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REPORT

Development of selective attention in young infants: Enhancement and attenuation of startle reflex by attention

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Abstract

This study examined the effect of level of attention engagement on the modification of the blink reflex in young infants. Infants at 8, 14, 20, or 26 weeks of age were presented with interesting visual or auditory stimuli. At delays defined by changes in heart rate known to be associated with sustained attention or attention disengagement, blink reflexes were elicited by visual or auditory blink reflex stimuli. Blink amplitude varied according to the level of attention, and the match between the foreground and blink reflex stimulus. If the infant was attending to the foreground stimulus, a blink reflex stimulus in the same modality resulted in enhanced blink reflex magnitude. A blink reflex stimulus in the other modality resulted in an attenuated blink reflex magnitude. If attention was not engaged with the foreground stimulus, this modulation of the blink reflex did not occur. This 'selective modality effect' showed an increasing tendency to occur between 8 and 26 weeks of age. These results show that selective attention to modalities increases over this age range.

Directing attention to one stimulus modulates the blink reflex to another stimulus. Several studies have shown that this effect is selective for modalities. Blink reflexes are enhanced when the modality of the blink stimulus and the modality of the stimulus to which attention is directed are the same. The blink reflex is attenuated when the modality of the blink stimulus and the attention-directed stimulus do not match (Anthony and Graham, 1983, 1985; Balaban, Anthony and Graham, 1989; Hackley and Graham, 1983; Haerich, 1994). This attentional modulation of the blink reflex is interpreted as showing the selectivity of attention towards specific modalities, and represents the modification of reflexes by higher-level cognitive processes.

The effect of attention on the blink reflex has been shown in young infants (Anthony and Graham, 1983; Balaban *et al.*, 1989). For example, Anthony and Graham (1983) varied attention engagement by presenting 'interesting' or 'dull', visual or auditory stimuli to 16-week-old infants. The interesting stimuli were complex visual patterns or sounds that elicited a heart rate deceleration. The dull stimuli were a simple light or tone and resulted in a smaller heart rate deceleration than the interesting stimuli. Following a 4-second delay, a visual or auditory probe that was known to elicit a blink reflex was presented. The blink reflex was enhanced in magnitude when attention was the greatest (interesting vs. dull) and when the blink probe and the foreground stimulus were in the same modality (match vs. mismatch). These results imply that the blink stimulus in the same modality was processed better (larger blink magnitude) than processing during the dull foreground, or for the mismatched stimulus. The relative enhancement or attenuation of the blink reflex for stimuli in the matched or mismatched modalities is evidence for selective modality attention effects early in infancy.

This experiment extends the Anthony and Graham (1983) study to younger and older age infants in order to determine if changes in selective attention occur in the early part of infancy. The infants in the Anthony and Graham study were 16 weeks of age (approximately 4 months). There is an increase in attention to visual and auditory stimuli over the age range from 2 to 6 months (Berg and Richards, 1997; Richards, 1987, 1997; Richards and Hunter, 1998). The increase in sustained attention to stimuli over this age range should differentially affect the modulation of the reflex blink. A specific hypothesis is that by six months infants should show

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relatively mature patterns of sustained attention to the foreground stimulus. This should lead to attenuation and/or facilitation of the blink reflex at that age in a pattern similar to that found in adult subjects. Infants at younger ages, whose attentional system is not as mature, should not have the system that affects the CNS control of the blink reflex, and should show less modulation.

This study used two strategies to study selective attention. First, I manipulated the match between the foreground stimulus and the blink reflex stimulus. This study used the same modality match-mismatch as the Anthony and Graham (1983) study: visual foreground and visual blink stimulus (match), visual foreground and auditory blink stimulus (mismatch), auditory foreground and visual blink stimulus (mismatch) and auditory foreground and auditory blink stimulus (match). The match/mismatch conditions show modality-based selective attention when the blink reflex is enhanced when the modality of the blink stimulus and the foreground stimulus are the same, and the blink reflex is attenuated when the modalities are different.

