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Brief article

Selection and inhibition in infancy: evidence from the spatial negative priming paradigm

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Abstract

We used a spatial negative priming (SNP) paradigm to examine visual selective attention in infants and adults using eye movements as the motor selection measure. In SNP, when a previously ignored location becomes the target to be selected, responses to it are impaired, providing a measure of inhibitory selection. Each trial consisted of a prime and a probe, separated by 67, 200, or 550 ms interstimulus intervals (ISIs). In the prime, a target was accompanied by a distractor. In the probe, the target appeared either in the location formerly occupied by the distractor (ignored repetition) or in another location (control). Adults exhibited the SNP effect in all three ISI conditions, producing slower saccade latencies on ignored repetition versus control trials. The SNP effect obtained for infants only under 550 and 200 ms ISI conditions. These results suggest that important developments in visual selection are rooted in emerging inhibitory mechanisms.

Keywords: Selective attention; Spatial negative priming; Inhibition; Eye tracking; Infant perception

Efficient allocation of visual attention is critical to learning in infancy. To organize the world into coherent percepts, an infant must attend to certain environmental features while simultaneously ignoring others. This requires selection of relevant stimuli for processing and inhibition of those that are irrelevant. Without inhibition, attentional selection would be random, effectively eliminating any prospects of meaningful learning from the environment.

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The ability to direct visual attention by the inhibition of irrelevant information is termed *visual selective attention* and has been examined with *negative priming* paradigms. In such paradigms, when a distractor object or location that had previously been ignored on one trial becomes the target to be selected on the next trial, responses to it are impaired, as revealed by a delay in its selection relative to a control stimulus (Neill, 1977; Tipper, 1985). The literature on visual attention highlights several possible explanations for the negative priming effect, such as episodic retrieval theory (Neill & Valdes, 1992). Inhibitory accounts (Houghton & Tipper, 1994; Tipper, 1985), however, are the most widely accepted and are supported by neurophysiological evidence (e.g. Desimone & Duncan, 1995; Duncan, Humphreys, & Ward, 1997). According to inhibitory accounts, selection impairment suggests that simultaneous presentation of target and distractor generates competition for attentional allocation. This competition is resolved by the inhibition of the distractor in favor of the selection of the target. An inhibitory network model of selection (Houghton & Tipper, 1994) proposed that target and distractor stimuli receive excitatory inputs initially and in parallel until target selection/distractor inhibition is accomplished. Distractor inhibition persists even at distractor offset, resulting in an inhibitory rebound. When the distractor subsequently becomes the target to be selected, responses to it are slowed. The time course of inhibition, therefore, provides a measure of selection efficiency: The more efficient the system, the more quickly the inhibitory effect commences.

Negative priming has been found to be effective to varying degrees early in development. Children exhibited the effect when the task involved inhibition of stimulus location (Tipper & McLaren, 1990) but not identity (Tipper, Bourque, Anderson, & Brehaut, 1989). More recent work with children ranging from 5 to 12 years of age suggests that negative priming can be obtained by the manipulation of identity, location, or conceptual task features (Pritchard & Neumann, 2004; Simone & McCormick, 1999). Investigations probing the involvement of the inhibition of interfering or competing information on 3- to 4-year-old children’s rule acquisition (Zelazo, Müller, Frye, & Marcovitch, 2003) and 9-year-old children’s strategy use (Houdè & Guichart, 2001) also provide evidence of functional inhibitory mechanisms. The magnitude of the spatial negative priming (SNP) effect (i.e. inhibition of location) has been found to remain constant across 6–12 years and into adulthood (Amso, Gehlbach, & Diamond, 2001).

These studies reveal effects of negative priming in children under a variety of circumstances, but they do not bear on the question of the functionality of inhibitory mechanisms in infancy. In the present report, we asked whether infants would provide evidence of SNP. There have been no published investigations of negative priming in infants, perhaps because it is a task that requires a motor reaction time response, traditionally assessed with a button press or movement of a joystick. Such responses are beyond infants’ motor skills, but the oculomotor system is largely functional even in very young infants (Johnson, 2001). The present article reports a new method for testing inhibition in infancy using a saccade latency measure. Specifically, we investigated the inhibitory mechanisms of selection in the face of competition as indexed by the SNP effect. We also examined the efficiency of inhibition by testing at three different processing delays, reasoning that inhibitory mechanisms would be revealed to be maximally efficient if they were activated after short latencies. We conducted two experiments, the first with 9-month-old infants and the second with a group of adults.

