SELECTIVE ATTENTION AND INDIVIDUAL DIFFERENCES IN INFANT LEARNING: A COMPREHENSIVE INVESTIGATION OF EXOGENOUS ORIENTING AMONG 7-MONTH-OLD INFANTS

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Julie C. Markant

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Abstract

Young infants learn incredible amounts of information as they interact with their environment, often without any explicit instruction. Though researchers have identified mechanisms that support learning about regularities in the environment, it is unclear how these mechanisms contend with the massive amount of potentially relevant stimuli available in the world. Selective attention may constrain early learning, since information that is selectively attended may be preferentially processed by learning mechanisms.

Previous studies have relied on social-cueing paradigms to examine learning of selectively attended items. However, attention can also be manipulated in a non-social manner using the spatial cueing paradigm, in which salient spatial cues initiate exogenous shifts of attention. Individuals are typically faster to respond to items appearing in the cued location; however, this facilitation is dependent on the timing between the cue and target presentations. Following relatively short cue-target delays, attention is biased towards targets in the cued location, whereas longer delays bias attention towards targets in the non-cued location, a process known as inhibition of return (IOR).

This dissertation consists of two studies. Study 1 examined whether selective attention biases modulate 7-month-old infants' learning of predictable information. Study 2 addressed individual differences in 7-month-old infants' sensitivity to spatial cues. Specifically, Study 2A examined the consistency of cueing behavior across repeated testing, while Studies 2B and 2C explored behavioral and genetic factors that may influence variation in infants' sensitivity to spatial cues.

Results of Study 1 indicated that spatial cueing modulated selective attention, with enhanced learning of the item that was preferentially attended. Study 2A demonstrated stability in IOR behaviors when using qualitative (categorical) but not quantitative measures. Studies 2B and 2C found that variations in infants' sensitivity to spatial cues were related to both individual differences in their reactivity to novel stimuli and genetic polymorphisms that affect the dopamine and acetylcholine neurotransmitter systems. These results highlight the complexity of interactions between early attention and learning processes, the wide array of factors that may impact infants' responses during a basic attention task, and the range of neural systems that are likely involved in early selective attention.

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Chapter 1

Infants rapidly and seemingly effortlessly learn an incredible amount of information simply by interacting with the environment during their first year of life. Furthermore, because young infants are pre-verbal, much of this learning occurs without explicit direction or instruction. The extent of this learning is especially impressive when considering the massive and complex array of information that could potentially be extracted from the environment. Researchers have proposed a number of mechanisms that contribute to infants' sensitivity to regularities in the environment and support rapid associative or probabilistic learning (Bates & Elman, 1996; Fiser & Aslin, 2002; Kirkham, Slemmer, & Johnson, 2002; Kirkham, Slemmer, Richardson, & Johnson, 2007; Lewkowicz & Berent, 2009; Saffran, 2003; Saffran, Aslin, & Newport, 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Despite these advances, researchers question whether these low-level mechanisms are sufficient given the prohibitive processing capacity that would be necessary in order to learn from the huge range of potentially relevant stimuli available in the environment (Fisher, 2007; von der Malsburg, 1995; Woodward, 2000). Even proponents of these learning mechanisms acknowledge that they would be successful in a real-world context only if they contain "a set of constraints to implicitly guide learning to acquire a minimally sufficient rather than a complete representation of the input" (Aslin & Fiser, 2005, p. 95). Thus, a comprehensive understanding of infant learning must account for factors that limit the amount of information to be learned.

One possibility is that attention processes provide these constraints by selecting specific aspects of the environment as input for learning mechanisms. At the core of learning is the ability to gather information from the world. This process of information gathering is not random; instead, the nature of the information that can be acquired from the environment is a function of the specific events and objects that are attended (Gibson, 1988). Thus, attention is fundamental to humans' capacity to perceive events, learn from these events, and plan subsequent behavior (Ruff & Rothbart, 1996). With respect to infant learning, the attention processes that are available earliest in life may determine the aspects of the world to which infants are most sensitive, thus providing a crucial contribution to the processes that initiate and maintain learning during infancy.

While the idea of a fundamental relationship between attention and learning might seem rather intuitive, it becomes much more complicated when trying to precisely define attention and identify its role in learning. Though it may seem that "everyone knows what attention is" (James, 1890, p. 261), attention processes are at the same time so multifaceted that it is difficult to identify a single defining feature (Duncan, 2006; Fernandez-Duque & Johnson, 2002). Attention researchers have dealt with this complexity by identifying component processes that contribute to a broader attention capacity. Posner and Boies (1971) identified three major components of interest: alerting, selectivity, and central processing capacity. Similarly, based on observed changes in heart rate during attention-demanding tasks, Richards (2001, 2003) described the three major components as sustained attention, stimulus orienting, and attention termination. Considering these models together, the alerting/sustained attention component is akin to

vigilance, involving processes that create and maintain a state of readiness or heightened sensitivity to external stimulation. The selectivity/orienting component refers to the ability to select information of a particular kind or from a specific source, which involves blocking irrelevant input as well as enhanced processing of selected information (Posner & Boies, 1971). Finally, the central processing capacity, more recently referred to as executive attention (Rothbart & Posner, 2001), refers to our ability to direct our attention in a goal-oriented manner and resolve conflict among multiple competing responses (Ruff & Rothbart, 1996). Thus, there is convergence on three main attention components: a process by which sensory receptors are directed to a location of interest and relevant information is selected, a process that enhances engagement or receptivity to this information, and a process that manages cognitive resources by resolving conflict among competing goals and response demands.

Though a comprehensive review of the development of the neural systems involved in these attention processes is beyond the scope of this paper, a broad outline of these systems will be important for interpreting the results of the present studies. Consistent with an understanding of attention as a more global function, research to date has largely failed to identify a single, discrete neural system that mediates attention. Nonetheless, several brain regions have been consistently implicated in various aspects of attention processing. Briefly, a posterior network consisting of the posterior parietal cortex, the pulvinar nucleus of the thalamus, and the superior colliculus is involved in several aspects of selective orienting of attention (Posner & Petersen, 1990), as are subcortical and cortical brain regions involved in oculomotor control (Rothbart & Posner,

2001). Along with these regions, an anterior network consisting of portions of the prefrontal cortex, the anterior cingulate cortex, and the basal ganglia supports more volitional and controlled aspects of attention (Posner & Dehaene, 2000). Furthermore, evidence for significant anatomical and functional connections between the anterior and posterior networks highlights the complex interactions across the various attention components.

