



## PAPER

## Embodied infant attention

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## Abstract

*Does real time coupling between mental and physical activity early in development have functional significance? To address this question, we examined the habituation of visual attention and the subsequent response to change in two groups of 3-month-olds with different patterns of movement–attention coupling. In suppressors, the typical decrease in body movement at the onset of looks persists into the looks. In rebounders, the initial decrease is more transient and movement quickly returns above baseline. Suppressors and rebounders did not differ on measures of looking during habituation, but when the stimulus changed rebounders looked more than suppressors. When it did not change, they looked less. In addition, during habituation rebounders spent more time looking away from the stimulus. Rapid motor reactivation soon after gaze locks onto a target, characteristic of rebounders, may influence visual foraging and the response to change by keeping attention near a threshold of engagement.*

## Introduction

The relation between mind and body has engaged philosophers and scientists for centuries. For most of that time, some flavor of dualism has prevailed. But in recent years, considerable interest has emerged across diverse fields in *embodied cognition*, the notion that mental activity is intrinsically coupled to the physical properties and activity of the body, whether natural or artificial (Ballard, Hayhoe, Pook & Rao, 1997; Brooks, Breazeal, Marjanovic, Scassellati & Williamson, 1999; Chiel & Beer, 1997; Clark, 1999; Lakoff & Johnson, 1999; Pfeifer, Lungarella & Iida, 2007; Varela, Thompson & Rosch, 1991). The notion of embodied cognition raises fundamental questions about the nature and function of real time coupling between mind and body early in development, and the processes of emergence and reorganization that occur on longer time scales (Bertenthal, Longo & Kenny, 2007; Lindblom & Ziemke, 2006; Lungarella, Metta, Pfeifer & Sandini, 2003; Piaget, 1952; Prince & Gogate, 2007; Robertson, Cohen & Mayer-Kress, 1993; Smith & Gasser, 2005; Thelen, 2000; Thelen, Schoner, Scheier & Smith, 2001; Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007).

We have looked for early signs of coupling between mental and physical activity in the rapid fluctuations of visual attention and body movement that occur when infants are awake and alert. These studies have revealed robust connections between attention and movement that appear to consolidate between the 4th and 12th postnatal week (Bacher & Robertson, 2001; Robertson,

Bacher & Huntington, 2001a; Robertson, Johnson, Masnick & Weiss, 2007). During this period, body movement is rapidly suppressed below baseline at the beginning of looks and increases rapidly above baseline just before the end of looks, suggesting that general motor activation might make visual attention more interruptible. Investigations of the dynamics governing body movement (Robertson, Bacher & Huntington, 2001b) and attention (Robertson, Guckenheimer, Masnick & Bacher, 2004) at this age suggest that stochastic variation in the lengths of looks and looks away during extended periods of visual foraging may reflect coupling between attention and the irregular fluctuations of motor activation.

Does the coupling between mental and physical activity in the first 3 months of life have any functional significance? Friedman, Watamura and Robertson (2005) recently reported that individual variation in the dynamic balance of motor suppression and activation at the beginning of looks in 3-month-olds is related to the number of attention problems reported by their parents 8 years later. In contrast, the infants' overall levels of motor activity or looking were not related to later attention problems. These findings suggest that the fast changes in motor activity at gaze onset in young infants might reflect an aspect of movement–attention coupling with some functional significance. In the present study, we asked whether infants who differ in this measure of coupling also differ in the habituation and recovery of visual attention, assessed concurrently.

We examined the habituation and recovery of visual attention for a number of reasons. First, habituation to

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unchanging sensory input and the detection of change reflect fundamental forms of learning and memory that are crucial for adaptive interaction between cognitive agents and their worlds (Meng & Lee, 2005; Rose & Rankin, 2001; Sokolov, 1963; Thompson & Spencer, 1966; Tighe & Leaton, 1976). Second, in studies of human infants, habituation and the response to novelty have long been used as methodological tools to probe a wide range of other perceptual and cognitive processes (Bornstein, 1985; Fantz, 1964; Jeffrey & Cohen, 1971; Robertson & Suci, 1980). Third, there has been considerable interest in identifying stable patterns of individual variation in the habituation of visual attention and the response to novelty (Bornstein & Benasich, 1986; Colombo, 1993; Colombo & Mitchell, 1990; Gilmore & Thomas, 2002; McCall, 1979), and there is substantial evidence that some measures of individual difference predict performance on cognitive tests later in infancy and childhood (Bornstein & Sigman, 1986; McCall & Carriger, 1993). Finally, habituation has broad theoretical significance, which has inspired the construction of biological, psychological, and computational models of the processes that might be responsible for decreased responsiveness to unchanging input and the detection of change (Cohen & Menten, 1981; Groves & Thompson, 1970; Kaplan, Werner & Rudy, 1990; Malcuit, Pomerleau & Lamarre, 1988; Schonert & Thelen, 2006; Sirois & Mareschal, 2002).

