THE EFFECTS OF STIMULUS MOVEMENT AND ATTENTION ON PERIPHERAL STIMULUS LOCALIZATION BY 8- TO 26-WEEK-OLD INFANTS

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This study examined the effect of stimulus movement on localization probability and latency during attention and inattention. Forty infants, 10 each at 8, 14, 20, and 26 weeks of age were presented with a central stimulus. Then, a peripheral stimulus was presented (static or dynamic checkerboard). Stimulus movement did not affect localization probability. Infants localized the dynamic peripheral stimulus more quickly than the static peripheral stimulus when there was no focal stimulus. Focal stimulus attention attenuated this difference in localization latency between static and dynamic stimuli. Signal detection analysis showed that sensitivity to the peripheral stimulus increased over this age range along with a decrease in the bias against responding. The effects of attention were on response bias rather than stimulus sensitivity. These results imply attention affected the localization response to the peripheral stimulus but did not affect the sensitivity of the sensory and perceptual pathways to peripheral stimuli.

peripheral stimulus movement signal detection analysis peripheral stimulus localization attention heart rate electrooculogram infants

INTRODUCTION

Localization of peripheral stimuli by young infants is known to be affected by several factors. Peripheral stimulus characteristics, such as contour (Salapatek, 1975), size and spatial density (Cohen, 1972), form (Maurer & Lewis, 1979), and flicker (Lewis, Maurer,

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Burhanpurkar, & Anvari, 1996), affect the probability and latency to move fixation from a central location to the peripheral stimulus. The presence of a focal stimulus will decrease the probability of localizing a peripheral stimulus (Aslin & Salapatek, 1975; Finlay & Ivinskis, 1982, 1984; Harris & MacFarlane, 1974), particularly if the focal stimulus is currently engaging attention (Richards, 1987, 1997a; Richards & Hunter, 1997). This study manipulated peripheral stimulus movement in an attempt to elicit localization during attention or inattention to a focal stimulus in 8- to 26-week-old infants. The purpose of the study was to determine how characteristics of the peripheral stimulus affected stimulus sensitivity under different attention levels.

The characteristics of the peripheral stimulus relative to the stimulus in the focal visual field is important in considering the probability of the infant's shifting fixation to the peripheral stimulus. Without a focal visual stimulus, a flickering visual stimulus will elicit a higher probability of responding in 3-month-olds than will a static visual stimulus (Lewis et al., 1996). Similarly, in the presence of a central stimulus, newborn infants will localize peripheral stimuli at greater eccentricities when the peripheral stimulus is flashing than when it is not flashing (MacFarlane, Harris, & Barnes, 1976). The speed at which the central and peripheral stimuli move also affect peripheral stimulus localization. Tronick (1972) found that if the central stimulus remains static and the peripheral stimulus is dynamic, the effective visual field more than doubles in infants from 2 to 10 weeks of age. However, he found that if the central stimulus is dynamic and the peripheral stimulus is static, the size of the visual field remains the same during this age range. Similarly, Finlay and Ivinskis (1984) used a dynamic peripheral stimulus and a central stimulus which moved either more slowly or at the same rate as the peripheral stimulus. The infants oriented more toward the peripheral stimulus when the central stimulus moved more slowly than when it moved at the same speed as the peripheral stimulus. Thus a peripheral stimulus that is more intense, or moves faster, than the stimulus in the focal visual field, will overcome the tendency of a central stimulus to inhibit peripheral stimulus localization.

Attention to a focal visual stimulus attenuates localization of the peripheral stimulus. This has been shown in several studies. Richards (1987) found that it took longer for an infant to switch fixation from a centrally-presented visual stimulus to a peripheral stimulus when heart rate changes indicated sustained visual attention was occurring, than when the central stimulus was presented and attention was unengaged (heart rate at prestimulus levels). A recent study suggested that this attenuation is not caused by a decrease in peripheral stimulus sensitivity, but is caused by an increase in the bias against responding. Richards (1997a) presented stimuli to 14- to 26-week-old infants in the periphery for a fixed duration, and measured localization probability. Control trials were presented with the focal stimulus present in the absence of a peripheral stimulus. This allowed the calculation of the probabilities (hit, miss, false alarm, correct rejection) necessary for signal detection parameters (sensitivity, d', and response bias, β).[1] Peripheral stimulus sensitivity (d') did not differ when focal visual attention was engaged or disengaged. The bias against responding (β) was much higher in sustained attention than in preattention or attention termination. This finding is similar to past studies (e.g., Aslin & Salapatek, 1975; Richards & Hunter, 1997) that found that sensitivity decreases with increasing eccentricity, but that the central stimulus presence (or attention to the central stimulus) results in equivalent suppression of response probabilities in control conditions as it does in peripheral stimulus present conditions (i.e., sensitivity equivalent and response bias differs).

The findings of no difference in peripheral stimulus sensitivity between focal stimulus attention and inattention, as well as the effects that the characteristics of the peripheral stimulus has on peripheral stimulus localization

probability and latency, suggests that peripheral stimulus processing may occur in the relative absence of overt localization. The presence of a central stimulus (and attention to the central stimulus) results in an overall attenuation of response probability. However, characteristics of the peripheral stimulus still have an effect on the infant's responses. The similar d' levels in attention and inattention (Richards, 1997a) imply that perceptual sensitivity is similar across attention levels. Both of these findings suggest that in situations in which the peripheral stimulus is not localized, information about that stimulus may still be processed. One goal of this study was to present peripheral stimuli with different characteristics (e.g., static and dynamic stimuli) to determine if differences in signal detection sensitivity exist between these stimuli in the presence of attention to a focal visual stimulus.

