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## Evidence for Sensory-Selective Set in Young Infants

Abstract. *The existence of low-level filtering of sensory input is a point of debate among cognitive theorists. This present study suggests that filtering by modality exists at levels low enough to modulate the brainstem blink reflex and that it is evident as early as the 16th week of life. During foreground listening or looking conditions, blinks elicited by acoustic or visual probes were larger when probe and foreground modality matched than when they mismatched. "Interesting" foregrounds, by comparison with "dull" ones, intensified the modality-selective effect.*

Reflexes mediated at low levels of the nervous system can be facilitated or inhibited by the neural activity of higher centers (*1*). This fact has recently been exploited in demonstrations that attention directed to selected inputs can modulate the brainstem blink reflex (*2*). The direction of modulation—reflex enhancement when an acoustic reflex-eliciting stimulus was attended and reflex reduction when attention was directed to a tactile or visual stimulus—suggests that selective attending might affect low-level sensory pathways, at least acoustic pathways. These findings were based on studies of human adults; the purpose of this study was to determine whether attentional activity in young infants produces similar reflex modulation. Although attentional or orienting behaviors such as visual fixation and heart rate deceleration can be elicited even in newborn infants (*3*), the functional consequences of the process indexed by these behaviors is not known.

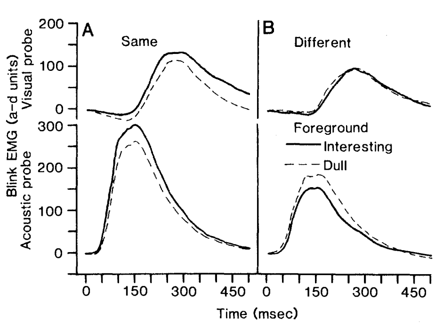


Fig. 1. Averaged evoked EMG activity in analog-to-digital (a-d) units for 500 msec after the onset of visual and acoustic probes for conditions in which modality of probe and concurrent foreground was the same (A) or different (B).

This experiment assessed the magnitude of blink reflexes elicited by visual as well as acoustic probes when probe modality either matched or mismatched the modality of other "foreground" stimulation to which infants were concurrently attending. We also determined whether any effect of modality match was intensified when attention was more strongly engaged, that is, by "interesting" rather than "dull" foregrounds. Heart rate decelerations were measured to verify a difference in attention-engaging quality.

The subjects were 32 medically normal infants, selected at an age (16 weeks ± 9 days) when attentional behaviors have become well established. The infants were divided into two equal groups (*4*). One group was exposed to visual and the other to acoustic foregrounds. The factor of probe modality, also acoustic and visual, and the factor of foreground interest were orthogonally combined to create four conditions varying within groups. Order of conditions was randomized without replacement in four-trial blocks, and each infant could receive as many as eight blocks. Half of the subjects began with block 1 and half with block 5. Because testing had to be discontinued if infants became fussy, the average number of trials completed was 28.3.

Infants were tested in a dimly illuminated and sound-attenuated chamber (Industrial Acoustics). Except for two acoustically shielded flash units (Vivitar), stimulus-generating and recording equipment was located outside the chamber. A PDP12 computer in an adjoining room controlled stimulus presentations, timing, and the digitizing of electromyographic (EMG) activity and heart rate. Present in the chamber were an observer and a parent. The observer rated infant state and visual fixation (*5*) through a peephole in a large projection screen placed 45 cm from the seated parent and infant (*6*). Trials were deleted if the infant was fussy (mean, 2.1) or did not maintain fixation on the center of the screen (mean, 6.5).

To help bring fixations to midline, trials began with 2 seconds of flashing light (200 msec on and off) from a small cold-cathode bulb attached to the screen. Foreground stimulation was then presented for 5 seconds. Visual foregrounds, slides projected on the screen to subtend a visual angle of 40°, were either interesting colored slides—one of 16 smiling faces photographed in natural settings—or dull blank slides—individually matched to the average luminance of a colored slide. As measured by a photometer (Spectra Pritchard), average luminance values ranged from 0.096 to 0.441 mL per slide and from 0.219 to > 0.249 mL per condition (1 L = 3183.099 cd/m$^2$). Acoustic foregrounds, delivered from a speaker centered behind the screen, were accompanied by one of the blank slides in order to maintain the central fixation. Recorded segments of music-box tunes provided the interesting acoustic foreground, and repetition of a 1000-Hz tone served as the dull foreground. Average sound pressure level re 20 $\mu$N/m$^2$ was 60 dB (scale A).