Without question, a complete understanding of the functional implications of attention development will require thorough consideration of behavioral and neural processes both within and across these multiple components. However, the present set of studies focuses on selective attention since this component develops early in infancy and seems especially relevant as a potential constraint on environmental input to basic learning mechanisms. This selectivity component can further be defined by identifying the processes involved in selecting relevant information. Specifically, the ability to select task-relevant stimuli involves disengaging from previously attended stimuli, shifting attention to a new location, and enhancing the processing of stimuli that are present at the new location (Hood, 1995; Posner & Raichle, 1994). Furthermore, the process of orienting attention to a new location can occur in either an exogenous or endogenous manner (Posner, 1980). Exogenous selection refers to shifts of attention that are primarily driven by stimulus properties, are relatively automatic, and lead to the subjective experience of attention being "captured" by an external event. In contrast, endogenous selection refers to goal-oriented shifts of attention that are primarily driven by top-down control, rather than by external stimuli. While exogenous target selection processes

develop within the first 6 months of life, endogenous control of attention develops later in infancy (Ruff & Rothbart, 1996) and preliminary evidence suggests that these endogenous shifts of attention may reflect the earliest development of the executive attention component (Sheese, Rothbart, Posner, White, & Fraundorf, 2008).

Over the past several decades, researchers have carefully examined the array of factors that influence young infants' exogenous orienting to stimuli in their environment. Infants' deployment of visual attention shows some selectivity even at birth, as their attention is preferentially drawn to certain types of stimuli, such as visual patterns (Fantz, 1963), motion (Rothbart & Posner, 2001), multiple contours (Rothbart & Posner, 2001; Ruff & Rothbart, 1996), and face-like stimuli (M. H. Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Cassia, & Umilta, 1996). Though this early orienting behavior is primarily driven by the amount or intensity of visual stimulation, there is a shift towards more qualitative influence on attention around 2 months of age as infants' improved visual acuity allows feature information to take on greater salience (Ruff & Rothbart, 1996; Ruff & Turkewitz, 1979). In particular, novel object features or locations begin to have an especially strong impact on infants' orienting. Ruff and Rothbart (1996, p. 80) note that this "selection for novelty is so pervasive in the first year of life in humans that it has been the foundation for much of the research on cognitive development during this period." Thus, from 2 months of age onward, novelty maintains a powerful influence over infants' selective attention behaviors.

In addition to the importance of individual stimulus properties, the relative salience of multiple competing stimuli has increasing influence over selective attention as

infants face a larger number of potential targets in their environment. The size of infants' visual field expands with improvements in visual acuity, allowing for increased orienting between stimuli, especially those presented in the periphery (Rothbart & Posner, 2001). This emerging sensitivity to peripheral stimulation can lead to competition between the object that is being fixated in any given moment and stimulation that occurs in the periphery (Ruff & Rothbart, 1996). Several studies (Atkinson, Hood, Braddick, & Wattam-Bell, 1988; Hood, 1995; Matsuzawa, 2001) have shown that infants' latencies to orient towards peripheral stimuli are considerably slower when a central fixation is still present, indicating that the competition created by multiple visual stimuli adds substantial demands on the selective attention system.

Selective attention during infancy is driven both by the salience of individual stimulus features as well as the processes that drive deployment of attention across multiple spatial locations. Just as salient stimulus features capture attention, salient spatiotemporal events can facilitate deployment of attention towards the spatial locations in which these events occur. Selective orienting towards specific locations often occurs in an overt manner, in which both eye gaze and the focus of attention concurrently shift towards the location of interest. Yet in many instances, orienting of attention occurs in the absence of overt shifts in eye gaze. Studies using the spatial cueing paradigm (Posner, 1980) have established that salient peripheral cues can capture visual attention in a covert manner that is independent of individuals' eye movements. In this paradigm, participants maintain eye gaze at a central location while a peripheral cue flashes briefly on one side of the screen. Following a brief delay a target stimulus appears either at the cued location

or in the position opposite to the cued location. In general, participants are faster to respond to the target when it appears in the cued location, indicating that their attention had been deployed to that location despite the absence of any overt shift in eye gaze (Posner, 1980; Posner & Cohen, 1984). Thus, the appearance of a peripheral cue in a specific location facilitates orienting of attention towards that location, allowing for more efficient responding following presentation of the target stimulus. Several studies using adapted versions of this spatial cueing paradigm have found similar effects of cueing during early infancy (e.g., Hood, 1993). Converging evidence suggests that facilitation effects induced by a peripheral cue begin to emerge after 4 months of age (Hood, 1993; Hunnius, 2007), with similar effects for both reaction times and probability of orienting towards the cued targets (M. H. Johnson & Tucker, 1996).

Selective attention involves processes that allow certain aspects of the environment to be preferentially attended while the processing of alternate or competing aspects of the environment is inhibited (Amso & Johnson, 2005; Houghton & Tipper, 1994). Thus, selection based on spatial cues is influenced both by facilitative effects and accompanying inhibitory processes. In the context of the spatial cueing paradigm, the facilitation effect is highly dependent on the length of the delay between the cue and the target. When this delay is short (< 250 ms), attention is facilitated at the cued location; however, when the delay is long (> 250 ms), attention is inhibited at the cued location and participants are faster to respond to targets appearing in the opposite, non-cued location (Klein, 2000). Figure 1.1 depicts both the facilitative and inhibitory effects that can be elicited by spatial cueing. Posner et al. (1985) labeled this effect inhibition of

return (IOR) and suggested that it reflects a mechanism that biases individuals towards processing information at novel locations (Posner & Cohen, 1984; Posner, et al., 1985; Posner, Rothbart, & Thomas-Thrapp, 1997; Posner, Rothbart, Thomas-Thrapp, & Geradi, 1998; Wright & Richard, 1998). This hypothesis has gained support from subsequent research with adults showing that the inhibitory effect enhances perceptual processing of novel visual input (Handy, Jha, & Mangun, 1999) and facilitates effective visual search behaviors (Klein, 1988, 2000; Lupianez, Klein, & Bartolomeo, 2006; Macinnes & Klein, 2003).