A consideration of the CNS structures that are thought to mediate peripheral stimulus sensitivity and the role of attention on peripheral stimulus localization may be relevant for this type of experiment. Peripheral vision is controlled by a "magnocellular" visual system (DeYoe & Van Essen, 1988; Merigan & Maunsell, 1993; Schiller 1985, 1998). A large proportion of cells in the peripheral retina are large magnocellular cells, or "parasol" cells (Schiller, 1998). These cells have high contrast sensitivity, fast response times, and transient responses. They project to "magnocellular" layers in the lateral geniculate nucleus, to layer 4B of the primary visual cortex, and to cortical areas such as the middle temporal cortex that are involved in movement analysis (Schiller, 1985, 1998). Lesion and recording studies in animals with isoluminant stimuli show the magnocellular pathway is sensitive to temporal stimulus characteristics, motion, and temporal-flicker (Schiller & Logothetis, 1990; Schiller, Logothetis & Charles, 1990a, 1990b, 1991). The infants' response to peripheral stimuli varying along these dimensions (e.g., movement, temporal-flicker, dynamic changes) suggests that these peripheral stimulus characteristics engage the magnocellular pathways and result in reflexive saccadic eye movements that bring the peripheral stimulus into the focal visual field. Focal stimulus attention, on the other hand, is controlled by different systems. One of these is the parvocellular pathway (DeYoe & Van Essen, 1988; Livingstone & Hubel, 1988; Schiller, 1985, 1998). A large proportion of cells in the foveal and parafoveal regions are small parvocellular cells, or "midget" cells (Schiller, 1998). These cells are color-opponent, have sustained responses, and are involved in the visual processing of form and detail. The parvocellular pathway travels from these cells to the lateral geniculate nucleus to visual areas 1 and 2, the parietal cortex, and to the frontal eye fields (Schiller, 1985, 1998). The parvocellular pathway is sensitive to color, detailed pattern analysis, and fine depth perception. This system mediates attention by controlling eye movements to the central stimulus. This "posterior attention network" (Posner, 1995; Posner & Petersen, 1990) inhibits the reflexive saccades to peripheral stimuli controlled by the alternative magnocellular pathway (Richards & Casey, 1992; Richards & Hunter, 1998; Schiller, 1985, 1998). This inhibition of peripheral stimulus saccades is consistent with the interpretation of attention affecting response processes (response bias) rather than stimulus discrimination processes (sensitivity). During focal stimulus attention, the peripheral visual system may remain sensitive to the peripheral stimulus and process information concerning the peripheral stimulus even when localization probability or latencies are attenuated.

This study had two goals. The first goal was to examine how characteristics of the peripheral stimulus affected peripheral stimulus localization. Infants were tested at 8, 14, 20, and 26 weeks of age. A central stimulus was first presented and then a peripheral stimulus was presented that consisted of a static or a dynamic checkerboard pattern. Given the sensitivity to movement of the peripheral retina's predominantly magnocellular neurons, the dynamic checkerboard pattern should be

responded to more readily than the static pattern. We tested the effect of the peripheral stimulus movement by comparing localization probability and latency to localize the peripheral stimulus. Stimulus discriminability (i.e., signal detection "sensitivity") was calculated by comparing these peripheral stimulus presentation trials (hits, misses) with trials with the peripheral stimulus absent (false alarms, correct rejection). These conditions control for the possibility that spontaneous fixation shifts may occur and allow the calculation of sensitivity and response bias measures (Baird & Noma, 1978; Green & Swets, 1966; Massaro & Cowan, 1993).

The second goal of the study was to examine the effect of peripheral stimulus movement on attention-related localization. The peripheral stimulus was presented before attention was engaged, during focal stimulus attention, or when attention was unengaged in the presence of a central stimulus. Attention was defined using heart rate changes elicited by the focal stimulus (Berg & Richards, 1997; Richards & Casey, 1992; Richards & Hunter, 1998). "Sustained attention" was measured by a significant deceleration of heart rate, and represents the period of time when significant processing of the focal stimulus is occurring. "Attention termination" was measured by the return of heart rate to its prestimulus level following sustained attention, and represents a period of time when there is a stimulus in the focal visual field but attention is unengaged. Peripheral stimulus localization for infants in this age range occurs with smaller probability during focal stimulus sustained attention than during preattention or attention termination (Richards, 1987, 1997a). This finding has been attributed to response processes (increased response bias during attention) rather than stimulus discriminability processes (Richards, 1997a). If this is true, then the expected enhanced sensitivity to the dynamic peripheral stimulus should be the same during attention and inattention.

METHOD

Participants

Infants were recruited from birth notices published in a Columbia, South Carolina newspaper. The infants were full term, defined as having birthweight of greater than 2500 grams and gestational age of 38 weeks or greater based on the mother's report of her last menstrual cycle. The parents reported that their infant had no prenatal or perinatal medical complications. A cross-sectional design was used to sample 40 infants with 10 each at 8, 14, 20, and 26 weeks. The mean testing ages of the infants were 63 days (SD = 4.42; 4 female, 6 male), 101 days (SD = 3.06; 3 female, 7 male), 145 days (SD = 5.10; 6 female, 4 male), and 185 days (SD = 4.52; 6 female, 4 male), respectively. Fifty-four additional infants were tested but became fussy, sleepy, or inattentive during the experimental trials, or did not successfully complete the minimum number of peripheral localization trials (fussy, missing data, experimental protocol mistakes), and were not included in the analysis. The proportion of infants not included in the analysis was higher than past research of this type (e.g., 34% attrition rate in Richards, 1997a). This was due in part to the exclusion of infants that completed just the minimum number of peripheral localization trials during testing, but for whom the offline judging did not find interobserver agreement for trial completion for all trial types (see Peripheral Stimulus Localization Judgements). The 94 infants that participated in the study were primarily of Caucasian (approximately, 81%) and African-American (approximately 17%) racial/ethnic descent, and less than 2% were of other racial/ethnic backgrounds.

Apparatus

The infant was held in a parent's lap approximately 51 cm from the inner edge of two black and white 49 cm (19 in) TV moni-

tors. The center of each screen was 56 cm from the infant's eyes and the far edge was 70 cm. The plane of the TVs was parallel to the infant's eyes. The TVs subtended 88°visual angle, with each TV subtending 44°visual angle. There was a visual angle of 48° from center to center of each monitor. A neutral color material covered the surrounding area. A video camera was placed above the TVs and in an adjacent room an observer judged infant fixations on a TV monitor. The session was recorded on videotape with a time-code in order to synchronize physiological and experimental information for analysis.

The focal stimuli consisted of 15 dynamic computer-generated patterns (e.g., a series of concentric squares of varying size, a flashing star, a small box shape moving across a diamond). The display area for the focal stimulus was a 40 cm wide by 30 cm vertical rectangle on one of the TV monitors, subtending 32° visual angle. These stimuli have been used in previous studies (e.g., Richards, 1987, 1997a, 1997b) and elicit approximately equivalent levels of heart rate change, and equivalent first fixation duration. The focal stimuli were presented on either of the two TVs, and were defined as "focal" because the infant's central fixation point was oriented toward that TV.