Four seconds after foreground onset, a blink-eliciting probe was introduced. If visual, it consisted of a < 500-$\mu$sec flash from the flash units, reflected from the screen image and having a luminance of approximately 10$^3$ mL. If acoustic, it was a 50-msec, 109-dB (scale A) burst of broadband noise delivered through

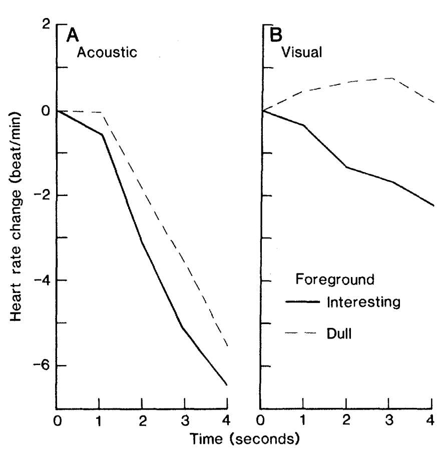


Fig. 2. Heart rate during 4 seconds between foreground and probe onsets, less heart rate during the 1 second preceding foreground onset (mean, 150.9 beats per minute).

speakers 2 feet to each side of the infant. Intertrial intervals ranged from 9 to 17 seconds between foreground offset and onset.

Blinking was measured every millisecond for 500 msec after probe onset. It was detected from musculus orbicularis oculi through two miniature Ag-AgCl electrodes (*7*) taped 4 mm (center to center) apart 5 mm below the temporal half of the lower left lid. The resulting EMG was amplified (bandpass 10 Hz to 10 kHz), full-wave rectified, and integrated before being converted to digital form. Figure 1 displays the 500-msec evoked wave form averaged over subjects and trials for each condition in each group. Blinks were larger when modalities of probe and foreground matched than when they differed.

We expected that interesting foregrounds would more strongly engage attention than dull ones, and that they should thus enhance the response to probes with matching modalities and not enhance the response to mismatching probes. This effect can also be observed in Fig. 1: for mismatching acoustic probes, the interesting-dull relation is actually reversed.

The assumption that attention would be differentially engaged by interesting and dull foregrounds was verified by recording heart rate from chest electrodes during foreground stimulation. Because slowing of heart rate presumably reflects attention to the information carried by a stimulus (*8*), we expected greater slowing with the stimuli we had selected to be more interesting. The larger heart rate deceleration occurring with interesting foregrounds (Fig. 2) differed significantly from the changes occurring during dull foregrounds: interaction of interest value with linear variation over seconds [$F(1, 30) = 10.65$, $MS_e = 6.57$, $P < .005$]. Interest value did not vary significantly as a function of foreground modality, probe modality, or modality match.

To test statistically the changes in EMG illustrated in Fig. 1, we used a computer program to identify the peak magnitude of responses initiated within a window 21 to 350 msec after probe onset (*9*). Figure 3 summarizes these data for the two major effects: (i) the modality-match effect (foreground probe interaction) [$F(1, 30) = 8.38$, $MS_e = 21943.51$, $P < .01$] and (ii) the interaction of modality match with foreground interest, [$F(1, 30 = 4.92$, $MS_e = 4104.32$, $P < .05$].

These findings show, in very young infants, that attention to a stimulus in one modality can enhance the processing

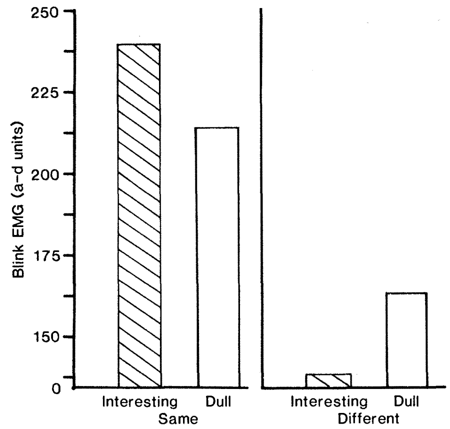


Fig. 3. Peak magnitude of EMG activity after probe onset where modalities of probe and concurrent foreground were the same or different.

of other stimuli in the same modality. Moreover, the effect is magnified when attention is more strongly engaged. Although attentional behaviors occur in the young infant, this experiment is, to our knowledge, the first demonstration that attention in infants has selective consequences for the processing of sensory input.