A number of studies have explored the development of the inhibition of return effect in infancy. Clohessy, Posner, Rothbart, and Vecera (1991) studied IOR based on overt orienting among 3-, 4-, 6-, 12-, and 18-month old infants. While the 3-month-olds preferentially oriented towards the cued targets, infants ages 6 months and older all showed a significant preference for the non-cued targets (Clohessy, et al., 1991). Based on these results, the authors concluded that IOR emerges between 3 and 6 months of age, though the effect is highly dependent on task parameters (Harman, Posner, Rothbart, & Thomas-Thrapp, 1994) and one study suggested that IOR may be evident among newborns when the cue is attractive enough to reliably elicit overt eye movements (Valenza, Simion, & Umilta, 1994).

Additional work has more consistently indicated that inhibition of return based on covert orienting does not emerge until 4-6 months of age. This work has replicated the facilitation effect at cued locations and has demonstrated inhibited orienting towards cued targets following long delays among 6-month-olds, but not 3-month-olds (Hood, 1993,

1995). A separate study found strong evidence across orienting and latency measures for both facilitation and IOR among 4-month-olds, but no evidence of IOR among 2- or 6-month-olds. However, in a subsequent experiment, 6-month-olds showed both facilitation and IOR when shorter delay lengths were used, suggesting that the effects of the cue occur more quickly and dissipate more rapidly among older infants (M. H. Johnson & Tucker, 1996). Overall, the research examining IOR based on covert orienting indicates that the inhibitory effect emerges between 4-6 months of age and may continue to develop as infants' processing becomes more efficient.

The research studying spatial cueing effects has highlighted processes that both facilitate and inhibit the deployment of selective attention during early development. Though the nature of these dual processes is highly dependent on the specific parameters used in various experiments, it is interesting to note that the effects observed among young infants are highly similar to those seen among adults, suggesting that the emergence of these processes may mark an important transition in the development of selective attention. However, though a great deal of research has been devoted to the timing of these developments, few studies have addressed the functional implications of these developing selective attention processes. In particular, it is unclear how the emergence of facilitative and inhibitory attention processes elicited by spatial cueing impact infants' interactions with the environment. How do these effects on selective attention shape the information that infants gather from the world? Furthermore, given the nature of development, it is likely that these emerging processes occur at different rates for different infants, and/or that individual infants at the same developmental point

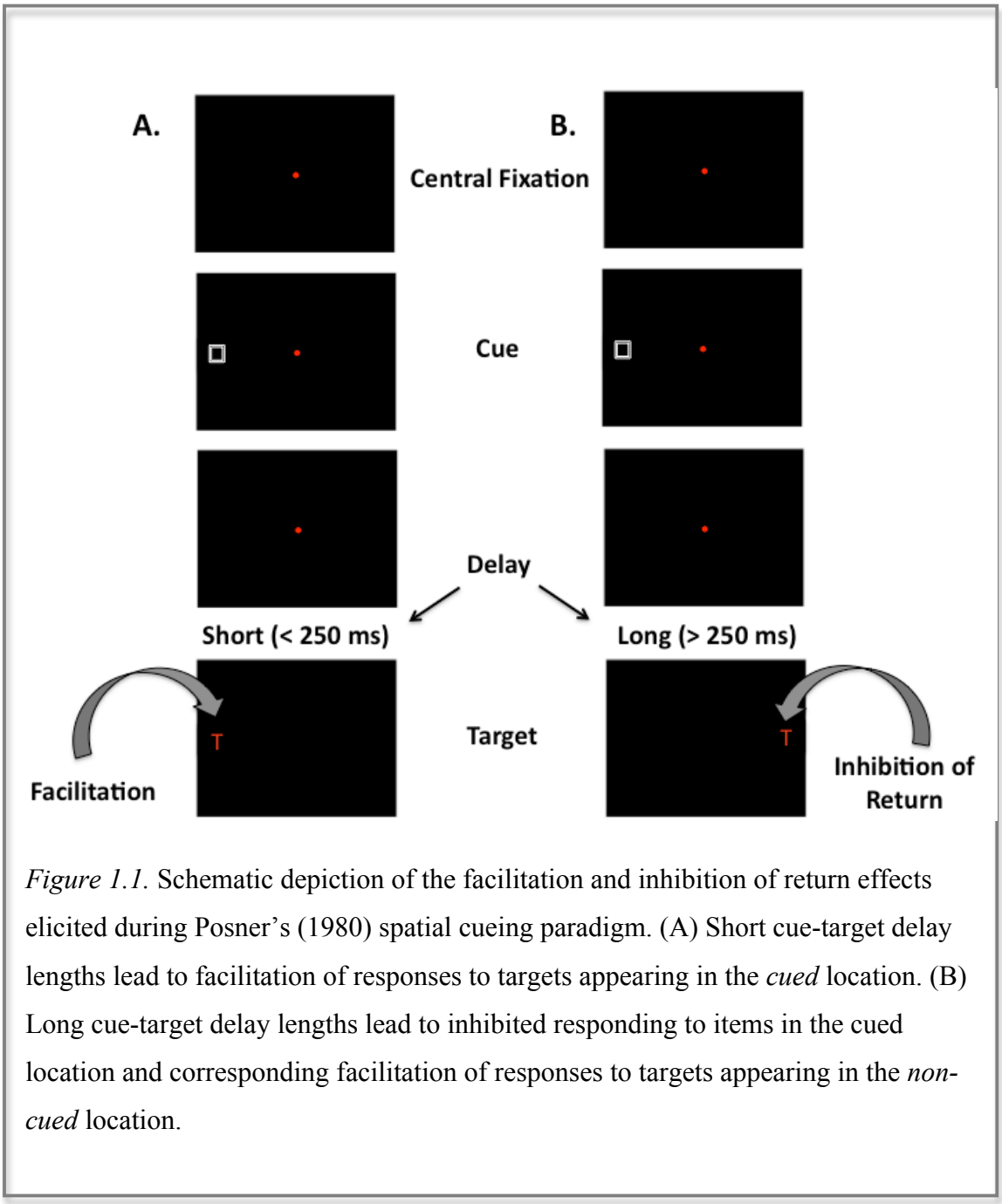


Figure 1.1. Schematic depiction of the facilitation and inhibition of return effects elicited during Posner's (1980) spatial cueing paradigm. (A) Short cue-target delay lengths lead to facilitation of responses to targets appearing in the *cued* location. (B) Long cue-target delay lengths lead to inhibited responding to items in the cued location and corresponding facilitation of responses to targets appearing in the *non-cued* location.

will show varying levels of sensitivity to salient spatial cues. These potential individual differences reflect an additional level of complexity for understanding the ways that developing selective attention processes impact infants' experiences with their world.