The peripheral stimulus consisted of an 11 cm wide by 17 cm high (10 degree by 17 degree) checkerboard that was 23 cm from the edge of the focal stimulus and 38 cm from the center of the focal stimulus (23° from the edge of the focal stimulus). The checkerboard was either static or dynamic. For the dynamic checkerboard, the patterns changed from black to white at 5.0 Hz. The size of the checks was 3.5 by 4.0 cm (4°). The peripheral stimuli were presented on the TV located away from the infant's central fixation point, and thus was presented in the periphery of the infant's gaze.

Procedure

The experimental trials consisted of the focal stimulus presentation, alone on some trials, and with the peripheral stimulus being presented at delays on other trials. At the start of each trial, a small blinking square that was 4° in size was presented at the center of one of the two TVs in order to orient the infant's fixation to the center of that TV. There were three types of trials: latency, detection and control trials (Table 1). *Latency* trials consisted of the presentation of the peripheral stimulus alone until the infant localized the stimulus. The *detection* trials consisted of the four delay conditions: a prestimulus condition, an immediate condition, a heart rate deceleration + 2 s condition, and a heart rate acceleration condition. In the prestimulus condition, the peripheral stimulus was presented alone. In the immediate condition, the focal and peripheral stimuli were presented simultaneously. In the heart rate deceleration + 2 s condition, the peripheral stimulus was presented 2 s after a significant cardiac deceleration had occurred. In the heart rate acceleration condition, the peripheral stimulus was presented when heart rate returned to the prestimulus level following a cardiac deceleration. The peripheral stimulus remained on for 2 s in the detection trials. If the infant looked toward the peripheral stimulus while it was on (or within 1 s of its being turned off) the focal stimulus was turned off and the peripheral stimulus remained on for 5 s. The *control* trials consisted of trials on which the peripheral stimulus was not presented. The no-stimulus control trial began with the presentation of the blinking square followed by no stimuli. The focal stimulus control consisted of the presentation of the focal stimulus alone, through 5 s following heart rate's return to prestimulus level. The control trials were used to provide estimates of false alarms and correct rejections. There was a minimum of 5 s between each trial.

There were 12 trial types (static/dynamic peripheral stimulus X latency and four detection, two control types). In each 18-trial-block there were four latency trials, four focal stimulus control trials, and two each of the four detection trial types and no-stimulus control trials. The four focal stimulus control trials provided false alarm and correct rejection

TABLE 1
Experimental trial type conditions

Trial Type	*Focal Stimulus*	*Peripheral Stimulus (Static and Dynamic)*
Latency Trials		
Latency	No focal stimulus	Peripheral stimulus until the infant localizes it
Detection Trials		
Prestimulus	No focal stimulus	Peripheral stimulus on for 2 s
Immediate	Focal stimulus	Focal stimulus and peripheral stimulus presented simultaneously, peripheral stimulus on for 2 s
HR Deceleration + 2 S	Focal stimulus	Focal stimulus on, peripheral stimulus delayed until HR deceleration + 2s, peripheral stimulus on for 2 s
HR Acceleration	Focal stimulus	Focal stimulus on, peripheral stimulus delayed until HR returns to prestimulus level, peripheral stimulus on for 2 s
Control Trials		
No Stimulus	No focal stimulus	No peripheral stimulus
Focal Stimulus	Focal stimulus on	No peripheral stimulus

rates for the immediate, heart rate deceleration + 2 s, and heart rate acceleration trials. The two no-stimulus control trials provided false alarm and correct rejection rates for the two prestimulus trials. The latency and detection conditions had equal numbers of trials with a static or dynamic peripheral stimulus. The focal stimulus control trials were presented every four trials, whereas the other stimuli were presented randomly within the 18-trial-block. Each participant received at least one trial block and as many as two trial blocks, and was included in the analysis only if they successfully completed at least one of each trial type. Trials were restarted if no heart rate deceleration occurred within 10 s of stimulus onset, if the infant looked away from the TV before heart rate returned to the prestimulus level, or if the infant was not looking when the peripheral stimulus was presented. A new focal stimulus was presented on the "restarted" trials. These "restarted" trials also provided data for the estimates of false alarms and correct rejections. Testing was done only if the subjects maintained an alert, awake state during the entire procedure (eyes open, no fussing or crying, responding to the protocol).

Measurement and Quantification of Physiological Variables

The ECG was recorded with Ag-AgCl electrodes on the infant's chest and was digitized at 1000 Hz (each ms) with a microcomputer. The R-wave was identified in the ECG, and inter-beat interval (IBI) was defined as the duration between successive R-waves in the ECG. This evaluation was made on-line

within 30-60 ms following the R-wave occurrence for the heart-rate-defined epochs. The delay for the "heart rate deceleration" condition occurred following a significant heart rate deceleration, evaluated on-line as 5 successive beats with IBIs each longer than the 5 prestimulus beats' median (i.e., sustained attention; Richards, 1987, 1997a). The delay for the "heart rate acceleration" condition occurred when heart rate returned to its prestimulus level, evaluated on-line as 5 beats with interbeat-intervals shorter than the 5 prestimulus beats' median (i.e., attention termination; Richards, 1987, 1997a). For quantitative analyses, artifact correction was done with the Cheung (1981) and Bernston, Quigley, Jang, and Boysen (1990) algorithms along with visual inspection of the ECG. The interbeat interval was calculated as the time between successive R-waves, and beats were proportionally assigned to 0.5 s intervals for the analysis.

The electrooculogram (EOG) was recorded with 6mm Ag-AgCl electrodes that were placed posterior to the outer canthus of each eye using disposable electrode collars. The EOG was digitized at 1000 Hz (each ms) with a microcomputer. The EOG was amplified at 2K and a DC-recording was made. The saccades were separated from the composite EOG record with an algorithm presented in Matsuoka and Ueda (1986; Matsuoka & Harato, 1983). A third-order differential filter was used to identify saccades, and a computer-based editing program was used to verify the onset/offset of each saccade. The onset/offset of the saccade, and the EOG amplitude (μV) at the beginning and end of the saccades, was recorded.

Peripheral Stimulus Localization Judgments

Each session was judged offline by two observers and data for the analysis came from one observer's judgments. A time code recorded on the videotapes allowed the judgement to have ms accuracy, though resolution was limited to a single video scan (0.5 * total frame length = ~ 16 ms). The observers judged the infant as looking toward the right TV, looking toward the left TV, or not looking toward either TV. The time code on the videotape was synchronized with the computer clock in order to synchronize the physiological measures with fixation.