We hypothesized that if general motor activation makes visual attention more interruptible, infants who differ in the balance of motor suppression and activation following gaze onset would differ on measures of the habituation of visual attention or the subsequent response to change. Two specific outcomes seemed reasonable. If rapid motor reactivation after gaze onset interrupts processing of visual input too soon, habituation might be slower or the response to change might be smaller. Alternatively, if motor activation facilitates a timely disengagement of attention after sufficient processing has occurred, habituation might be faster or the response to change might be larger.

## Methods

### Participants

Usable data were obtained from 41 (21 female) healthy, 3-month-old infants with no known motor or sensory deficits. Median gestational age at birth was 40 post-menstrual weeks (37–42) and median birth weight was 3628 g (2608–4457). Median postnatal age when studied was 84 days (80–90). Fourteen additional infants (10 female) did not provide usable data due to insufficient looking at the stimulus object, failure to habituate, fussiness, sleepiness, or equipment problems; they did not differ from those who provided usable data on gestational age, birth weight, postnatal age, or sex (all  $ps > .2$ ).

### Procedure

Infants sat in an infant car seat approximately 94 cm from the stimulus, which was mounted in front of a black cloth screen. Additional black cloth screens to the left and right minimized visual distractions. Ambient light and sound levels were approximately 200 lx and 50 dbA, respectively.

Each infant was tested in both a Change and No Change condition, with order counterbalanced across infants. In the Change condition, the stimulus object began to rotate ( $\pm 4$  degrees perpendicular to the infant's line of sight at 1.7 cycles/s) immediately after the end of the look that met the habituation criterion (see below), which marked the end of the habituation phase and the beginning of the test phase. In the No Change condition, the object stayed still during the test phase. Different stimulus objects were used for each condition, with the assignment of objects to conditions counterbalanced across infants. Both objects were brightly colored toys (Big Bird and Zoe) that subtended approximately 25 degrees of visual angle. Small incandescent lamps (Radio Shack 272-1143) were mounted on the objects to increase the brightness of their corneal reflections, which were recorded with a video camera (Cohu 4910) behind a hole in the center of the object.

An observer watched the corneal reflections of the stimulus on a video monitor and operated a switch that indicated to the data acquisition program when gaze shifted to and from the stimulus. Based on 119 gaze shifts from seven infants, agreement between independent observers on occurrence was 92%, the correlation between the durations was .995, and the median absolute difference was 350 ms.

The habituation criterion was met when the average length of two successive looks (*habituation* looks) was less than half the average length of the two successive preceding looks with the largest average length (*peak* looks). Peak and habituation looks could not overlap, so the minimum number of looks for the habituation phase was four; the maximum allowed was 15. Glances less than 500 ms toward or away from the stimulus were ignored. A trial was stopped if a continuous look lasted more than 60 s, a look away lasted more than 30 s, or the infant became fussy or sleepy. For most (28) infants, more than one attempt separated by short breaks was needed to obtain usable data in both conditions.

Infant body movement was detected by piezoelectric sensors (Radio Shack 273-091) in the back and bottom of the infant seat, as in previous studies (e.g. Robertson *et al.*, 2001a, 2007). Sensor output was amplified (Coulbourn S75-01), band pass filtered (1–40 Hz; Coulbourn S75-34), and digitized with 12 bit resolution (National Instruments AT-MIO-16H9). Analog to digital conversion was triggered at the beginning of each video field (59.94/s) by the camera recording the corneal reflections of the stimulus.