The present set of studies had three primary aims. First, Study 1 examined whether selective attention biases elicited by the spatial cueing paradigm impact the nature of infants' information gathering and the extent to which infants learn about information appearing in preferentially attended locations. Second, Study 2 addressed individual variation in infants' sensitivity to the effects of spatial cueing on deployment of selective attention. This study was composed of three sections. The first section specifically examined whether individual infants' behaviors during the spatial cueing task were consistent across repeated testing and a relatively short period of development (< 1 month). Finally, the second and third sections of this study utilized behavioral and biological measures to examine the factors that may influence individual variation in infants' sensitivity to salient spatial cues.

All of the work presented in these studies is based on the spatial cueing paradigm that was initially developed by Posner and colleagues (1980; 1984; 1985) and that has been utilized in the studies of inhibition of return in infancy described above (Hood, 1993, 1995; M. H. Johnson & Tucker, 1996). All infants will complete a spatial cueing task that includes a central fixation stimulus, salient peripheral cues, and target stimuli that appear in the cued and non-cued locations. In addition, the task will include trials with a short cue – target delay in order to measure facilitation of attention, as well as trials with a long cue – target delay in order to measure inhibition of return effects.

Finally, these measures of facilitation and inhibition of return will include the proportion of trials during which infants initially orient to the cued or non-cued locations, as well as a reaction time measure that reflects whether infants are faster to orient to the cued or non-cued locations.

Chapter 2

Study 1: The Role of Reflexive Orienting in Infants' Learning of Predictable Information

Selective attention processes may support learning because they inherently limit the amount of input to perception and learning systems. Recent neurophysiological models propose that selective attention reflects a competitive process by which information that is especially salient or relevant for goal-oriented behavior "wins" cognitive processing resources over other available information (Duncan, 2006; Fernandez-Duque & Johnson, 2002; Kanwisher & Wojciulik, 2000). As a result of this processing bias, the selected information can become the focus of multiple cognitive processes, including learning. Thus, the aspects of the world that are selectively attended may be more readily or robustly learned over those that are ignored.

The importance of linking attention and learning has been recognized by a number of modern learning theories derived from animal models of classical and operant conditioning. These learning theories are based on the premise that surprising or unexpected outcomes provide the most influential feedback for learning. More specifically, the extent to which the predicted outcome is incongruous with the actual outcome, known as the prediction error, is related to the degree to which behavior changes following the surprising outcome (Schultz & Dickinson, 2000). While some learning models assert that the prediction error directly influences the strength of associations between stimuli, alternative attention-based learning models propose that the impact of prediction error on learning is mediated by differential allocation of selective attention (Dayan, Kakade, & Montague, 2000; Pearce & Hall, 1980; Schultz &

Dickinson, 2000). According to these models, prediction error increases the likelihood that attention will be allocated to specific stimuli or events, and this attention bias ensures that the stimuli will be more readily associated with a reinforcer (Schultz & Dickinson, 2000). These attention-based models have been substantiated by neurophysiological research demonstrating the plausibility of such mechanisms on a neural level (Roesch, Calu, Esber, & Schoenbaum, 2010; Schultz & Dickinson, 2000). Although the direct and attention-based mechanisms are not mutually exclusive, the addition of attention factors to modern learning theory highlights the potentially critical role of attention in everyday learning.

Researchers studying infant development have also recognized the importance of considering early learning in the context of developing attention. Overall patterns of attention during early infancy have been linked to global cognitive functioning later in life (Bornstein & Sigman, 1986; Hunnius, 2007) and in the domain of language acquisition, selective attention to the direction of another's gaze has been shown to provide a foundation for developing an understanding of referential intent (Baldwin, 1991). Rovee-Collier and colleagues (Rovee-Collier, Earley, & Stafford, 1989; Rovee-Collier & Giles, 2010) have argued that many of the behavioral changes that are assumed to reflect infants' developing memory skills may instead reflect changes in infants' developing attention. For example, Rovee-Collier et al. (1989) demonstrated that 2-month-olds' apparently poor memory for retrieval cues in a conjugate reinforcement task was instead a result of poor initial encoding of the cues due to limitations in young infants' attention skills. Specifically, 2-month-olds have less flexible orienting skills and

demonstrate high levels of "obligatory fixation," during which infants have difficulty disengaging from a salient stimulus. As a result, infants at this age show relatively little scanning of arrays containing multiple stimuli. Two-month-olds' performance on the conjugate reinforcement task improved after the parameters were altered to allow sampling of all relevant cues in a single fixation, indicating that 2-month-old infants' capacities for successful encoding and subsequent retention in memory are limited by their attention patterns (Rovee-Collier, et al., 1989). Similarly, Rovee-Collier and Giles (2010) suggest that evidence of "exuberant learning" during infancy can be explained by changes in infants' selective attention skills. From this perspective, young infants' rapid learning is possible because infants are sensitive to multiple environmental stimuli and are less able to selectively attend to a subset of stimuli in a controlled manner, allowing them to "notice more about the same event and actually form more intra-event associations" (Rovee-Collier & Giles, 2010, p. 198). Overall, this body of work clearly demonstrates that developing attention can have important implications for infants' learning and memory.

In addition to establishing broad links between developing attention and cognitive development, a number of studies have also begun to examine mechanisms that might mediate the relationship between selective attention and early learning. Several of these studies have dealt with the development of object perception, specifically the ability to perceive an occluded object as a single entity. Perception of object unity is tested by familiarizing infants to a display in which a rod moves behind an occluder, followed by test displays showing either a single un-occluded rod or two separate items corresponding

to the top and bottom of the rod. Infants who look longer at the separate items are considered successful perceivers of object unity, whereas those who look longer at the single rod are considered non-perceivers. These experiments have indicated that infants go through a period of perceptual learning at 2-4 months of age that ultimately leads to robust object unity perception (S. P. Johnson, Slemmer, & Amso, 2004). Several studies have explored whether selective attention processes contribute to this perceptual learning. In one study, 3-month-old infants' eye movements were tracked while they viewed the occluded-rod displays (S. P. Johnson, et al., 2004). Based on their test performance, the infants were later classified as perceivers or non-perceivers of object unity. The researchers then examined the infants' eye movements to determine whether perceivers and non-perceivers could be discriminated based on their patterns of attention during the familiarization phase of the task. The two groups of infants showed similar global patterns of attention (e.g., frequency of eye movements). However, unlike non-perceivers, perceivers demonstrated optimal intake of information from the display by fixating the rod elements more frequently and scanning across the moving rod's path. One possible explanation for this result is that infants who are better able to selectively attend to salient information (e.g., motion) receive more exposure to the critical information that supports successful object perception (S. P. Johnson, et al., 2004).