Second, attention was manipulated using heart rate changes elicited by the foreground stimuli. Heart rate changes have been used in young infants to distinguish attention phases labeled stimulus orienting, sustained attention, and attention termination (Berg and Richards, 1997; Graham, 1979; Graham, Anthony, and Zeigler, 1983; Richards and Casey, 1992; Richards and Hunter, 1998). Heart rate deceleration in the young infant is elicited by interesting visual or auditory stimuli and indicates stimulus orienting, and a sustained lowered heart rate indicates that attention is still engaged (sustained attention). Alternatively, after attention engagement, infants will often keep fixation on a stimulus, but heart rate will return to its prestimulus level. At this point the infant is not actively attending to the stimulus (attention termination). Thus, rather than presenting the blink stimulus delayed at a fixed point in time for 'interesting' or 'dull' stimuli, only 'interesting' stimuli were used on each trial and the blink stimulus was presented following delays in which heart rate indicated sustained attention was occurring (heart rate deceleration) or attention was unengaged (return of heart rate to prestimulus level following sustained attention; Richards, 1987, 1997). These heart-rate-defined attention phases should result in blink reflex modification consistent with the experimental manipulations of attention used in adult studies (Hackley and Graham, 1983; Haerich, 1994) or the use of different stimuli to elicit attention/inattention (Anthony and Graham, 1983). The selective attention effects elicited by the match-mismatch manipulation should depend on attention engagement. Selective attention should occur when attention is engaged (stimulus orienting, sustained attention) but not when attention is unengaged (prestimulus, attention termination).

Methods

Participants

The participants were infants tested at 8 ($M = 57.8$ days, $S.D. = 3.84$, $N = 40$, 24/16 female/male), 14 ($M = 99.5$ days, $S.D. = 3.69$, $N = 40$, 17/23 female/male), 20 ($M = 141.1$ days, $S.D. = 3.71$, $N = 40$, 22/18 female/male), or 26 ($M = 185.1$ days, $S.D. = 5.09$, $N = 40$, 19/21 female/male), weeks of age.[1] The participants were assigned to one of four between-subjects conditions of a 2×2 factorial design – foreground stimulus (visual, auditory) X blink stimulus (flash, noise). There were equal numbers of subjects per age in each condition (10 per condition).

The infant was held in the parent's lap approximately 55 cm from a 49 cm (19 in) TV monitor. There were four pre-experimental trials consisting of the presentation of the foreground stimulus alone (two trials) or the presentation of the blink stimulus alone (two trials, 'blink reflex control'). The experimental trials consisted of the presentation of the foreground stimulus followed by a delay, and the presentation of the blink stimulus. One of four delays was used on each trial: a 2-s delay, a heart rate deceleration +2-s delay, a delay until heart rate returned to its prestimulus level following a heart rate deceleration, and a delay of 5-s after heart rate returned to its prestimulus level.[2] These conditions represent 'stimulus orienting' (2-s), 'sustained attention' engagement (heart rate deceleration +2-s) and 'attention termination' (return of heart rate to prestimulus level following sustained attention). Trials in which the foreground stimulus was presented alone, or in which

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[1] An additional 50 infants were also tested, but were eliminated because they did not have at least two identifiable blinks in the prestimulus condition ($N = 5$), did not show at least one identifiable blink in each testing condition ($N = 22$), or did not complete all of the testing sessions due to fussiness or crying ($N = 23$). These infants were approximately equally distributed across the four testing ages.

[2] An online algorithm was used to identify the QRS complex in the ECG and inter-beat interval (IBI) was defined as the duration between successive R-waves. This evaluation was made within 30–60 ms following the R-wave occurrence. The 'heart rate deceleration' was defined as 5 successive beats with IBIs each longer than the median of the 5 prestimulus beats. The 'return of heart rate to prestimulus level' was defined as occurring after a heart rate deceleration, and when 5 successive beats occurred each with IBIs shorter than the median of the 5 prestimulus beats (see Richards, 1987, 1997).

the blink stimulus was presented alone (blink reflex control), were interspersed with the experimental trials. These six trial types were presented randomly without replacement in 6-trial blocks.

The foreground visual stimuli were interesting black-and-white patterns shown on the TV.[3] These stimuli are known to elicit heart rate decelerations, typically result in first look durations of greater than 10 s, and are easily discriminable by each of the four age groups (Richards, 1997). The foreground auditory stimuli were changing patterns of sound presented on speakers above the TV. The auditory patterns elicit significant heart rate decelerations in infants in this age range (Richards and Gibson, 1997). The visual blink stimuli were two Vivitar photo flash units (Model 2800) placed 60 cm on either side of the infant. The auditory blink stimulus was a noise burst that was presented binaural on Radio Shack Realistic speakers at 100 dB (A-scale) with 5 ms rise/fall times, and 50 ms at the maximum level.