Localizations were based on the observers' fixation judgements in conjunction with the existence of saccades in the EOG. First, for a trial or any period of time within a trial to be used in the analysis, both observers had to agree that the infant was looking toward the TV with the focal stimulus at the peripheral stimulus onset, or looking at the focal stimulus TV at the onset of periods defined by delay conditions (see next section, "Experimental Design for Statistical Analysis," and "Signal Detection Analysis" in Results). Second, on the "latency" condition trials, for the trial to be included in the analysis both observers had to agree that a localization of the peripheral stimulus occurred. A look was considered a localization on the latency trials when the observer(s) judged that the infant's eyes moved from the TV that had the blinking dot to any location within the peripheral stimulus, and a saccade occurred in the EOG recording in the appropriate direction. Third, for the localizations on the other trials, we used the localization judgements of only one of the observers in conjunction with saccades in the EOG. A look was considered a localization when that observer judged that the infants' eyes moved from the focal stimulus to any location within the peripheral stimulus, a saccade occurred in the EOG recording in the appropriate direction and with an appropriate amplitude, and no other saccade occurred before that saccade. The "appropriate amplitude" of the saccade was defined as at least within 1 standard deviation of the mean of the latency condition trials that had a localization and had both observers judge that the localization occurred. The amplitude could be obtained with a single saccade in the correct direction, or multiple saccades sequentially in

the correct direction if their summed magnitude was of the appropriate amplitude. Localizations also were defined in which there was a saccade of the appropriate direction and amplitude but for which the observer did not judge a localization (approximately 6% of trials). However, on those trials the observers judged the infants to be looking at the TV(s), and such trials were excluded if either observer judged that the infant was not looking at either TV during the saccade (i.e., the saccade was a look away from the focal stimulus to not looking at either TV). The latency of the localization was defined as the onset of the first localizing saccade occurring after the onset of the peripheral stimulus. Fourth, nonlocalizations were defined when the observer judgement indicated that fixation remained on the focal stimulus, and there was no saccade (of appropriate amplitude) in the EOG recording.

Experimental Design for Statistical Analysis

Discrete periods of time in the peripheral stimulus localization trials were identified in which a delay condition criterion (prestimulus, immediate, heart rate deceleration + 2s, heart rate acceleration) was met. These periods were classified into four categories: localization, non-localization, correct rejections and false alarms. *Localizations* ("hits" in Signal Detection Analysis of Results section) were defined as the infant correctly moving fixation toward the TV with the peripheral stimulus within 3 s of its onset. *Non-localizations* ("miss" in Signal Detection Analysis of Results section) were defined as the infant continuing fixation on the focal stimulus TV for 3 s following peripheral stimulus onset. *Correct rejections* were defined on any trial when a delay type criterion was met, a peripheral stimulus was not present and the infant continued to fixate on the focal stimulus. *False alarms* were defined as looks away from the TV monitor with the focal stimulus toward the other TV monitor when no peripheral stimulus was being presented. These categories were obtained from any trial with a peripheral stimulus presentation and any trial that was "restarted". The time code on the videotape was used by the computer to determine if the peripheral stimulus was present (localization, non-localization) or not (correct rejection, false alarm).

The frequency of localization and nonlocalization was analyzed as a "categorical dependent variable" using linear categorical models. A signal detection analysis was done with the localizations (hits), nonlocalizations (misses), correct rejections and false alarms. Because only one or two peripheral stimulus presentations were given for each delay to a subject, the parameters used in signal detection analysis (d' and β) could not be calculated for individual subjects for analysis with parametric statistics (e.g., ANOVA). Alternatively, the four categories' frequency distributions were analyzed with linear categorical models and signal detection parameters were calculated with the frequencies summed over effect categories.

RESULTS

Interbeat Interval Changes

The interbeat interval (IBI) changes during the trials were examined. The IBI changes elicited by the focal stimulus during the control periods were compared to the IBI changes on localization trials where the peripheral stimulus was present but the infant did not localize it. This analysis was done to verify that the IBI changes were similar to those found in past work (e.g., Richards, 1997a, 1997b; Richards & Casey, 1991, 1992), and to determine whether the peripheral stimulus affected IBI changes when the infant continued to fixate the focal stimulus (Richards, 1997a). The values for the 2.5-s preceding these periods, the 3.0-s period during the control and nonlocalization periods, and 2.0-s following this period were analyzed with an Age

(4; 8, 14, 20, 26 weeks) × Delay (3; immediate, heart rate deceleration + 2 s, heart rate acceleration) × Stimulus Movement (2; static/dynamic) × Intervals (15; 0.5-s intervals) × Localization (2; control and nonlocalization) ANOVA[2]. There were no significant effects or interactions involving the localization factor. This indicates that the IBI changes were not affected by the non-localized peripheral stimulus. There were significant effects of the intervals factor, $F(14, 504) = 6.30$, $p < .0001$, delay, $F(2, 72) = 67.77$, $p < .0001$, and an interaction between the intervals and delay factors, $F(28, 11976) = 43.85$, $p < .0001$. As expected from previous research using the a priori definitions of heart rate change, the immediate trial had a deceleration of heart rate during the first 5 s, the heart rate deceleration + 2 s trials had the expected deceleration of heart rate, and heart rate returned to prestimulus levels on the heart rate acceleration trials. The pattern of results was nearly identical to that found in past research (e.g., Richards, 1997a, 1997b; Richards & Casey, 1991) and the graphs for these effects are not presented. Given the hypothesized link between attention and heart rate changes (Berg & Richards, 1997; Richards & Casey, 1992; Richards & Hunter, 1998) these results indicate that attention was occurring to the stimulus in the immediate and heart rate deceleration + 2 s conditions, whereas the heart rate acceleration condition trials reflected inattention.

Localization Percentage

The localizations (hits) and nonlocalizations (misses) in the detection trials were analyzed using an Age (4) × Delay (4; prestimulus, immediate, heart rate deceleration + 2 s, heart rate acceleration) × Stimulus Movement (2) design with linear categorical modeling. The null hypothesis of homogeneity among the marginals was rejected for the main effect of age, χ^2 (3, $N = 341$) = 70.14, $p <$ .0001. The age effect confirmed the expectation that older infants would have higher localization percentages for both types of peripheral stimuli than younger infants. There was an increase in localization percentages from 8 (25.5%, $N = 90$), to 14 (65.9%, $N = 94$), to 20 (92.5%, $N = 81$) weeks of age[3] ($ps <$ .0001). The 20-week-olds' localization percentage was not significantly different from that of the 26-week-olds' (89.4%, $N = 86$).