Amso and Johnson (2006) further explored the possibility that infants' developing control over selective attention enhances their ability to engage in optimal sampling of the environment, and thereby hone in on information that is critical for perceptual learning. In this study, 3-month-olds completed the standard perceptual completion task

and were again classified as perceivers or non-perceivers. The same infants were then tested on a visual search task that involved two conditions. In the non-competition condition, a highly salient moving target was presented in a field of static distracters. In contrast, the competition condition consisted of a field of vertical distracters and a less salient target that was oriented at various degrees from vertical. Thus, while the non-competition condition involved simple reflexive orienting to the target, the competition condition required more controlled selective attention. While there were no differences between perceivers and non-perceivers in the non-competition condition, perceivers detected the target more slowly and accurately than non-perceivers during the more challenging competition condition. These results suggest that perceivers have greater control over selective attention, which may support optimal information-gathering and subsequent learning during the perceptual completion task (Amso & Johnson, 2006). Taken together, these studies demonstrate that early selective attention processes are related to the ways that infants acquire and learn from environmental information.

Though Amso and Johnson (2006) focused on the role of endogenous control of selective attention during perceptual learning, it is also possible that reflexive orienting of selective attention can influence early learning. This possibility is especially intriguing because it would mean that the salience of stimuli in the environment contributes to the organization of infants' learning about the environment. Many studies have shown that detection of another person's shift in eye gaze triggers infants' reflexive orienting to the target of that person's gaze (Farroni, Johnson, Brockbank, & Simion, 2000; Farroni, Mansfield, Lai, & Johnson, 2003; Hood, Willen, & Driver, 1998; Langton, Watt, &

Bruce, 2000). Several studies have further demonstrated that this sensitivity to gaze cueing has functional implications for the processing of information that appears in the cued location. Reid and Striano (2005) presented 4-month-old infants with two objects, one of which was cued by another person's shift in gaze while the second object appeared in a non-cued location. Following this gaze-cueing experience, infants consistently looked longer at the non-cued object when they were shown the same objects in a visual paired comparison task. Infants' novelty preference for the non-cued object suggested that this object had been processed to a lesser degree because they had been biased to examine and learn about the cued object (Reid & Striano, 2005). Similar studies have replicated and extended this effect, showing that infants spend a greater proportion of time during familiarization looking at a gaze-cued toy compared to a non-cued toy (Theuring, Gredeback, & Hauf, 2007) and that an electrophysiological (i.e., ERP) signal associated with differentiating novel and familiar stimuli is enhanced when infants view a non-cued object compared to a gaze-cued object (Reid, Striano, Kaufman, & Johnson, 2004). Thus, these studies indicate that reflexive orienting based on the direction of another person's gaze can affect the degree to which infants learn about cued versus non-cued objects.

Overall, these studies provide evidence that developing selective attention and early learning are interrelated. Furthermore, this research has begun to reveal *how* these complex cognitive processes might be linked. Selective attention can modulate the strength of associations between stimuli, influence the information that is input to cognitive systems, and affect the robustness of long-term memory traces. Infants'

developing control over selective attention may support optimal information-gathering and their reflexive responses to salient social cues enhance processing of information that is present in cued locations. Thus, maintaining a balance of flexibility and control over selective attention likely benefits learning throughout development.

Though this work reflects important advances, it also highlights the need for further research examining this relationship. The goal of the current study is to further explore the relationship between reflexive orienting of selective attention and infants' learning of predictable information. Two features of this study represent especially important contributions to the existing body of work. First, this study uses non-social cues to reflexively orient infants' attention to specific information. To date, all studies demonstrating the effects of reflexive attention on learning and object processing have utilized gaze-cueing paradigms. Thus, it remains unclear whether non-social cueing can have similar effects on learning, or if gaze cues are uniquely influential due to their social nature. Second, previous studies have compared the extent to which infants process cued and non-cued objects, but have not compared infants' responses to these objects to their responses to a truly novel object. This failure to include a completely novel object makes it difficult to confidently interpret the infants' looking preferences. The present study includes this comparison item in order to more clearly determine the effects of reflexive orienting on infants responses to cued, non-cued, and completely novel information.

Method

Participants

One hundred and seven 7-month-old infants (58 M, 49 F; M_{age} = 7 mos, 0 days; range = 6 mos, 22 days – 7 mos, 7 days) participated in a single testing session at the University of Minnesota. Infants were recruited from an existing database of volunteers from the Minneapolis-St. Paul metro area. Parents were interviewed prior to enrollment to ensure that their infant met inclusion criteria. Infants were excluded from the study if they had been born prematurely (<37 weeks gestation) or if they weighed less than 5 lbs at birth. Infants were also excluded if they had been exposed to drugs or alcohol in utero, experienced any major complications either prenatally or at birth, spent an extended amount of time in the neonatal intensive care unit (NICU) following birth, or had any serious health problems at the time of screening. Parents gave informed consent in accordance with the University of Minnesota Institutional Review Board (IRB) at the beginning of the test session. The entire session took 30 minutes to complete, including the actual testing, which lasted approximately 5 – 10 minutes. Participants received an infant-sized t-shirt as a thank-you for their participation.

Materials

All stimuli were presented on a 42" television screen using Macromedia Director. During the task, the room was dark and the experimenter's computer was separated from the infant and the television screen by a dark curtain. The experimenter viewed the infant's responses on a remote screen using a standard Sony digital camera with infrared "night vision" capabilities.

Stimuli

Stimuli consisted of brightly colored shapes appearing on a black background. The task consisted of two sections, an initial familiarization section followed by the test portion. Stimuli for the familiarization period included a central fixation, a peripheral cue, and two sets of target shapes. The central fixation consisted of a purple X that was presented in the center of the screen and loomed in and out (min size = 1.25"; max size = 3.5") in order to sustain infants' attention. The cue was a 2" bright yellow ring that appeared 16 inches to the left or right of the central fixation. The target stimuli included two pairs of shapes, simultaneously presented 16 inches to the left and right of the location in which the central fixation appeared. Targets were 3.5" in size and were presented as static images. Each shape pair was composed of two uniquely colored shapes. For example, an orange diamond and a blue cross could appear on the left side of the screen while a green heart and a red star simultaneously appeared on the right side of the screen (see Figure 2.1). The makeup of the shape pairs was counterbalanced across infants and remained constant throughout the entire task.