The electromyogram (EMG) of the obicularis oculi muscle was measured by placing miniature (SensorMedic, 3 mm contact, 11 mm collar) Ag/AgCl electrodes just below the lower right eyelid (11 mm center-to-center). The electrodes were affixed with adhesive collars, and SignaCreme electrode cream was used to complete the electrical contact. The EMG signal was amplified (20 k) and filtered (bandpass 10 Hz to 300 Hz) and digitized at 1 kHz. The root-mean-squared (rms) EMG was calculated and blinks were scored on each trial for latency to blink onset, latency and amplitude of rms EMG amplitude (see Haerich, 1994). The ECG was recorded with Ag-AgCl electrodes on the infant's chest and was digitized at 1 kHz. A computer algorithm identified the QRS complex in the ECG and inter-beat interval (IBI) was defined as the duration between successive R-waves in the ECG.[4]

Results

The blink latencies and amplitudes from the blink reflex control trials were examined.[5] There were no significant differences in the blink amplitude over the four testing ages, and no difference in blink amplitude between the visual and auditory blink stimuli ($Ms = 24.89$ rms μV and 27.95 rms μV, respectively). The amplitude of the blinks did not change significantly between the two pre-experimental trials and the blink reflex control trials interspersed in the experimental trials, nor did it show habituation within the experimental trials. There were significant effects of blink stimulus type on the blink onset latency, $F(1, 186) = 11.02$ $p = 0.0011$, and peak latency, $F(1, 186) = 4.62$, $p = 0.0329$. The onset and peak latencies were shorter for the auditory blink stimulus (M's = 133.6 and 46.3 ms, for onset and peak, respectively) than for the visual blink stimulus

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[3] The visual foreground stimuli consisted of 16 dynamic computer-generated patterns presented on the TV (e.g., a series of concentric squares of varying size, a flashing checkerboard pattern, a small box shape moving across a diamond). The TV subtended 44º visual angle, and each stimulus was approximately 32º visual angle. The auditory foreground stimuli consisted of 12 different changing patterns of sound (e.g., a pulsed 1200 Hz tone, a pulsed 1400 Hz tone, a pulsed tone alternating 1200 Hz/1400 Hz, a sliding frequency from 0 to 1200 Hz or from 400 to 1600 Hz, random frequencies across the range of 0 to 1600 Hz). The audio stimuli were generated by Colbourn Precision Signal Generator (S81-06) and Voltage Controlled Oscillator (S24-05) modules, and were presented on two Radio Shack Realistic audio speakers located above the TV and amplified by two channels of a Yamaha Power Amplifier (MX−35, 4 channels in pairs of 2), and were approximately 60 dB (A-scale) at the infants' ears. The audio reflex blink stimulus was generated by a Colbourn White Noise Generator (S81-02), and shaped with a Colbourn (S84-04) rise/fall gate. A Yamaha Power Amplifier amplified the sound that was played through two Radio Shack Realistic audio speakers that were placed at the edges of the TV, and produced 100 dB (A-scale) sounds at the location of the infants ears. The visual reflex blink stimulus was generated by two Vivatar photo flash units (Model 2800) which were placed in the same location as the auditory reflex blink speakers.

[4] The changes in inter-beat interval (IBI) were analysed to determine if the experimental manipulations had their desired effect. There was a significant Delay Condition X 'Intervals' (0.5-s intervals) effect on the IBIs in the 2.5-s period immediately preceding the presentation of the blink stimulus. This reflected the a priori definition of heart rate changes on the heart rate deceleration +2-s, return of heart rate to prestimulus levels, and return of heart rate to prestimulus levels +5-s, delay conditions (cf. Richards, 1987, 1997). There were no significant effects involving a 'match' (2; match−visual-visual and auditory-auditory, mismatch−visual-auditory and auditory-visual) factor, and no effects involving the foreground stimulus modality. Finally, periods of time that met the heart rate change criterion on the control trials in which the foreground stimulus was presented alone were compared with the pre-blink IBI pattern. The pattern of heart rate response prior to the onset of the blink stimulus was similar on these control trials and the experimental trials.