1. Experiment 1

1.1. Methods

1.1.1. Participants

Thirty-six 9-month-old infants (*M* age = 277 days, SD = 8 days; 22 girls) composed the final sample. Twenty infants were observed but excluded from the sample because a majority of trials were deemed invalid according to criteria described subsequently (1 infant), uninterpretable eye movement data resulting from poor calibration of the point of gaze, or POG (5 infants), excessive head or body motion (10 infants), or as a result of program error (4 infants). All infants were full term with no known developmental difficulties.

1.1.2. Apparatus and stimuli

Infants were tested individually, seated approximately 100 cm from a 76 cm monitor used to present the stimuli. Eye movements were recorded using a remote-optics corneal reflection eye tracker (Applied Science Laboratories model 504). Infants viewed a white cross-shaped grid against a black background with four possible locations in which a stimulus could appear (see Fig. 1). Two types of trial were presented in random order, *ignored repetition* (IR) and *control*, for a total of 48 trials. Each trial consisted of a *prime* and a *probe*, each lasting 2000 ms and separated by an interstimulus interval (ISI) of 67, 200, or 550 ms in a between-subjects design. Targets were selected randomly from a series of colorful, animated images that moved in synchrony with various sounds. In all prime trials, the target in one location was accompanied by a distractor (gray diamond) in another location. Target and distractor locations were randomized across trials. In ignored repetition probe trials, a target appeared in the location that the distractor had previously occupied. Control probe trials were identical except the probe target appeared in a different location. (The negative priming effect has been shown to remain intact whether a distractor is present or absent during the probe; Buckolz, Van Damme, & O'Donnell, 1998; Milliken, Tipper, Houghton, & Lupianez, 2000; Neill, Terry, & Valdes, 1994; Tipper, Brehaut, & Driver, 1990; a finding that we corroborated during piloting. We elected to omit the distractor during the probe to prevent additional invalid trials due to looking at the distractor.) The interval between trials (prime/probe pairs) was 1500 ms. Data from individual trials were considered invalid if the infant (a) fixated the distractor during the prime presentation, (b) did not fixate the target during the prime presentation, (c) produced a preprogrammed eye movement toward the target location in probe trials (167 ms or less before the stimulus actually appeared; see Canfield, Smith, Brezsnyak, & Snow, 1997), or (d) the POG was not recorded or was directed elsewhere on the stimulus. Twelve infants were assigned randomly to each ISI condition.

1.1.3. Procedure

Each infant's POG was calibrated by showing an attention-attracting stimulus that contracted and expanded in synchrony with a rhythmic sound at the top left and bottom corners of an imaginary rectangle that contained the possible stimulus locations. The infant then viewed the calibration stimulus at several random locations on the screen.