An attentional interpretation of the blink modification results, implying efferent control of afferent pathways, is strengthened because the effects were demonstrated with visual as well as acoustic startle stimuli. Thus, specific auditory system mechanisms, by themselves, cannot account for the pattern of results. In addition, the modification mechanism cannot be a general activation process or one acting solely in the final motor path. If that were the case, the reflex should have been affected in the same way whether elicited by visual or acoustic probes. Thus, the effect must be restricted to the sensory-central portions of the reflex pathway that are modality-specific. A masking hypothesis would predict opposite effects; that is, the response to a probe in the same modality as concurrent foreground stimulation should have been reduced rather than enhanced. Concurrent foreground stimulation need not be present to obtain modality-specific blink modifications. We have found these modifications in adults when a warning stimulus directed attention to an expected but absent stimulus (*10*).

The modification of a reflex response implies that, however the effects of foreground modality were achieved, they influenced a low-level automatic process. This suggests that attention can act early in the perceptual process. Peak magnitude of the reflex blink, the point at which selective effects were measured, was reached by 90 msec on the average (for acoustic probes) by infants. Moreover, recent work with adults suggests that enhancement can be observed as early as 25 msec from stimulus onset (*11*). These findings bear on the major debate between those who believe that attention can modify sensory input at an early stage of processing and those who argue that selectivity occurs only at a later stage after all input has been fully analyzed (*12*). The blink modification results suggest that, under appropriate conditions, attention can filter input differing in broad physical characteristics, such as modality, and that the effects of this biasing process can be observed in a reflex organized at the brainstem level.

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4. An additional 58 infants failed to meet minimum criteria for inclusion because of fussiness, lack of central visual fixation, and procedural or equipment problems. The criteria were that probes elicit a nonzero blink response on at least two trials in each dull condition and on at least one trial in each interesting condition.
5. Observers were technicians unaware of the hypothesis being tested, the interest value of the visual foregrounds, and, at the time of rating, the modality of the probe to be delivered. Fixation was rated as off the slide, on the slide but off center, or on slide center.
6. A pilot study of four infant-mother pairs showed that any maternal response to probes has negligible effects on infant blinking. Under conditions similar to those of the main experiment, only the mother received blink-eliciting acoustic probes while the infant observed interesting slides. Three infant blinks, averaging three digitized units, were recorded on the 40 trials of 43 that elicited measurable maternal response averaging 950 units.
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9. The scoring program discarded trials if EMG activity was present at the time of probe onset (indicating a blink in progress) or if peak latency exceeded 450 msec. Onset and peak latency windows were increased beyond previously described values [F. K. Graham, B. D. Strock, B.

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## Single Visual Neurons Code Opposing Motion Independent of Direction

Abstract. *Cells in intermediate and deeper layers of the pigeon optic tectum respond best when a textured background pattern is moved in the opposite direction to a moving test spot. Complete inhibition occurs when the background moves in the same direction as the test stimulus. Most noteworthy is the invariance of this relationship over a wide range of test spot directions. These cells represent a higher level of abstraction in a motion-detecting system and may play a role in figure-ground segregation or the discrimination of the motion of an object from self-induced optical motion.*

One of the fundamental tasks required of any sensory system is to "parse," or decompose, patterns of stimulation into clusters of attributes that represent the distal sources giving rise to them. In audition, this entails segregating the neural patterns produced by the complex pressure wave reaching the ears into separate "streams" representing their separate sound sources. This "auditory stream segregation" (*1*) is complex, involving spatial, temporal, and harmonic relationships. Nevertheless, our experience in the everyday world of sounds attests to their efficiency. They enable us to untangle many concurrent sounds, even when their spectra seem hopelessly intertwined.