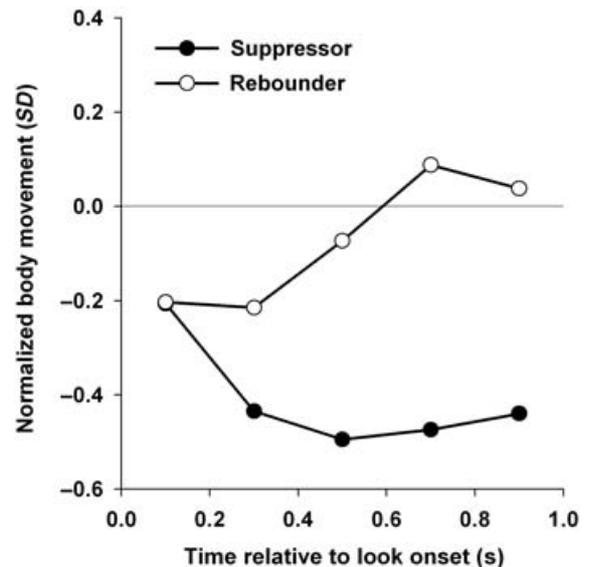
### Data reduction and analysis

The measure of movement–attention coupling used in this study was based on Friedman *et al.* (2005). The magnitude of movement sensor output that exceeded a predetermined threshold was averaged in 200 ms bins around the beginning of each look, time-locked to look onset. The sensor threshold was set to exclude electrical noise and activity caused by breathing movements. Look onset was determined to the nearest video field (17 ms) from the recorded corneal reflections of the stimulus. The bin values time-locked to look onset were normalized using the mean and standard deviation of the sequence of all 200 ms bin values from the beginning of the habituation phase to the end of the test phase. Thus an infant's body movement around look onset was measured relative to the infant's own baseline, where the baseline was the average movement sensor output above threshold and the departure from baseline was expressed in standard deviation units. For each infant, the normalized bin values around look onsets in the habituation phase of both conditions were averaged across looks. To stabilize the coupling measure (described below), the changes in body movement following look onset were evaluated using a three-term moving average (weights = .25, .5, .25) of the average bin values. In Friedman *et al.* (2005), the average location of the first minimum in the moving average occurred in the 4th 200 ms bin (600–800 ms) after look onset, and the next maximum occurred in the 6th bin (1000–1200 ms). Therefore, in the present study we used the moving average centered on the 5th bin (800–1000 ms) after look onset as our coupling measure to capture individual differences in the balance between motor suppression and rebound at the beginning of looks.

*Suppressors* were infants ( $N = 26$ ) in whom motor suppression dominated; their coupling measure was negative ( $-.25 \pm .03$  standard deviation units, mean  $\pm$  sem), indicating that body movement remained below baseline at the end of the first second of their looks. *Rebounders* were infants ( $N = 15$ ) in whom motor rebound dominated; their coupling measure was positive ( $.26 \pm .07$  standard deviation units), indicating that body movement was above baseline by the end of the first second of their looks. Figure 1 shows an example of an infant who exhibited the suppressor pattern of movement–attention coupling and another infant who exhibited the rebounder pattern. Figure 2 shows the durations of successive looks and looks away for the same infants. Suppressors and rebounders did not differ on overall motor activity (proportion of time that movement sensor activity was above threshold), gestational age, birth weight, postnatal age, or sex (all  $ps > .15$ ).

## Results

Analysis of variance revealed no main or interaction effects involving infant sex for any looking or movement



**Figure 1** Examples of an infant who exhibited the suppressor pattern of movement–attention coupling and another infant who exhibited the rebounder pattern, based on their looks during the habituation phase of both conditions. Each point is the weighted average of normalized body movement in the indicated 200 ms interval and the immediately preceding and following intervals (weights = .25, .5, .25). For the suppressor, the last point is below the infant's baseline; for the rebounder, it is above baseline.