The null hypothesis of homogeneity among the marginals also was rejected for the main effect of delay, χ^2 (3, $N = 341$) = 15.72, $p =$ .0013. The localization percentages during the prestimulus, immediate, deceleration, and acceleration delay were 85.9 ($N = 71$), 50.0 ($N = 96$), 64.4 ($N = 90$), and 72.6 ($N = 84$), respectively. A "competition/attention" effect occurred in that peripheral stimulus localization on the prestimulus trial (no focal stimulus) occurred more frequently than that on the immediate ($p < .0001$) and heart rate deceleration + 2 s ($p = .0226$) trials. The prestimulus trial localization percentage was larger but not significantly different from that on the heart rate acceleration trial when, presumably, attention to the focal stimulus had waned. Infants were much more likely to localize the peripheral stimulus when there was no focal stimulus present, or attention was unengaged with the focal stimulus, than when attention was engaged on the focal stimulus.

The expected effect of the dynamic and static stimuli on the localization percentage did not occur. There was no significant difference between the two stimuli on localization percentages, and this factor did not interact with any other factor.

Localization Latency

The latency to localize the peripheral stimulus during the latency and detection trials was analyzed with an Age (4) × Delay (5; latency, prestimulus, immediate, heart rate deceleration + 2 s, heart rate acceleration) × Stimulus Movement (2) ANOVA. There was a main effect of age, $F(3, 36) = 8.37$, $p = .0002$. The localization latency means for the 8-, 14-, 20-, and 26-week-old infants were 835.1 ms ($SD = 635.73$), 745.1 ms ($SD = 498.29$), 541.5 ms

(SD = 352.89) and 578.2 ms (SD = 350.76), respectively. The decrease in localization latency from 8 to 14 weeks and 14 to 20 weeks was significant ($ps < .0001$), but the difference for the 20 and 26 week olds was not significant. This age difference shows a faster reaction time across this age range than has been shown in other studies of infants in this age range (e.g., Richards, 1997a; Richards & Hunter, 1997).

Peripheral stimulus localization latency was significantly affected by the type of trial (delay main effect), $F(4, 109) = 9.16$, $p < .0001$. Differences among the trial types for the latencies were examined with planned comparisons. Localization latency during the latency, prestimulus, and heart rate acceleration trials was not significantly different (latency, M = 544.0 ms, SD = 332.99; prestimulus, M = 627.7 ms, SD = 332.43; heart rate acceleration, M = 628.0 ms, SD = 475.44). These three conditions represent periods when attention was hypothesized to be unengaged. The latency and prestimulus trials have no focal stimulus to engage attention, and on the heart rate acceleration trials attention has waned in the period when the peripheral stimulus is presented. Localization latency during the immediate and heart rate deceleration trials was compared. Attention is hypothesized to be engaged on these trials. The latency on the immediate trials (M = 901.0 ms, SD = 644.34) was significantly longer than the heart rate deceleration + 2 s trials (M = 765.1 ms, SD = 541.69; $p < .05$). Finally, the three trials in which focal stimulus attention was unengaged (latency, prestimulus, heart rate acceleration) were significantly different from those on which attention was hypothesized to be engaged (immediate, heart rate deceleration + 2 s; $p < .0001$).

There were three significant effects on localization latency involving the stimulus movement factor: main effect of stimulus movement, $F(1, 34) = 6.75$, $p = .0112$; interaction of delay and stimulus movement, $F(4, 108) = 2.45$, $p = .0484$; and interaction of age and stimulus movement, $F(3, 34) = 3.60$, $p = .0243$. As expected, the infants were faster to localize the dynamic peripheral stimulus (M = 623.7 ms, SD = 441.84) than the static peripheral stimulus (M = 669.9 ms, SD = 465.52). The post hoc analyses determined how attention to the focal stimulus affected peripheral stimulus localization in the different "attention" conditions. Table 2 contains the means for the comparisons between the static and dynamic stimulus localization latencies for these comparisons. When there was no focal stimulus (latency and prestimulus trial types), the dynamic stimulus was localized faster than the static stimulus ($p < .0001$; see Table 2). When there was a focal stimulus, and attention was hypothesized to be engaged, the latencies were in the same direction but the difference was smaller and not statistically reliable ($p = .1942$; see Table 2). This shows that the effect of the peripheral stimulus movement on peripheral stimulus localization was much greater when attention was unengaged than when it was engaged. Finally, and unexpectedly, when there was a focal stimulus and attention was unengaged (heart rate acceleration), the latency to localize the static stimulus was faster than the dynamic stimulus ($p < .0001$; see Table 2).

Figure 1 shows the latency means separate for each age and stimulus movement, and combined across some of the trial types. The significant interaction of age and stimulus movement on localization latency was due to the smaller difference in the localization latencies for the static and dynamic stimuli at the older ages in the latency and prestimulus trials (Figure 1A). Figure 1A shows faster localization of the dynamic stimulus on the latency and prestimulus trials, whereas Figure 1B shows the faster localization of the static stimulus on the heart rate acceleration trials (cf. Table 2). This finding was unexpected, given the hypothesis that these three trial types represent unengaged focal attention with a focal stimulus present (heart rate acceleration) or no focal stimulus present (latency, prestimulus trials). Figure 1C presents the localization latencies on the immediate and heart rate

TABLE 2
Peripheral stimulus localization latency (ms) for dynamic and static stimuli, for different hypothesized levels of attention engagement

		Hypothesized Level of Attention Engagement		
Stimulus Movement	*Overall Means*	*Attention Unengaged: No Focal Stimulus (Latency, Prestimulus)*	*Attention Engaged: Focal Stimulus Present (Immediate, HR Deceleration + 2s)*	*Attention Unengaged: Focal Stimulus Present (HR Acceleration)*
		Dynamic		
M	623.7	529.9	782.9	789.2
SD	(441.84)	(291.57)	(587.61)	(607.17)
SE	(33.49)	(27.80)	(89.60)	(132.49)
N	174	110	43	21
		Static		
M	669.9	608.4	813.6	543.4
SD	(465.52)	(371.93)	(573.23)	(370.64)
SE	(32.75)	(36.82)	(77.13)	(58.60)
N	202	102	60	40

deceleration + 2 s trials. These two trial types, representing engaged focal stimulus attention, resulted in localization latencies that were not significantly different for the static and dynamic stimuli.