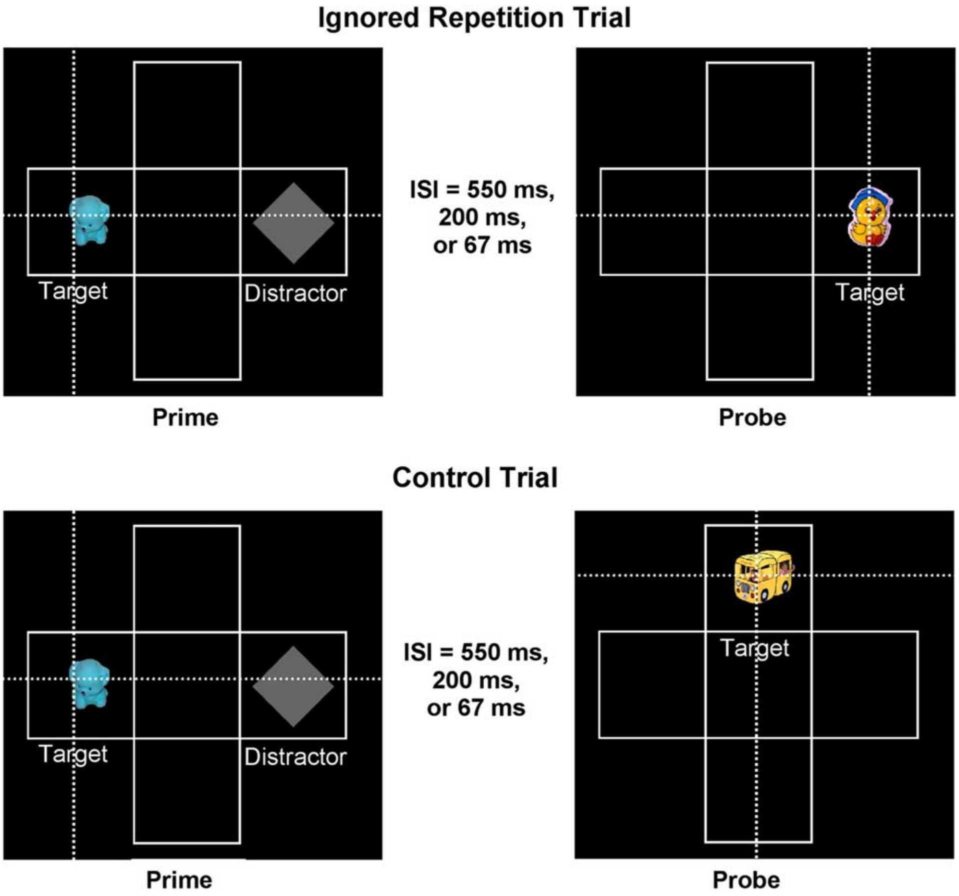

Fig. 1. The two types of trials presented to infants. Each trial consisted of two presentations, a prime and a probe. In the *Ignored Repetition* probe display, the target appeared in a location occupied by the distractor in the prime. In the *Control* probe display, the target appeared in one of the other possible locations outlined by the grid. The dashed lines represent the observer's point of gaze.

If the POG was not within 0.5° of the center of the attention-getter at all locations (minimum of 6), the calibration procedure was repeated. Once the calibration criterion had been reached, the experiment began. Data (the POG superimposed on the stimuli) were recorded onto digital videotape and coded offline.

1.2. Results and discussion

The dependent variable consisted of eye movement latencies toward the probe stimulus (see Table 1), log-transformed prior to analysis due to excessive skew in some of the cells (a common characteristic of infant data). Infants produced interpretable eye movements on a mean of 70.3% of trials (SD = 14.8). Fig. 2 shows difference scores of individual infants

Table 1
Saccade latency data by condition

	ISA (ms)	N	Mean	SD
Infants				
Ignored repetition	550	12	393.82	101.37
	200	12	301.84	81.00
	67	12	303.08	47.11
Control	550	12	322.18	59.26
	200	12	254.85	51.58
	67	12	317.47	61.24
Adults				
Ignored repetition	550	10	230.81	46.10
	200	10	207.91	32.34
	67	10	193.99	73.71
Control	550	10	188.50	39.23
	200	10	148.84	18.84
	67	10	177.84	70.27

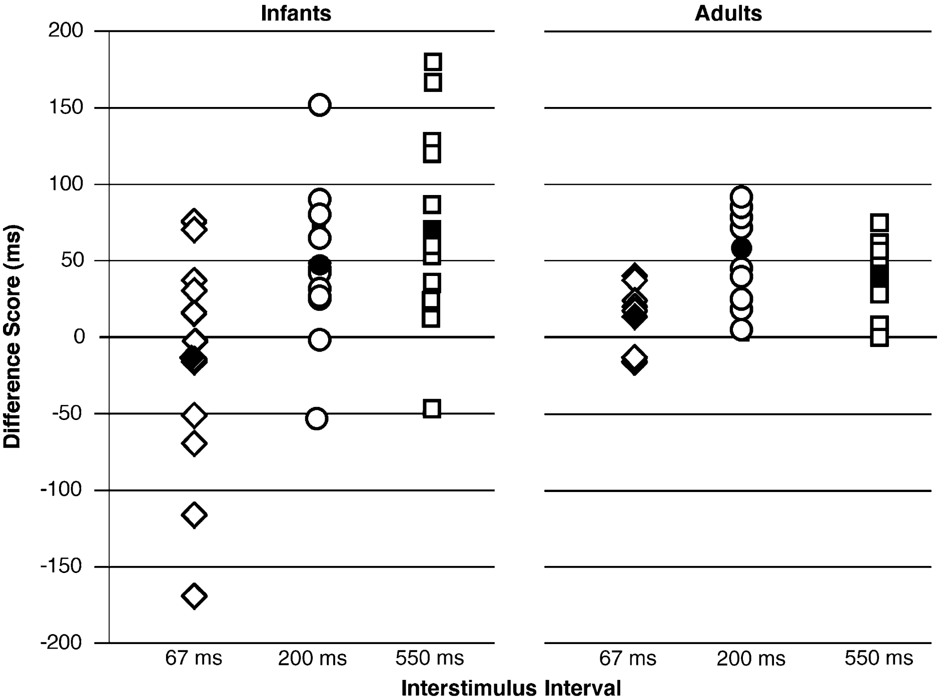

Fig. 2. Difference scores (Ignored Repetition—Control saccade latency) for infants and adults in each of the three ISI conditions. Adults in all ISI conditions and infants in the 200 and 550 ms ISI conditions were slower on Ignored Repetition relative to Control trials, providing evidence of the spatial negative priming effect. Infants in the 67 ms ISI condition showed no evidence of the effect.