**Table 1** Measures of looking during habituation

	Suppressors ( $n = 26$ )	Rebounders ( $n = 15$ )
Number of looks	6.2 $\pm$ 0.3	7.1 $\pm$ 0.5
Total look time (s)	77.0 $\pm$ 9.0	82.3 $\pm$ 11.1
Average look (s)	12.3 $\pm$ 1.2	12.0 $\pm$ 1.5
Average of 1st two looks (s)	15.4 $\pm$ 2.0	17.5 $\pm$ 2.4
Average of 2 peak looks (s)	22.4 $\pm$ 2.4	21.6 $\pm$ 2.4
Average of 2 habituation looks (s)	4.4 $\pm$ 0.6	4.0 $\pm$ 0.4
Habituation rate <sup>a</sup> (s/look)	-2.2 $\pm$ 0.4	-1.8 $\pm$ 0.5

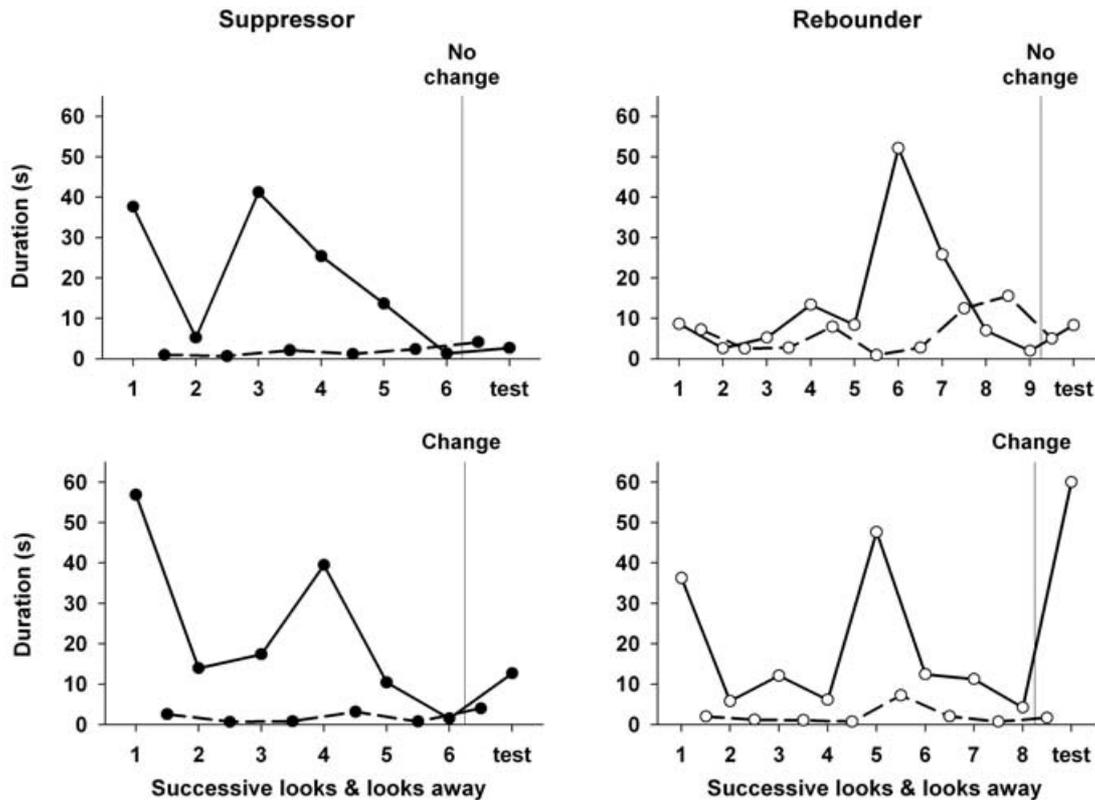
Note: Mean  $\pm$  SEM. For each infant, values of the measure from the habituation phase of both conditions (no change, change) were averaged before computing group results. <sup>a</sup>Habituation rate = [(average duration of the last two looks) - (average duration of the first two looks)]/(number of looks).

variable (all  $ps > .05$ ). Therefore, sex was not included in the analyses reported below. Where relevant, the reported  $p$ -values reflect the Huynh-Feldt correction for non-sphericity or correction for unequal variances.