[5] The analyses had unequal numbers of observations in each cell due to trials without blinks and unequal numbers of stimulus presentations for a subject. Thus, some cells of any particular Foreground Stimulus X Blink Stimulus X Delay X Subjects were unfilled, or had unequal numbers of data in each cell. Because of the missing cells, the ANOVAs were computed with a general linear models approach using non-orthogonal designs. The sums of squares (hypothesis and error) for the nested effects in the design were estimated using 'subjects' as a class and nesting repeated measures (delay) within this class variable. The 'PROC GLM' of SAS was used for the computations. The probability of the blink reflexes also was examined. The only significant effect was that there was a higher probability of a blinks occurring to the auditory than the visual stimuli. There were no effects of age, match-mismatch, or attention delay condition on blink probability.

($Ms = 169.0$ and 56.6 ms). There were no significant effects on the latencies involving testing age, or any habituation effects across trials.

Figure 1 presents the peak amplitudes for the different delays and the match/mismatch between the foreground and blink stimuli. The amplitudes in this figure represent the rms µV difference between the foreground + blink stimulus trials and blink reflex control trials. This figure shows a selective modality effect for attention. The reflex blinks were enhanced in the delay conditions representing attention engagement (2-s, heart rate deceleration +2-s) when the foreground and blink stimuli matched, and showed attenuation when the foreground stimulus did not match the blink reflex stimulus. The delay conditions representing attention unengaged (return of heart rate to prestimulus level, return of he art rate to prestimulus level +5-s) did not show the facilitation of the reflex blink. The reflex blink was attenuated in both the match and mismatch trials when heart rate had just returned to prestimulus level, and returned to normal levels after 5 s (Figure 1). A statistical analysis of the peak amplitudes[6] resulted in a significant 'match' effect (match/mismatch), $F(1, 162) = 6.23$, $p = 0.0039$, reflecting the larger blink reflexes when the foreground and blink stimuli were in the same modality. There also was a significant interaction between the match factor and the delay factor, $F(3, 393) = 2.92$, $p = 0.0338$. Scheffe' *post hoc* tests for this interaction showed the attention delay conditions were significantly different than the inattentive conditions when the stimuli matched, but not when the foreground and blink stimuli were in different modalities. There were no significant main effects involving the type of foreground stimulus or type of blink stimulus, or an interaction between the foreground and blink stimuli. Thus, both the visual and auditory foregrounds were equally effective in the enhancement/attenuation of stimuli in the same/different modality.

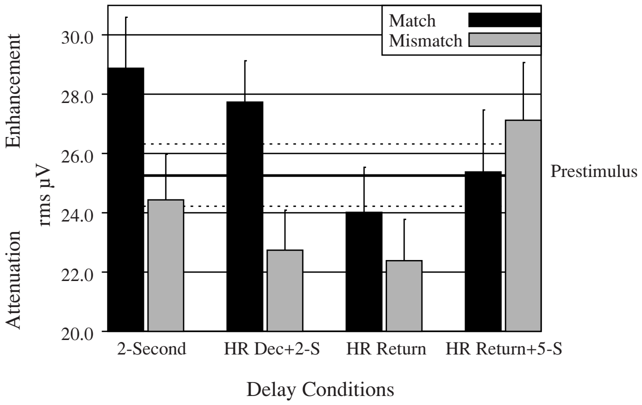

Figure 1 *Reflex blink magnitude (rms µV) as a function of the delay types and the match/mismatch between the foreground and blink stimulus. The black bars represent trials on which the foreground and reflex blinks stimulus were in the same modality (visual-visual or auditory-auditory) and the gray bars represent trials on which the foreground and blink stimulus were in different modalities (visual-auditory or auditory-visual). The average blink magnitude on the prestimulus trials is plotted (solid line) with SE ranges (dotted lines). The error bars are the SE of the mean.*