Signal Detection Analysis

A signal detection analysis was done to determine if the static and dynamic stimuli affected stimulus discriminability (d') or response bias (β) processes. Any 3-s period of time from the peripheral stimulus localization trials that met the delay condition criteria (prestimulus, immediate, heart rate deceleration + 2 s, heart rate acceleration) was identified, with the start of the 3-s period identified by the criterion being met. These 3-s periods were classified into six categories for a signal detection analysis: localization (2; hit of static or dynamic), non-localization (2; miss of static or dynamic), correct rejection and false alarm. The hits and misses came from the detection trials, and correction rejections and false alarms came from detection trials in periods when the peripheral stimulus was not present, the two control conditions, and any restarted trials that met the criteria for the categories. Signal detection parameters (percentages, d' and β) were calculated by summing over subjects within categories for which there was a statistically significant effect from the categorical modeling.

The six detection type categories were analyzed with an Age (4) X Delay (4) design with linear categorical modeling. The null hypothesis of homogeneity among the marginals was rejected for the age, χ^2 (15, N = 1520) = 94.11, $p < .0001$ and delay, χ^2 (15, N = 1520) = 158.34, $p < .0001$, but not the interaction between age and delay. These significant effects on the six detection categories indicate a difference across the factors (age, delay) for the signal detection parameters of the model.

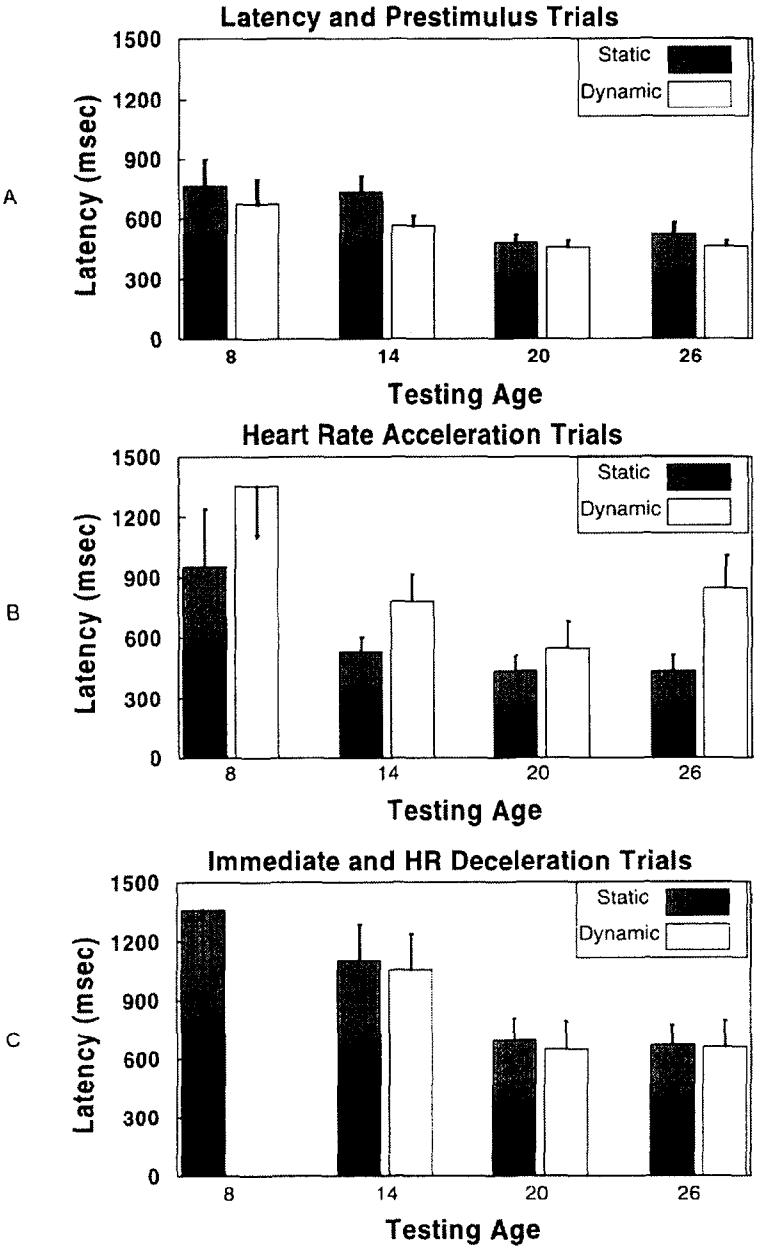

FIGURE 1

Peripheral stimulus localization latency for the four testing ages on the latency and prestimulus trials (A), the heart rate acceleration trials (B), and the immediate (simultaneous focal and peripheral stimulus) and heart rate deceleration + 2 s trials (C), separately for the static and dynamic peripheral stimuli. There were no localizations of the dynamic peripheral stimuli by 8-week-old infants and only five localizations of the static stimuli by that age on the immediate and heart rate deceleration + 2 s trials (C). The error bars are the +1 *SE* for each mean.

The signal detection parameters for the delay effect were examined. The pattern of d' and β was similar across the static and dynamic stimuli. The sensitivity parameter was equivalent in the four delay types, and the response bias primarily accounted for the significant effects. The sensitivity parameter, d', remained approximately equivalent across the four delay types (d' = 1.187, 1.253, 1.357, 1.293 for the prestimulus, immediate, heart rate deceleration + 2 s, and heart rate acceleration trials, respectively). The bias against responding was the largest during the immediate (β = 1.557) and heart rate deceleration + 2 s conditions (β = 1.328), was at an intermediate level in the heart rate acceleration condition (β = 0.819), and the smallest in the prestimulus condition (β = 0.441). This indicates that the infants were more likely to move fixation towards the peripheral stimulus location regardless of the stimulus position in the two conditions when attention was unengaged (prestimulus, heart rate acceleration). They were biased against responding in the two conditions when attention was engaged (immediate, heart rate deceleration + 2 s). This signal detection analysis indicates that the delay effect on localization percentage (previous section) was due to a change in response bias across the delay conditions.

The signal detection parameters for the four ages are presented in Table 3, separately for the static and dynamic stimuli. There was an increase in the sensitivity to the presence of the peripheral stimulus across this age range (Table 3). This increase in d' was similar for the two stimulus movement types, though at the later ages the infants showed increased sensitivity to the dynamic stimulus. The response bias parameter decreased in size from 8 to 14 to 20 weeks of age, and was similar in the 20 and 26 week old infants (Table 3). This indicates that the older aged infants were more likely to move fixation towards the peripheral stimulus location regardless of the stimulus presence than were the two youngest ages. The signal detection analysis showed an increase in sensitivity across all four ages, even though localization percentages were similar at the two older ages (previous section). This signal detection analysis indicates that the increasing localization percentages across this age range (previous section) were due to changes both in sensitivity and response bias.