### Habituation phase

#### Looking

Suppressors and rebounders did not differ on measures of looking during habituation (see Table 1). Condition (no change, change) by Coupling (suppressors, rebounders) analyses of variance, with repeated measures on Condition, revealed no effects of Condition or Coupling, and no

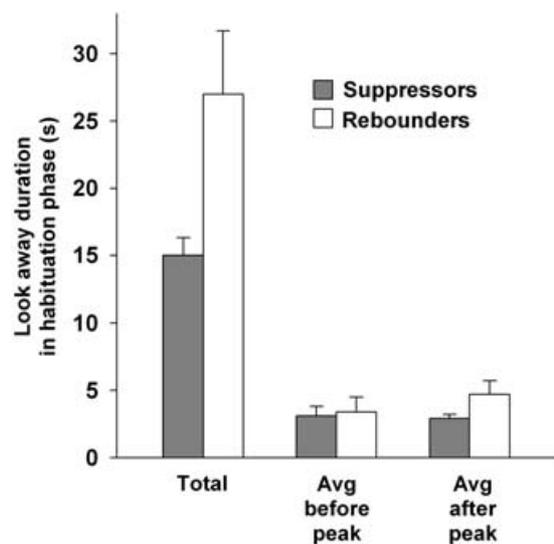


**Figure 2** Durations of successive looks (solid lines, numbered) and looks away (broken lines) from the stimulus in the no change and change conditions for the two infants in Figure 1. The vertical line separates the habituation and test phases.

interactions between Condition and Coupling, for the number of looks to habituation, total looking time, average look duration, the duration of the first two looks in the habituation phase, the duration of the two peak looks, the duration of the two habituation looks, the change between the first two looks and the two peak looks, the change between the two peak looks and the two habituation looks, the change between the first two looks and the two habituation looks, or overall habituation rate (all  $ps > .05$ ). As expected, the increase in look duration from the first two looks to the two peak looks was different from zero,  $F(1, 39) = 24.11, p < .001, \eta_p^2 = .38$ , as was the subsequent decrease to the two habituation looks,  $F(1, 39) = 131.25, p < .001, \eta_p^2 = .77$ . The decrease from the first two looks to the two habituation looks was also different from zero,  $F(1, 39) = 83.04, p < .001, \eta_p^2 = .68$ . There were no main effects of Condition, and no interactions between Condition and Coupling (all  $ps > .1$ ).

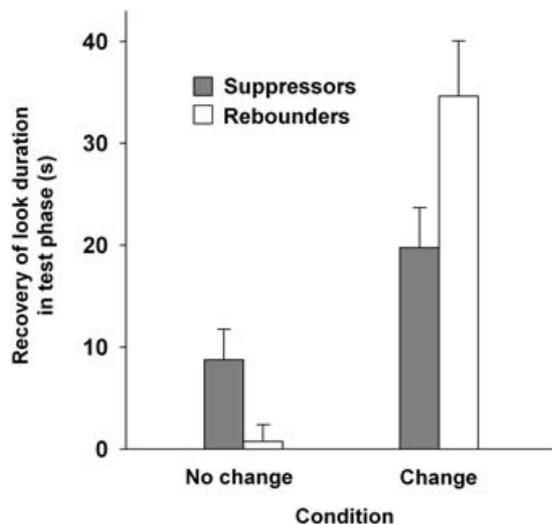
Looking away

Rebounders looked away more than suppressors during habituation. Condition (no change, change) by Coupling (suppressors, rebounders) analyses of variance, with repeated measures on Condition, revealed a main effect of Coupling on total time looking away (see Figure 3),  $F(1, 39) = 9.25, p = .004, \eta_p^2 = .19$ , and the average duration of looks away (suppressors  $3.0 \pm 0.3$  s, rebounders  $4.5 \pm$



**Figure 3** Duration (mean  $\pm$  SEM) of looks away from the stimulus in the habituation phase for suppressors and rebounders. Total, cumulative time looking away between the first and last look; Avg before peak, average duration of looks away before the longest peak look; Avg after peak, average duration of looks away after the longest peak look.

0.9 s),  $F(1, 39) = 5.36, p = .026, \eta_p^2 = .12$ . There were no main effects of Condition, and no interactions between Condition and Coupling, for either measure of looking away (all  $ps > .2$ ). To examine the differences between



**Figure 4** Recovery (mean  $\pm$  SEM) of look duration (duration of the first look in the test phase minus the average duration of the two looks that met the habituation criterion) in the no change and change conditions for suppressors and rebounders.

suppressors' and rebounders' looking away more closely. Condition by Coupling analyses of the average duration of looks away were carried out for looks away in the early and later parts of the habituation phase. In the early part of habituation, before the longest of the two peak looks, suppressors and rebounders did not differ; there were no main effects of Condition or Coupling, and no interaction between Condition or Coupling (all  $p$ s  $>$  .2). In the later part of habituation, after the longest peak look, rebounders looked away more than suppressors; there was a main effect of Coupling,  $F(1, 39) = 4.55$ ,  $p = .039$ ,  $\eta_p^2 = .10$ , but no main effect of Condition and no interaction between Condition and Coupling (both  $p$ s  $>$  .5; see Figure 3).