One pair of shapes was pre-selected as the "expected dyad" and was always presented in the location of the expected attention bias. During trials with a short cue – target delay, the expected dyad was presented in the cued location, since infants' attention should be facilitated towards the cued location. Similarly, during trials with a long cue – target delay, the expected dyad was presented in the opposite, non-cued location, since infants' attention should be inhibited at the cued location and facilitated at the non-cued location. The remaining shape pair was defined as the "distractor dyad" and

was always presented in the location outside the expected attention bias. During trials with a short delay, the distractor dyad was presented in the opposite, non-cued location, while it was presented in the cued location during trials with a long delay. Thus, the expected and distractor dyads always appeared simultaneously and in opposing locations.

Test stimuli consisted of brightly colored shape pairs presented as static images in the center of the screen. All test stimuli were drawn from three different test conditions. In the "expected" condition, the test stimulus was the same shape pair that had been the expected dyad during the familiarization portion of the task. Similarly, in the "distractor" condition, the test stimulus was the same shape pair that had been the distractor dyad during familiarization. Finally, in the "novel" condition, the test stimulus was a completely novel pair of shapes consisting of a purple moon and a pink star. This novel stimulus was consistent for all infants, regardless of the makeup of the expected and distractor dyads.

Finally, in addition to these familiarization and test stimuli, a bright, dynamic "attention-getter" stimulus was used between every trial to re-orient infants' attention to the center of the screen. This attention-getter consisted of a blue and white, checkered sphere that loomed in and out against a grid-like background composed of white dots. The background filled the majority of the screen, while the looming sphere was always located in the center of the screen. This visual stimulus was also accompanied by a repetitive, non-vocal auditory stimulus. A second attention-getter stimulus was used to re-engage infants' attention between the familiarization and test portions of the task. This

second attention-getter consisted of a short Sesame Street video clip that was presented in the center of the screen.

Procedure

Infants were seated on their parents lap, about 48 inches from the screen, for the entire task. An example of a familiarization trial is presented in Figure 2.1. The task began with the looming attention-getter stimulus presented in the center of the screen. The experimenter pressed a key to begin the first familiarization trial when she determined that the infant was looking at the center of the screen. Each familiarization trial began with presentation of the fixation stimulus in the center of the screen. After 1000 ms, the cue stimulus appeared on either the left or right side of the fixation and remained on the screen for 100 ms. The cue presentation was followed by a short (33 ms) or long (600 ms) delay, during which the central fixation remained on the screen. At the end of this delay, the central fixation stimulus disappeared and the target stimuli (i.e., the expected and distractor dyads) simultaneously appeared on the left and right side of the screen. One of the targets appeared in the location in which the cue had appeared, while the other target appeared in the opposite, non-cued location. The target stimuli remained visible for up to 1500 ms or until the infant looked away for more than 500 ms. When the targets disappeared, the attention-getter reappeared in order to refocus the infant's attention towards the center of the screen before beginning the next trial.

The experimenter monitored the infant's eye movements throughout every trial and used key presses to indicate when the infant was looking center, left, right, or away

from the screen. The experimenter was kept blind to all of the stimuli that were presented. The computer program scored trials as invalid if the infant looked away before target onset or if the infant failed to make an eye movement towards a target within the 1500 ms time window following target onset. Trials scored as invalid were replaced with a new trial from the same condition. Familiarization trials continued until the infant completed 32 valid trials, including 16 trials with the short cue – target delay and 16 trials with the long delay. After reaching this criterion of valid trials, the second attention-getting stimulus appeared in the center of the screen for approximately 15 seconds in order to re-engage the infant's attention before moving on to the test section of the task.

The experimenter pressed a key to begin the first test trial when she determined that the infant was looking at the center of the screen. Test stimuli were drawn from the three test conditions in a pseudo-random manner, with the constraint that one trial from each of the three conditions had to be presented before any test condition was repeated. Examples of the three test conditions are depicted in Figure 2.1. During every test trial, the test stimulus was presented in the center of the screen and the experimenter used key presses to indicate when the infant was looking at the central location or when the infant was no longer looking at the screen. The experimenter was kept blind to the test stimuli being presented. Test trials lasted for up to 10 seconds or until the infant looked away from the central location for more than 800 ms. The computer program scored test trials as invalid if the infant did not look at the central location for at least 500 ms. Any trial