in each ISI condition, computed as the mean latency from IR trials minus mean latency from control trials (these difference scores are based on raw data). Eleven of the 12 infants in the 550 ms ISI condition produced slower saccade latencies for IR than control trials (Wilcoxon matched pairs test, $z=2.51$, $P<0.05$), as did 11 of 12 infants in the 200 ms ISI condition ($z=2.35$, $P<0.05$). In contrast, only five of 12 infants in the 67 ms ISI condition showed the effect ($z=0.36$, *ns*).

These conclusions were confirmed with parametric analyses. A 2 (trial type: IR vs. control) × 3 (ISI) repeated measures ANOVA yielded a reliable main effect of trial type, $F(1, 33)=9.19$, $P<0.01$, and of ISI, $F(2, 33)=4.86$, $P<0.05$, as well as a significant trial type × ISI interaction, $F(2, 33)=4.58$, $P<0.05$. Post hoc analyses (simple effects tests) revealed slower saccade latencies after the 550 ms ISI, $F(1, 33)=10.44$, $P<0.01$, and the 200 ms ISI, $F(1, 33)=7.40$, $P<0.05$, but not the 67 ms ISI, $F(1, 33)=0.49$, *ns*. These results indicate that infants exhibited the SNP effect at the two longest delays, but not at the shortest delay. Given sufficient time, therefore, infants appear to have inhibited the distractor stimulus.

2. Experiment 2

In the second experiment, adults were tested in the same paradigm as in Experiment 1.

2.1. Methods

2.1.1. Participants

Thirty undergraduate and graduate student volunteers served as participants, all with normal or corrected-to-normal eyesight. Ten were assigned randomly to each ISI condition.

2.1.2. Apparatus, stimuli, and procedure

Adults were tested under the same conditions, and with the same stimuli, as described previously for infants. The criterion for rejecting data due to a preprogrammed eye movement was 100 ms (vs. 167 ms for infants).

2.2. Results and discussion

All 10 adults in the 550 ms ISI condition produced slower saccade latencies (see Table 1) for IR than control trials ($z=2.80$, $P<0.01$), as did all 10 adults in the 200 ms ISI condition ($z=2.80$, $P<0.01$), and 8 of 10 adults in the 67 ms ISI condition ($z=1.99$, $P<0.05$) (see Fig. 2). A 2 (trial type) × 3 (ISI) repeated measures ANOVA yielded a reliable main effect of trial type, $F(1, 27)=62.42$, $P<0.0001$, as well as a significant trial type × ISI interaction, $F(2, 27)=6.96$, $P<0.01$. Post hoc analyses (simple effects tests) revealed slower saccade latencies after the 550 ms ISI, $F(1, 27)=19.66$, $P<0.001$, and the 200 ms ISI, $F(1, 27)=52.72$, $P<0.0001$, and a marginally significant difference at the 67 ms ISI, $F(1, 27)=3.96$, $P=0.056$. Similar to the infants, adults exhibited inhibition at the two longest ISIs, but in contrast to infants, there is evidence of inhibition at the shortest ISI, though the effect is somewhat weaker.

Planned comparisons of infant versus adult responses (IR vs. control) revealed no reliable differences at the 550 ms ISI, $F(1, 60)=0.06$, *ns*, a significant difference at the 200 ms ISI, $F(1, 60)=5.46$, $P<0.05$, and a trend toward significance at the 67 ms ISI, $F(1, 60)=3.02$, $P=0.087$, with stronger inhibitory effects in adults at the two shortest ISIs.

3. General discussion

We adapted a spatial negative priming task to assess the ability of 9-month-old infants and adults to select between simultaneously presented locations by inhibition of the distractor location. Interstimulus intervals (ISIs) were manipulated to generate an inhibitory temporal profile as an index of selection efficiency. Both infants and adults exhibited the SNP effect at the longest (550 ms) and intermediate (200 ms) ISIs, though the magnitude of the effect was stronger in adults (relative to infants) at the 200 ms delay. At the shortest (67 ms) ISI, only adults provided some evidence of SNP.