#### Test phase

There were substantial differences between suppressors and rebounders in the test phase (see Figure 4). A Condition (no change, change) by Coupling (suppressors, rebounders) analysis of variance for the change in look duration from the two habituation looks (the last two looks of the habituation phase) to the first look of the test phase revealed an interaction between Condition and Coupling,  $F(1, 39) = 9.80$ ,  $p = .003$ ,  $\eta_p^2 = .20$ . Compared to suppressors, rebounders exhibited a larger increase in look duration during the first look in the test phase of the change condition ( $34.6 \pm 5.4$  vs.  $19.8 \pm 3.9$  s),  $t(39) = 2.23$ ,  $p = .034$ ,  $d = .73$ , and a smaller increase in the no change condition ( $0.8 \pm 1.6$  vs.  $8.8 \pm 3.0$  s),  $t(39) = 2.35$ ,  $p = .025$ ,  $d = .69$ . The increase in look duration was larger in the change condition than in the no change condition for both suppressors,  $t(25) = 2.44$ ,  $p = .022$ ,  $d = .479$ , and rebounders,  $t(14) = 6.00$ ,  $p < .001$ ,  $d = 1.55$ . For rebounders, the increase was different from zero in

the change condition,  $t(14) = 6.40$ ,  $p < .001$ ,  $d = 1.65$ , but not in the no change condition,  $t(14) = .46$ ,  $p = .65$ . However, for suppressors, the increase in look duration was different from zero in both the change,  $t(25) = 5.05$ ,  $p < .001$ ,  $d = .99$ , and no change conditions,  $t(25) = 2.93$ ,  $p = .007$ ,  $d = .57$ . Subsequent looks in the test phase were not analyzed because 12 infants (five suppressors, seven rebounders, Fisher Exact Test  $p > .05$ ) did not look a second time before the test phase ended in one or both conditions.

#### Relations between looking and looking away

##### Habituation phase

Among suppressors, the average durations of looks and looks away were inversely related,  $r = -.42$ ,  $p = .034$ . Among rebounders, they were not related,  $r = .09$ ,  $p = .75$ . The difference between the correlations among suppressors and rebounders was not significant,  $z = 1.50$ ,  $p = .13$ , using Fisher's  $z'$  transformation. Among both suppressors and rebounders, there were no linear relations between habituation rate and the average duration of looks away, or between the total times spent looking and looking away, all  $p$ s  $>$  .05.

##### Test phase

Among both suppressors and rebounders, the recovery of looking on the first test trial of both the change and no change conditions was unrelated to the average duration of looks away during habituation or to the total time spent looking away during habituation, all  $p$ s  $>$  .05.

## Discussion

Three-month-old infants with different patterns of movement-attention coupling were compared on various measures of the habituation and recovery of overt visual attention. Infants whose body movement decreased and stayed below baseline at the beginning of looks (suppressors) and infants whose movement decreased transiently but rebounded quickly (rebounders) did not differ on any measure of looking during habituation. However, once look durations started to decrease during habituation, rebounders spent nearly twice as much time as suppressors looking away. When the stimulus changed, rebounders' looking increased substantially more than suppressors'. When the stimulus did not change, rebounders' looking stayed low while suppressors' looking increased modestly. Among rebounders, measures of looking and looking away were unrelated. Among suppressors, look and look away durations during habituation were inversely related; other measures of looking and looking away were unrelated.

Because suppressors and rebounders did not differ on any measure of looking during habituation, the findings cannot be readily explained by individual differences in

looking (e.g. short and long) and habituation (e.g. fast and slow) that have been previously documented and shown to have functional significance (Colombo, 1993; Colombo & Mitchell, 1990; Bornstein & Benasich, 1986; McCall, 1979). However, it is possible that neurophysiological measures that reflect the strength of attention during a period of looking, such as changes in heart rate and event-related brain activity (de Haan, 2007; Richards, 2001), might reveal differences between suppressors and rebounders during their quantitatively similar patterns of looking.