DISCUSSION

The hypothesis that movement of the peripheral stimulus would aid peripheral stimulus localization was partially supported in this study. There was an overall main effect of stimulus movement on the peripheral stimulus localization latency. Infants localized the dynamic peripheral stimulus faster than the static peripheral stimulus. This was true primarily for the latency and prestimulus trials, when there was no central stimulus, and true to a lesser degree (though nonsignificant) on the trials when there was a central stimulus to which attention was directed (Table 2). These findings are similar to past research showing that a flickering stimulus (Lewis et al., 1996) or movement in the peripheral stimulus (Finlay & Ivinskis, 1982, 1984; MacFarlane et al., 1976; Tronick, 1972) increases the likelihood of localization and decreases the latency of eye movements toward the peripheral stimulus. Similar to this study, Cohen (1972) drew fixation of 4-month-old infants to one location and presented checkerboard patterns of different size and complexity in the periphery. He found that infants localized a large checkerboard pattern in the periphery faster than a small checkerboard patterns.

Some studies of 3-month-old infants (e.g., Finlay & Invinkis, 1982; Lewis et al., 1996) have reported that localization probabilities were affected by stimuli of differing characteristics. The localization probabilities in this study were not different for the static and dynamic stimuli, although they were in the expected direction for the three older ages (Table 3). We do not have a ready explanation for the differences between this study and oth-

TABLE 3
Signal detection parameters for the four testing ages, seperately for the static and dynamic stimuli

	Testing Age (weeks)			
	8	*14*	*20*	*26*
Sensitivity (d')				
Dynamic	0.029	1.259	1.810	2.009
Static	0.415	1.162	1.645	1.768
Response Bias (β)				
Dynamic	1.044	0.934	0.375	0.395
Static	1.238	0.922	0.397	0.538
Proportion Hits				
Dynamic	.221	.714	.923	.910
Static	.357	.680	.918	.875
Proportion False Alarms				
Dynamic	.217	.335	.418	.386
Static	.210	.337	.441	.383

ers that have found localization differences. The lack of a difference in the probability of responding may be partially due to the length of the stimulus (2 s) and response window (3 s) in this study, relative to the localization latencies (623 and 669 ms, Table 3). The relatively short response latencies may have masked any differences due to the length of the peripheral stimulus presentation (2 s), and a presentation length closer to the mean response latencies would produce such a difference. Alternatively, the size and composition of the stimuli chosen may be above the response threshold for the peripheral pathways involved in their detection, and movement effects were therefore only present in the latency to localize the stimuli. The stimuli in this study are not directly comparable to those in the Finlay and Ivinkis (1982) or Lewis et al. (1996) studies, so differences in stimuli between studies may account for the different results. Infants at the three older ages did have a slightly higher localization probability to the dynamic stimuli, and manipulations of peripheral stimulus presentation length or other characteristics may enhance this difference.

The infants became more responsive to the stimulus movement from 8 to 26 weeks of age. The overall probability of localizing the peripheral stimulus increased over this age. The signal detection analysis showed that this was not just due to the decrease in bias against responding, but that sensitivity to the peripheral stimulus also was increasing. In addition to the overall increase in sensitivity, there was a larger increase in sensitivity to the dynamic than to the static stimulus, and sensitivity was larger at the three older ages to the dynamic stimulus. Sensitivity in signal detection analysis reflects sensory and perceptual processes (stimulus characteristics, discriminability, state of the sensory system) (Baird & Noma, 1978; Green & Swets, 1966; Massaro & Cohen, 1993). The increase in sensitivity to movement suggests that the sensitivity measure is affected by more than just properties of the retina and lateral geniculate nucleus. The magnocellular pathways in the peripheral retina and the lateral geniculate nucleus are thought to be functioning at mature levels by 8 weeks (Johnson, 1990, 1995; Richards & Hunter, 1998), so that these changes in sensi-

tivity to movement must reflect other structures in the CNS involved in movement analysis. Other structures in the CNS are involved in movement analysis, including specific layers of the primary visual cortex, columns in the secondary visual cortex, and the middle temporal cortex (DeYoe & Van Essen, 1988; Merigan & Maunsell, 1993; Schiller, 1985, 1998). These CNS structures show changes over the first year of life (Johnson, 1990, 1995). This is reflected both in the perception and the control of eye movements to smoothly moving stimuli, which develops over a long time period (Aslin, 1985; Richards & Holley, 1996). The difference in sensitivity to the static and dynamic peripheral stimuli increased with age, demonstrating that infants became increasingly sensitive to stimulus movement over this age range.

One goal of the study was to examine the interaction between peripheral stimulus movement, and attention's effect on peripheral stimulus localization. Attention to a focal stimulus affected peripheral stimulus localization in this study as has been found in previous studies (e.g., Richards, 1987, 1997a). Peripheral stimulus localization probability was higher if no focal stimulus was present, or if a focal stimulus was present but attention was unengaged, than if the infant was actively attending to the focal stimulus. Concurrently, there was an increase in false alarms in the inattentive conditions to a similar extent as the increase in localization, resulting in the decreased response bias measure (β) in the inattentive conditions. The effect of the focal stimulus attention was to increase the bias against making a localization response (e.g., increase in response bias parameter, β) rather than decreasing the sensitivity to the peripheral stimulus (sensitivity parameter, d'; cf. Richards, 1997a). Peripheral stimulus movement did not interact with this effect. Sensitivity differences between the static and dynamic stimuli were unaffected by the attention conditions. The increased bias against responding during attention implies that focal stimulus attention raised infants' overall response threshold independent of the characteristics of the peripheral stimulus.

Another aspect of the response that attention affected was the latency to make the eye movements toward the peripheral stimulus. Localization was faster when no central stimulus was present than when a stimulus was presented and had engaged focal attention (Table 2). There was an interaction between attention's effect on localization latency, and peripheral stimulus movement. The latency difference between the static and dynamic stimuli found when a focal stimulus was not present (latency and prestimulus conditions) was much smaller and not significantly different when a focal stimulus was present and attention was engaged (immediate and heart rate deceleration + 2 s condition; see Table 2, Figure 1A, C). The peripheral stimulus was thus less likely to elicit a fixation shift to the peripheral location during focal stimulus attention, and responses that were made were delayed during focal stimulus attention. Peripheral stimulus movement did interact with the effect of attention on response latency. When a response difference did exist in the response to the peripheral stimulus (e.g., latency difference to dynamic and static stimuli on attention unengaged trials) this difference was attenuated by focal stimulus attention. Attention affects peripheral stimulus localization through the infant's response processes rather than through other aspects of the information processing system.