The changes over age in the blink reflex modulation are presented in Figure 2. This figure shows the change in peak rms µV amplitude from the blink reflex control trials to the foreground + blink stimulus trials, separately for the four testing ages and match/mismatch trials, and combined across trials in which attention was engaged (2-s, heart rate deceleration +2-s) and unengaged (return of heart rate to prestimulus level, return of heart rate to prestimulus level +5-s). There was a dramatic increase over the four testing ages in the difference between blink reflex modification on the attention-engaged trials. There was an increasing facilitation of the blink reflex over the four ages when the foreground and blink stimulus were in the same modality, and a corresponding increase in the attenuation of the blink reflex when the stimuli were in the different modalities. The statistical analysis of the peak amplitudes showed that the match/mismatch factor interacted significantly with the age factor for the attention-engaged delay conditions (Figure 2, left panel, $F(3, 351) = 3.80$, $p = 0.0105$), but did not interact significantly with the age factor for the attention-unengaged delay conditions (Figure 2, right panel, $F(3, 351) = 1.38$, $p = 0.2478$).

Blink onset latency and onset-to-peak latency were also analysed. These were analysed both as difference scores from prestimulus latencies, and as absolute times. The blink latencies during the foreground stimuli were

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[6] The design of the ANOVA's for these analyses was an Age (4; 8, 14, 20, 26 weeks) X Foreground (2; visual, auditory) X Match (2; match–visual-visual and auditory-auditory, mismatch–visual-auditory and auditory-visual) X Delay Type (4; 2-s, heart rate deceleration +2-s, return of heart rate to prestimulus level, return of heart rate to prestimulus level +5-s). An interaction between Foreground and Match would show a differential effect for the foreground and the blink stimulus. *Post hoc* tests were controlled for testwise error rate with the Scheffe' correction method. Blink amplitude on the foreground + blink stimulus trials was equated for individual differences in blink magnitude by using the proportion change from no-foreground blink reflex magnitude as the dependent variable. The results section (and Figures 1 and 2) show the blink amplitude in rms µV to allow the comparison of this with prestimulus blinks and with other studies using blink amplitude.

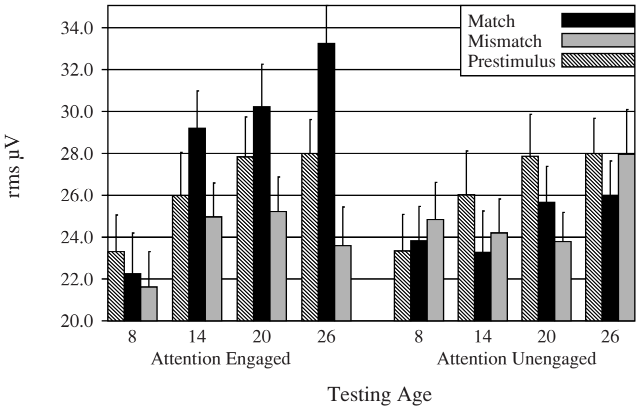

Figure 2 *Reflex blink magnitude (rms μV) as a function of testing age and the match/mismatch between the foreground and blink stimulus, separately for the delay conditions hypothesized to have attention engaged and attention unengaged at blink stimulus onset. The black bars represent trials on which the foreground and reflex blinks stimulus were in the same modality (visual-visual or auditory-auditory) and the gray bars represent trials on which the foreground and blink stimulus were in different modalities (visual-auditory or auditory-visual). The hatched bars represent blink magnitude on the prestimulus trials. The difference between the match/mismatch trials and the prestimulus trials represent blink facilitation (match trials, ages 14, 20, 26, attention engaged) and blink attenutation (match trials, older three ages, attention engaged).*

not significantly different than those occurring during the blink reflex control trials. There were main effects and interactions that showed that the difference in latency between the blinks elicited by the auditory and visual stimuli was similar in the blink reflex control trials, and in the trials when the blink stimulus was presented during the foreground stimuli. The latency measures were not affected significantly by any main effects or interactions involving age or the attention delays. Table 1 contains the blink onset latency for the trials on which the foreground stimulus and blink reflex stimulus matched or did not match, separately for the attention delay conditions.

Discussion

This study showed that blink reflexes in young infants are reliably affected by selective attention. There was a clear enhancement of the reflex blink response over control trials when the infants were attending to the foreground stimulus, and when the modality of the foreground stimulus matched the modality of the blink-eliciting stimulus. Alternatively, there was an attenuation of the blink reflex under attention conditions when there was a mismatch between the foreground and blink stimulus. This facilitation/attenuation in the attention delay conditions showed an increase over the age range (2–6 months) used in this study (Figure 2).