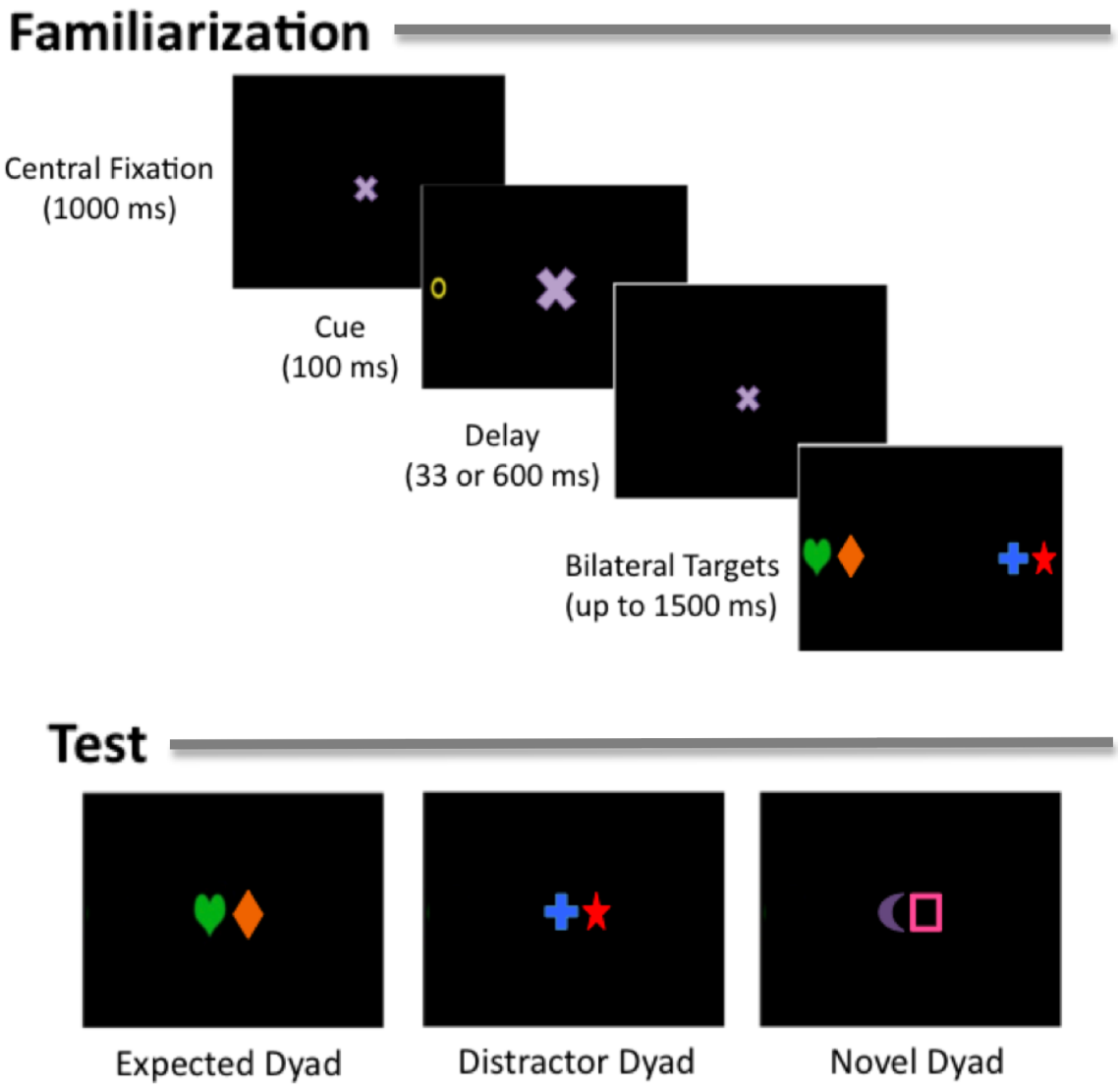


Figure 2.1. Examples of familiarization and test trials used in Study 1.

scored as invalid was replaced with another trial from the same test condition. Test trials continued until the infant completed 21 valid trials (7 trials from each test condition).

The task could be aborted at any time during the familiarization or test sections if the infant became excessively bored and/or fussy. Infants who did not complete 32 familiarization trials and at least 18 test trials (six trials from each test condition) were excluded from the final sample.

Data Coding and Processing

Infants' responses were recorded onto DVD over the course of the entire task for subsequent eye-movement coding. Trained research assistants hand-coded the timing of every eye movement the infant made during each trial. In addition, coders determined whether these eye movements were directed towards the center, left, or right stimulus locations, or if the eye movement resulted in the infant looking away from the screen. Videos of infants who did not complete 32 valid familiarization and at least 18 valid test trials were coded but not included in the final sample.

For familiarization trials, the coded data were used to compute the direction and latency of the infant's first look following target onset. Individual trials were excluded if the infant looked away from the screen before looking at one of the peripheral targets ("look-away" trials), or if the infant never looked at either target stimulus ("center-only" trials). In addition, trials were excluded if there was a negative value for the latency of the infant's first look, which indicates that the infant broke fixation from the central stimulus prior to target onset ("fixation-break" trials). After excluding these trials, each infant's first look latencies were further filtered to account for especially fast or slow eye

movements. Any latency that was less than 200 ms was filtered out, as these likely represent anticipatory looks rather than reactive looks following target onset. Especially long latencies were filtered out if they were greater than two standard deviations above the infant's mean latency. In order to be included in the final sample, infants needed a minimum of four trials with valid latency data for each of the delay lengths (33 and 600 ms) after trial exclusion and latency filtering were complete.

After compiling this information, valid trials were sorted into four different categories based on delay length and the infant's response: 1) trials in which there was a short cue – target delay and the infant first looked to the expected (i.e., cued) location, 2) trials in which there was a short cue – target delay and the infant first looked to the unexpected (i.e., non-cued) location, 3) trials in which there was a long cue – target delay and the infant first looked to the unexpected (i.e., cued) location, and 4) trials in which there was a long cue – target delay and the infant first looked to the expected (i.e., non-cued) location. Proportion of orienting scores were computed for each of these four categories. Mean latency difference scores were also computed for each delay length by subtracting the infant's mean latency to look towards the non-cued location from the infant's mean latency to look towards the cued location. Use of these difference scores allowed for an assessment of *relative* reaction time benefits for targets appearing in the cued and non-cued locations. A positive difference score indicates a reaction time benefit for looks to the non-cued location, while a negative difference score indicates a reaction time benefit for looks to the cued location. Overall, we expected that infants would display a reaction time benefit and higher proportion of orienting towards the cued

location when the delay was short. At the long delay length, we expected infants to display a reaction time benefit and higher proportion of orienting towards the non-cued location.

In addition to these measures, the amount of time the infant spent looking at the targets appearing on the left versus right sides of the screen was calculated for each trial. The proportion of total looking time that was devoted to looking at the two target shapes pairs was calculated for each trial and averaged over all trials to determine each infant's mean proportion of looking time devoted to the expected and distractor dyads during familiarization. This proportional measure quantifies the extent to which infants were exposed to the two target dyads across all familiarization trials. In addition, the proportional measure accounts for the fact that infants did not typically sustain one look towards a single target, but instead often looked back and forth between the two targets or spent brief moments looking away from the screen.

This proportional measure of sustained looking towards the expected and distractor dyads was computed twice. The measure was first computed using all familiarization trials, regardless of whether they had been excluded for the latency analysis. This allowed for an assessment of the total amount of exposure to the expected and distractor dyads over the course of familiarization. The second calculation only included the valid trials that remained following the exclusions for the latency analysis. This allowed for a more precise measure of the effects of spatial cueing on infants' exposure to the expected and distractor dyads, since cueing effects are likely to be strongest during these valid trials.

For test trials, the coded data were used to compute the total amount of time the infant spent looking towards the central stimuli during each trial. Trials were excluded if the infant's total looking time to the center stimulus was less than 500 ms. Several looking time measures were computed for each test condition, including the infant's mean looking time across all test trials, median looking time across all test trials, and total looking time during the first trial of each test condition. Because one trial of each condition had to be presented before any test condition was repeated, the initial looking time values were always drawn from the first three trials of the test phase.