An unexpected finding in this study was the lengthened response latencies to the dynamic stimuli relative to the static stimuli in the heart rate acceleration condition trials. The return of heart rate to its prestimulus levels in the presence of a focal stimulus has been interpreted as unengaged attention (Berg & Richards, 1997; Richards & Casey, 1992; Richards & Hunter, 1998). In this study the conditions in which attention was hypothesized to be unengaged (latency, prestimulus, heart rate acceleration) did not significantly differ among themselves in either response probability or latency. These attention-unengaged condi-

tions differed in both response probability and latency with the conditions in which attention was hypothesized to be engaged (immediate, heart rate deceleration + 2 s). These findings were consistent with several studies examining response latency differences among these conditions (e.g., Richards, 1987; see Richards & Casey, 1992) and a recent study showing similar localization probability differences between attention-engaged and attention-unengaged conditions (Richards, 1997a). Given that the heart rate acceleration condition represents unengaged attention, we had a strong expectation that the differences in responses to the static and dynamic peripheral stimuli in the heart rate acceleration condition should parallel those found in the latency and prestimulus conditions. That was not the case. The response latency means to the static stimulus in the heart rate acceleration condition trials were similar to that of the prestimulus and latency condition trials (overall, Table 1; and by age, Figure 1A, B). The localization latency to the dynamic stimulus in the heart rate acceleration condition was similar to that of the immediate and heart rate deceleration + 2 s conditions (overall, Table 1; and by age, Figure 1B, C). This implies that the infant was responding differentially to the stimuli (as in the no focal stimulus conditions) but that the dynamic stimuli slowed down the reaction to the peripheral stimulus. We have no ready explanation for this effect based on an understanding of the peripheral or CNS pathways mediating responses to peripheral stimulus movement.

The difference in response latency to the dynamic and static stimuli in the no-focal stimulus conditions and the heart rate acceleration condition emphasizes the need for a distinction between attention phases. The period of time after the heart rate returns to its prestimulus level following sustained attention, but when the infant's fixation remains on the focal stimulus, has been labeled "attention termination" (Casey & Richards, 1988, 1991; Richards & Casey, 1992). Attention is hypothesized to be unengaged, and thus the explicit effects of attention (enhanced focal stimulus processing, stimulus selectivity) are removed and the response to a peripheral stimulus is similar in some ways to conditions where no focal stimulus exists. However, this period of time is not totally equivalent to no-focal-stimulus conditions. The heart rate orienting response of infants is attenuated during this period (Casey & Richards, 1988, 1991; Richards & Casey, 1991). Focal stimulus processing during this period differs both from the immediate ("stimulus orienting") and heart rate deceleration ("sustained attention") conditions (Richards, 1997b). The delayed responding in this study to the dynamic stimulus was different than that when no focal stimulus was present. It has been hypothesized that the "attention termination" phase represents a refractory period in attention, and that several seconds must elapse before heart rate responses to new stimuli match that of the no-focal stimulus conditions (Casey & Richards, 1991). We would predict that after reaching the criterion for the heart rate acceleration condition that one would have to wait several seconds (e.g., 5 s) before the infant would be in a state more equivalent to the no-focal-stimulus conditions.

The pattern of results in this study is consistent with neural (Schiller, 1985, 1998) and "neurodevelopmental" (Johnson, 1990, 1995; Richards & Casey, 1992; Richards & Hunter, 1998) models of the effects of attention on eye movement control. The perceptual sensitivity differences between the static and dynamic peripheral stimuli reflect the initial processing of the stimuli by the magnocellular cells in the peripheral retina that are sensitive to temporal and movement stimulus characteristics. These sensitivity differences affect CNS structures in the initial sequence of visual processing steps (e.g., retina, lateral geniculate nucleus, primary visual area, and perhaps visual areas involved with the processing of movement; Schiller, 1985, 1998). The final response processes controlling the eye movement to the peripheral stimulus involve a short-latency reflexive pathway involving the retina, lateral

geniculate nucleus, primary visual area, and superior colliculus. The control of the superior colliculus in affecting this peripheral localization is inhibited by CNS structures controlling focal stimulus attention (e.g., posterior parietal cortex, frontal eye fields, "posterior attention network"; Posner, 1995; Posner & Petersen, 1990). Thus, the focal stimulus attention inhibits peripheral localization response processes (response bias) occurring relatively late in the visual processing sequence rather than processes occurring early in the processing sequence.

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NOTES

1. Sensitivity (d') in signal detection analysis reflects sensory and information acquisition processes (stimulus characteristics, discriminability, state of the sensory system) (Baird & Noma, 1978; Green & Swets, 1966; Massaro & Cowan, 1993). It is calculated as the difference between the probability (z-transformed) of responding when a stimulus is present (hits) and responding when a stimulus is absent (false alarms), and has a range similar to the z-distribution. It represents how "sensitive" the responder is to the presence of the stimulus. Response bias (β) in signal detection analysis reflects subject-controlled decision processes (Baird & Noma, 1978; Green & Swets, 1966; Massaro & Cowan, 1993). It is calculated as the ratio of the probability density of the hits to the probability density of the correct rejections. Lower numbers represent a smaller hits probability density (tail of the z-distribution) and thus a greater likelihood to respond, and higher numbers representing a smaller probability density of the correction rejections and thus a bias against responding. It therefore represents how willing a participant will respond independent of the stimulus.
2. The ANOVAs for the interbeat interval and latency analyses were done with a general linear models approach using non-orthogonal design because of the unequal distribution of localizations across factors, including some cells in which no localizations occurred. 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 (e.g., delay, stimulus movement) within this class variable. The "PROC GLM" of SAS was used for the computations. Post hoc and planned comparisons were done with the Scheffe' method to correct for error rate, using the error term from the omnibus analysis and the effects estimated with the general linear model contrasts.
3. The linear categorical models used to analyze the localization frequencies and signal detection analyses use maximum likelihood estimates for response function parameters that consist of "generalized" logits (log ratios) of the marginal probabilities for the independent variable effects (PROC CATMOD in SAS). The maximum likelihood optimization procedure results in an "information matrix" that provides the numerical basis for a χ^2 value for the independent variable effects based on the "Wald" test, with df equal to the number of parameters used from the information matrix for the effect. Post hoc tests were single df Wald tests for the contrasts, and represent the significance of the change in the χ^2 for the overall model that would result if the response function for the particular effect were dropped from the model.

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