It is not surprising that infants exhibit oculomotor behavior characteristic of a functional visual selective attention system: Research using visual search tasks to probe competition in stimulus-driven (exogenous) orienting has revealed that infants select targets based on salience (e.g. Dannemiller, 1998). The current report is the first to our knowledge to examine complementary *inhibitory* mechanisms that are activated as selection is underway. An important advantage of our design is that it allows us to measure inhibition parametrically rather than to simply conclude that infants succeed or fail at a SNP task. Our results reveal that by 9 months after birth, infants are capable of inhibition, provided sufficient time. Several theories have proposed that developmental changes in attention and memory are due to increases in processing speed and efficiency (e.g. Case, 1985). The differences in inhibition as a function of ISI that we observed suggest that the development of this mechanism is not an all-or-none phenomenon but is graded in nature (cf. Munkata, 2001), a distinction that may take on increased importance as younger infants are tested in this paradigm. Having validated that SNP is testable in 9-month-olds using this novel methodology, we are now in a position to investigate the developmental trajectory of this mechanism in a younger population using a more sensitive within-subjects ISI design.

Understanding the development of inhibition is essential to the study of cognitive development. Diamond suggested that “development appears to proceed by destruction and inhibition, as well as by construction and acquisition” (1990, p. 637) and an important aspect of cognitive development is overcoming the susceptibility to interference or conflict (Dempster, 1993; Diamond, 1990). A considerable amount of research effort has been geared toward investigating contributions of inhibition on the development of executive functions and control from early childhood through adolescence (Casey et al., 1997; Diamond, Kirkham, & Amso, 2002; Durston et al., 2002; Friedman & Leslie, 2004; Houdè & Guichart, 2001; Kirkham, Cruess, & Diamond, 2003; Leslie & Polizzi, 1998; Perner & Lang, 2002; Zelazo et al., 2003). These experiments examined children’s ability at different ages to inhibit a perceptual stimulus, belief, rule, strategy, or motor response in favor of selecting a competing or interfering task-irrelevant alternative. Very little is known about inhibitory abilities from this perspective in infants, and it has proven difficult to disambiguate development of inhibitory mechanisms from that of other kinds of change in infancy. For example, there is evidence that by 12 months, infants can inhibit a prepotent motor response to a location as revealed by performance in an A-not-B search task (Diamond, 1991), but it is not yet clear whether this is related to emerging functionality of the dorsolateral prefrontal cortex (Diamond, 1991), emerging object representations (Piaget, 1954), or more general developments in motor habits (Smith, Thelen, Titzer, & McLin, 1999).

Other work has provided evidence for a mechanism that inhibits return eye movements to a cued object or location, known as *inhibition of return* (IOR), functional in young infants (Harman, Posner, Rothbart, & Thomas-Thrapp, 1994; Hood, 1993). This type of cueing paradigm is often used to investigate developmental changes in visual orienting as well as developmental differences in overt shifts of attention (involving an eye movement) and covert shifts (no eye movement). Paradigms that rely on overt orienting elicit IOR in newborns (Simion, Valenza, Umiltà, & Dalla Barba, 1995; Valenza, Simion, & Umiltà, 1994) whereas those that require covert orienting have found evidence of IOR only in infants 4 months of age and older (Johnson, 1994; Johnson & Tucker, 1996; Richards, 2000). It has been suggested that IOR and SNP may share common underlying mechanisms (Milliken et al., 2000). Behaviorally, however, they differ in their prime-trial processing demands (Buckolz, Boulougouris, & Khan, 2002). Scanning efficiency is assessed in the IOR paradigm by the inhibition of return movements to previously processed locations. In SNP tasks, competition between the target and distractor must be resolved by suppression of the distractor and *simultaneous* selection of the target, a demand unnecessary in IOR tasks because the cue generally *precedes* the target. Impairment during the probe can be seen as a validation that the distractor location was indeed inhibited *during* target selection in the prime. A population that provides evidence of SNP (such as the infants and adults we observed) shows a capacity to suppress interfering information so that the most relevant stimulus can be processed. IOR, therefore, is a measure of preference for novel unattended locations, whereas SNP provides a quantitative measure of the ability to inhibit one location while selection of another is underway. These are two very distinct processing demands, and behavioral results from the two methods shed light in unique ways on the development of inhibition and its role in learning in infancy.

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