How might the kinds of *movement–attention coupling* characteristic of suppressors and rebounders account for the findings in this study? Rebounders' long looks away from a familiar target and looks back that are short if the target has not changed, but long if it has, suggest an attentional system that is poised near a threshold between engagement and disengagement. A bistable, stochastic dynamical system that incorporates such a threshold can account for the durations of looks and looks away in slightly younger infants (Robertson *et al.*, 2004). A common property of these model systems, which has been demonstrated in a range of real physical and biological systems, is stochastic resonance (Gammaitoni, Hanggi, Jung & Marchesoni, 1998; McNamara & Wiesenfeld, 1989; Moss, Ward & Sannita, 2004). At low levels of noise in systems exhibiting stochastic resonance, environmental inputs are relatively ineffective in triggering threshold crossings. At high levels of noise, inputs are swamped. However, at intermediate levels of noise, the *joint* effects of inputs and noise are sufficient to trigger threshold crossings and the system is optimally responsive to the environment. One likely source of intrinsic noise that could play a similar role in 3-month-olds is spontaneous motor activity, which fluctuates in a sustained, irregular way (Robertson *et al.*, 2001b) and appears to facilitate shifts of gaze (Robertson *et al.*, 2001a, 2007). Rebounders' motor activity, which returns to near baseline levels after decreasing at the onset of a look, may therefore keep attention near a threshold between engagement and disengagement.

In contrast, suppressors' shorter looks away from a familiar target, and their tendency to re-engage somewhat if the target remains unchanged, suggest an attentional system that is more stable. Increased responding to an unchanged target following habituation can sometimes be an artifact of using a relative habituation criterion (Bertenthal, Haith & Campos, 1983; Dannemiller, 1984). However, the fact that rebounders did not show increased looking in the no change condition argues against the interpretation of the increased looking by suppressors as an artifact. In terms of the stochastic systems and the phenomenon of stochastic resonance described above, greater attentional stability in suppressors would result from greater suppression of the noisy fluctuations of spontaneous motor activity at the onset of looks, which would keep attention farther from the threshold separating engagement and disengagement. Furthermore,

because the relative influence of noise on threshold crossings increases near a threshold, the inverse correlation between the durations of looks and looks away found in suppressors would be attenuated in rebounders.

From a functional point of view, the pattern of differences between suppressors and rebounders suggests that rebounders might be more efficient visual foragers. Longer looks *away* from a target after it becomes familiar increase the chance of finding something new to look at. Subsequent looks *back* to a familiar target that are brief allow change to be detected with minimal cost to the broader search. Finally, a long look at a target as soon as change is detected permits timely and thorough processing of the new information.

There was no evidence that rapid motor reactivation prematurely interrupted rebounders' perceptual/cognitive processing of the initial target of attention. There were no differences between suppressors and rebounders in any measure of the habituation of visual attention, and rebounders exhibited a more (not less) differentiated response in the test phase that followed habituation. It is possible, however, that under more natural conditions – for example, when multiple distracters are present – rebounders' processing of the original target could end too soon if attention is captured by another stimulus during their longer looks away. In such cases, the relative costs and benefits associated with efficient visual foraging might be different, especially if secondary rewards come from sustaining attention to targets that are familiar or uninteresting, as may happen later in school classrooms or doing homework. The requirement for sustained attention in those situations may explain why a seemingly adaptive pattern of movement–attention coupling – shown by the rebounders in the current study – is associated with more parent-reported attention problems 8 years later (Friedman *et al.*, 2005).

The present findings show that movement–attention coupling during visual foraging has functional implications for the detection of change by young infants. The findings cannot resolve the question of whether movement–attention coupling reflects a fundamental unity of mind and body of the sort implied by current notions of radical embodiment (Clark, 1999; Thompson & Varela, 2001; Wilson, 2002; Ziemke, 2004), or a more limited integration of mental and physical activity early in life. But given the adaptive significance of detecting change, its empirical links to later cognitive performance, and its widespread use to study other perceptual and cognitive processes in infants, the mechanisms underlying early movement–attention coupling and the role such coupling plays in the subsequent development of embodied cognition merit closer study.

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