 80 percent, and facilitated the reorienting of gaze to the nearby object, increasing the likelihood that reorientation would occur and speeding it by more than a factor of 2 when it did occur. Ongoing body movement, already below baseline during fixation of the first object, was suppressed still further when the non-fixated object began to rotate and gaze had not yet shifted, consistent

with the onset of a classic orienting reflex (Sokolov, 1958/1965, 1965; Stechler, Bradford, & Levy, 1966).

In spite of these large perturbations of overt attention and body movement, the phasic increases in spontaneous motor activity that normally precede shifts of gaze during free looking (Robertson et al., 2001b) remained intact. Approximately 1 s before gaze shift, spontaneous body movement increased quickly toward baseline in both control and distracter events. For distracter events, strong motor quieting followed immediately although gaze remained directed at the first, non-moving object. For both types of events, the gaze shift was accompanied by a large burst of body movement. For distracter events, the burst was short-lived and appeared to be superimposed on the substantial motor quieting that began before the gaze shift. The persistence of these characteristic bursts of body movement preceding gaze shift, previously found during free looking, under the very different conditions of this experiment demonstrates the robust nature of movement-gaze coupling at 3 months of age. These findings leave open the possibility that spontaneous fluctuations in ongoing motor activity may play a causal role in unlocking gaze during natural visual foraging at this age.

The smaller systematic perturbations of body and head movement found in this study reveal additional details about the dynamic links between movement and attention. The transient decrease in body movement during control events, which began at the same time as the protracted decrease during distracter events, suggests that infants may have learned the timing of the non-fixated object's motion in distracter events sufficiently to show conditioned motor quieting in control events. If so, the absence of a strong difference in the magnitude of the quieting between early and later control events indicates that the learning occurred quickly, after one or two exposures to the distracter event. Furthermore, the tight coupling between motor quieting and the onset of overt visual attention during free looking at this age (Robertson et al., 2001b; Friedman et al., 2005), and the protracted motor quieting during distracter events in this experiment, suggest that the transient decrease in body movement during control events may have been accompanied by covert changes in the intensity or distribution of attention.

The pattern of findings on head movement is consistent with a kindling of spatial orienting in control events. As with motor quieting, there was a temporal correspondence between transient increases in the magnitude of lateral head movement during control events and protracted increases during distracter events, beginning around the time the nonfixated object started to rotate in distracter events. In both types of events, these early head movements were small compared to those that accompanied the subsequent gaze shifts, but their timing with respect to

event onset was the same. In distracter events, they were largely in the direction of the nonfixated object; in control events they were not. However, the increases in directional head movement associated with gaze shifts were identical in both types of events.

The results of this study raise further questions. First, what is the role of *attention* in the coupling between movement and gaze? Does spontaneous variation in general motor activation influence the intensity or distribution of covert as well as overt attention, or do decreases and shifts in attention release the inhibition of body movement that accompanies the onset of looking? More direct measures of the neural or behavioral effects of attention on very short time scales are needed to test these possibilities (Robertson, Watamura, Muenke, Gooch, & Kleiman, 2005).

Second, how might the dynamic coupling between general motor activation, gaze, and attention influence ongoing perceptual and cognitive processes such as those involved in habituation? The robust nature of movement–gaze coupling demonstrated in this study suggests that it may be a potent regulator of the infant's interaction with its environment, influencing the speed or efficiency of behavioral strategies for extracting information from and learning about the world.

Finally, what is the significance of individual differences in the coupling of movement, gaze, and attention? For example, if such coupling influences ongoing perceptual and cognitive process, it might help explain the documented links between early measures of habituation and novelty preference and later cognitive abilities (McCall & Carriger, 1993; Rose, Feldman, & Jankowski, 2004). Similarly, a recent follow-up (Friedman et al., 2005) of a small sample of 8-year-old children who had been studied in a free looking experiment 3 months after birth revealed moderate correlations between early measures of movement–gaze coupling and later attention problems. If confirmed in a larger study, the findings would suggest that individual differences in the dynamic coupling of body movement and gaze in early infancy may have clinical significance on a developmental time scale. In that context, the results of the present study raise the possibility that measures of how movement–gaze coupling responds to *perturbations* may provide additional insight into the emergence of attention problems early in development.

## NOTES

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