In vision also, the neural patterns produced by complex retinal images must be parsed into objects, and their three-dimensional locations and motion characteristics preserved separate from ambient variations. Figure-ground segregation has been studied extensively in relation to stereopsis (*2*) and computer "scene analysis" (*3*). Gibson's early work (*4*), however, has been followed by a growing awareness that image motion characteristics may play a key role in this process. For example, visual psychophysical experiments with coherently moving dots show vivid emergence of figures among other incoherently moving dots (*5*). Differentially moving dots also lead to compelling and accurate sensations of depth (*6*). Recent theoretical accounts have also shown that retinal flow patterns, generated by an observer moving through space, can provide, in principle, information about object rigidity, boundaries, and orientation (*7, 8*), also suggesting how neural mechanisms might make some of these computations (*8*).

In this report we describe single cells that might perform such functions. These units, which have very large inhibitory receptive fields, are inhibited by the in-phase movement (same direction, same velocity) of a test stimulus and background and are often facilitated by anti-phase movement (opposite direction, same velocity) (*9*). We have demonstrated that these results hold, within an individual cell, for test spot directions

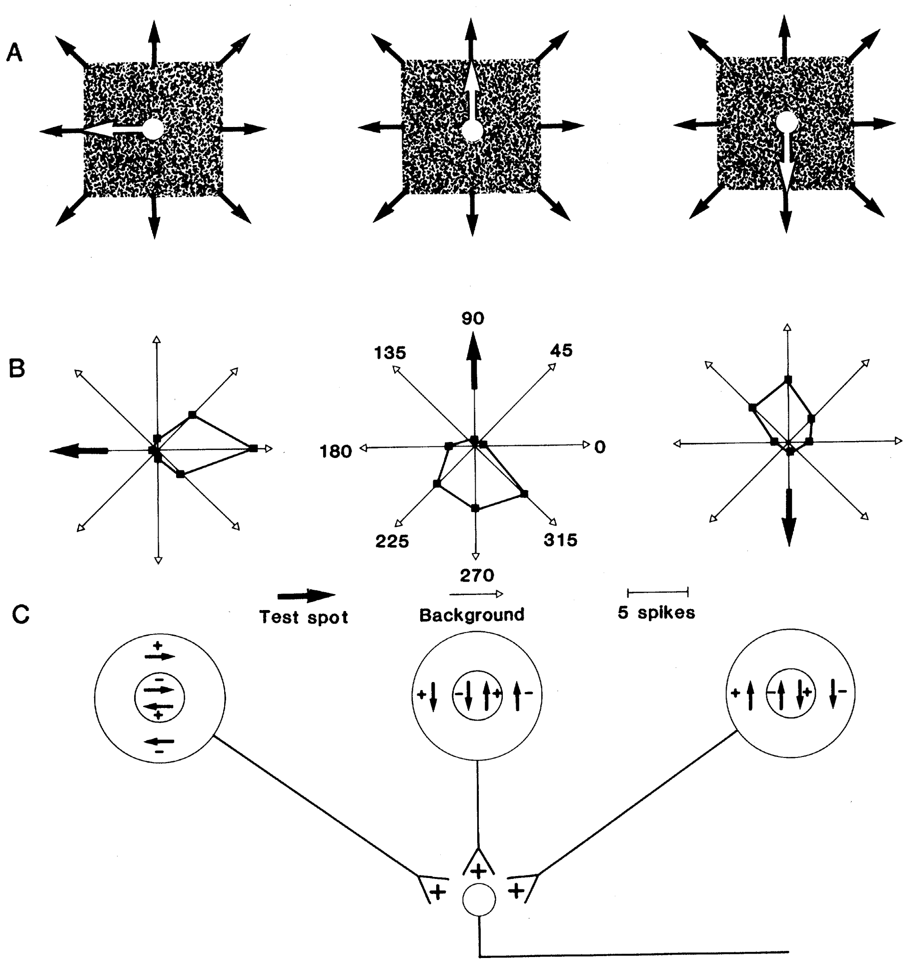


Fig. 1. (A) Schematic diagram representing visual stimulating conditions presented to individual pigeon tectal cells. The white spot indicates the test stimulus, and the textured pattern represents the background. Arrows indicate the direction of motion of these components used to measure the responses portrayed in the corresponding polar plots. (B) Polar response plots obtained from a single cell showing the mean number of impulses as a function of background direction. Each plot was obtained by choosing a fixed test spot direction (bold arrows) and varying background direction. Despite changes in test spot direction, cells responded best when the background motion was opposite test motion in all three cases. (C) Hypothetical scheme to account for the results. Concentrically overlapping subunits having different preferred directions and with opponent center-surround organization converge onto a cell of higher order.