This study replicates the Anthony and Graham (1983) study in several respects. For example, Figure 1 in Anthony and Graham is similar to the results summed over all ages (e.g., Figure 1 this experiment). The reflex blink during the interesting foreground stimulus (Anthony and Graham, 1983) or during the attention-engaging delays (this study) was significantly larger than the reflex blink during the dull stimulus (Anthony and Graham, 1983) or the attention-disengaged delays (this study). The development effects in this study show an increase from 8 to 26 weeks in this selective modality effect. The 8-week-old infants show no significant enhancement or attenuation in the size of the blink reflex in the attention conditions over the prestimulus condition (Figure 2). From 14 to 26 weeks of age in the attention-engaged conditions, there were increases in the enhancement of the blink reflex when the foreground and reflex blink stimuli matched, and an increased attenuation of the blink reflex when the foreground and reflex blink stimulus were in different modalities (Figure 2). The 16-week-old infants in the Anthony and Graham (1983) study would be expected to fall between the effects found in the 14 and 20 week old infants.

There were two aspects of the attenuation of the reflex blink amplitude that are of interest. First, there was an attenuation of the blink reflex during attention when the foreground and blink stimulus were different (Figures 1, 2). This was a statistically significant

Table 1 *Latency to blink onset as a function of match between the foreground stimulus and reflex blink stimulus, separately for the experimental delay conditions (variability measure is SE of mean).*

	Experimental Delay Conditions				
	Prestimulus	2-Second	HR Dec +2-S	HR Return	HR Return +5-S
Match between foreground and blink stimulus	145.13 (4.86)	130.90 (6.11)	137.53 (8.38)	137.30 (8.27)	142.16 (6.84)
Mismatch between foreground and blink stimulus	150.99 (4.80)	151.86 (6.05)	145.30 (5.49)	145.63 (6.26)	151.35 (7.37)

attenuation relative to the amplitude of the blink reflex found in control trials, in which no foreground stimulus was presented. The inclusion of the no-foreground control condition highlights the conclusion that inhibition of the reflex response during attention occurs relative to its non-attentive level (i.e., prestimulus condition, and return of heart rate to prestimulus level +5-s, Figure 1). Second, there was an attenuation of the reflex blink amplitude that occurred in both match and mismatch trial types when heart rate had just returned to prestimulus levels. Thus, the blink reflex is initially facilitated during attention on the match trials, attenuated just as attention ends on match and mismatch trials, and returns to pre-attention levels 5 s after the heart rate returns to its prestimulus level (Figure 1). This finding is consistent with the hypothesis that infant sustained attention is followed by a period labeled 'attention termination' (Casey and Richards, 1991; Richards and Casey, 1992) during which the response to new stimuli in the same modality is temporarily attenuated. This suggests a 'refractory period' in the sequence of infant attention phases during which the infant is resistant to new stimulus information (Casey and Richards, 1991). The attention termination phase is not just 'unengaged attention', but 'resistant attention'.

This study provides information about the nature of sustained attention in young infants. The heart rate changes in infants occurring during sustained attention have been interpreted (Richards and Casey, 1992; Richards and Hunter, 1998) as indexing a general arousal/alertness system (Heilman, Watson, Valenstein, and Goldberg, 1987; Mesulam, 1983; Posner, 1995; Robbins and Everitt, 1995) that 'invigorates' specific stimulus networks. The reflex blink represents simple pre-attentive cognitive processing and is controlled by subcortical mechanisms. The reflex blink enhancement for the same modality stimulus during sustained attention implies that attention may operate by enhancing complementary sensory systems, either peripheral or subcortical in origin. At the same time, sustained attention attenuates competing attention systems, whether they are sensor redirection (shift in fixation, Richards, 1987, 1997) or automatic interrupt responses to stimuli in non-attended modalities (blink reflex in mismatch condition). This aspect of attention shows developmental changes over the first few months of infancy, and is consistent with neurodevelopmental models hypothesizing an increasing influence of cortically controlled behavior in the first six months of life (e.g., Johnson, 1990, 1995; Johnson, Gilmore, and Csibra, 1998; Richards and Casey, 1992; Richards and Hunter, 1998).

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