Results

Task Completion

Of the 107 infants who participated in this study, 31 (29%; 17 M, 14 F) became fussy during the session and did not complete all portions of the task. These infants were excluded from all analyses. One additional infant (0.9%) was excluded due to both fussiness and falling outside of the required age range. Infants were also excluded if they did not complete a sufficient number of valid familiarization and/or test trials. As discussed earlier, individual trials were excluded if the infant looked away before target onset, if the infant broke fixation prior to target onset, if the infant failed to look away from the central fixation, or due to experimenter error. An additional 28 infants (26.2%; 17 M, 11 F) were excluded because they did not provide enough valid trials after trial exclusion and filtering were complete (excessive look-away trials = 7 infants, 6.5%; excessive fixation-break trials = 8 infants, 7.5%; excessive experimenter error trials = 12 infants, 11.2%; excessive outlying latency values = 1 infant, 0.9%). This constituted an

overall exclusion rate of 55.1%, leaving a final sample of 48 infants (24 M, 24 F). All analyses were conducted with this final sample.

Successful completion of the task required accruing 32 familiarization trials and 21 test trials that were coded as valid during the experimenter's online coding. On average, infants completed 37 familiarization trials (*SD* = 5.34) and 21 test trials (*SD* = 1.03) in order to reach this criterion. However, additional trials were excluded after the more stringent hand coding of the videos was complete. For the familiarization portion of the task, 14.7% (*SD* = 12.9%) of trials were excluded because the infants looked away from the screen before trial onset, 16.1% (*SD* = 9.9%) of trials were excluded because the infants broke fixation prior to trial onset, 0.2% (*SD* = 0.9%) of trials were excluded because the infants failed to look away from the central fixation, and 0.2% (*SD* = 1.1%) of trials were excluded due to experimenter error. Thus, on average, 68.5% (*SD* = 15.8%) of trials were retained as valid familiarization trials. For the test portion of the task, 2.1% (*SD* = 3.7%) of trials were excluded because the infants did not reach the minimum look time of 500 ms and 0.4% (*SD* = 2.7%) of trials were excluded due to experimenter error. Thus, 97.5% (*SD* = 5.3%) of trials were retained as valid test trials.

There was no relationship between infants' ages at the time testing and the number of trials that they completed, for either familiarization trials ($r = -0.239$, $p = 0.102$) or test trials ($r = -0.063$, $p = 0.67$). This was also true when considering the proportion of completed trials that were ultimately excluded (familiarization: $r = -0.017$, $p = 0.911$; test: $r = -0.076$, $p = 0.609$).

Missing Data and Outliers

As discussed earlier, reaction time difference scores were calculated for each infant based on their mean latencies to orient to targets appearing in the cued and non-cued locations. This calculation thus required that the infants' first looks were distributed between the cued and non-cued locations. One infant demonstrated "perfect" cueing effects on orienting during the short-delay trials (e.g., first looks were directed to the cued location on 100% of trials), which precluded assessing relative reaction time benefits for looks towards the cued and non-cued locations at this delay length. This infant's orienting data were included in the data analyses; however, this infant was treated as a missing data point for analyses of reaction time benefits during the short-delay trials.

Some infants also appeared to have a consistent side bias, as the majority of their first looks were directed to the same side of the screen regardless of the location of the cue or delay length. Because this kind of orienting bias could interfere with potential cueing effects, infants with extreme side biases were excluded from the analyses. These infants were identified by computing the proportion of first looks that were directed to the left or right side of the screen, regardless of trial type. Data were excluded for 5 infants whose proportion of first looks to either side of the screen was more than three standard deviations above the group mean.

Finally, 2 infants had extreme outlying values (i.e., greater than 3 standard deviations above the group mean) for their reaction time difference scores. The data from these 2 infants were excluded for all analyses. Thus, all analyses were based on a final

sample of 41 infants; analyses of reaction time difference scores from the short-delay trials were based on a sample of 40 infants.

Analysis Plan

The analyses for this study consisted of several steps, which are listed in Table 2.1. First, the proportion of orienting and reaction time measures obtained during the familiarization were assessed to determine whether the overall group of infants demonstrated significant facilitative and inhibitory cueing effects. Next, the proportion of total looking time measure was used to determine whether the overall group demonstrated greater selective attention to the expected dyad over the distractor dyad. However, not all of the infants showed cueing effects; thus the analysis of infants' selective attention to the two target dyads was repeated for two separate sub-groups. One of these groups, labeled "Full Cueing," included infants who showed cueing effects on both orienting and reaction time during either the short-delay trials (i.e., facilitation) or the long-delay trials (i.e., inhibition of return). The second sub-group, labeled "Any Cueing," included infants who showed any facilitative or inhibitory effect of cueing on either the orienting or the reaction time measures.

For the test portion of the task, paired comparisons were conducted to determine whether the initial looking time and mean looking time measures differed across the three test conditions. These analyses were first conducted for a sub-group of infants who had demonstrated greater selective attention to the expected dyad during familiarization, as we hypothesized that this differential exposure would affect infants' discrimination of the expected and distractor dyads at test. Next, these analyses were conducted for the overall

	Familiarization: Dependent Variables				
	Facilitation (short-delay trials)		IOR (long-delay trials)		Exposure to Target Dyads
Group Analyses	Orienting Effect (Proportion of Orienting)	Reaction Time Effect (RT Difference Score)	Orienting Effect (Proportion of Orienting)	Reaction Time Effect (RT Difference Score)	Proportion of Total Looking Time (Expected Dyad vs. Distractor Dyad)
Full Sample (N = 41)	✔	✔	×	×	×
Full Cueing (N = 24)	-	-	-	-	✔
Both orienting AND reaction time effects during short-delay or long-delay trials					
Any cueing (N = 39)	-	-	-	-	×
Any orienting OR reaction time effect during short-delay or long-delay trials					

	Test: Dependent Variables					
	Initial Looking Time Measure			Mean Looking Time Measure		
Group Analyses	Expected Dyad vs. Distractor Dyads	Expected Dyad vs. Novel Dyad	Distractor Dyad vs. Novel Dyad	Expected Dyad vs. Distractor Dyads	Expected Dyad vs. Novel Dyad	Distractor Dyad vs. Novel Dyad
Full Sample (N = 41)	×	×	×	×	✔	×
Differential Exposure (N = 25)	✔	✔	×	✔	✔	×
During familiarization, proportion of total LT to Expected > proportion of total LT to Distractor						
Prefer Familiar (N = 20)	✔	✔	×	×	✔	✔
During test, mean LT to Expected > mean LT to Novel						
Full Cueing (N = 13)	×	×	×	×	✔	✔
Both orienting AND reaction time effects during short-delay or long-delay trials						
Differential exposure (N = 8)	×	×	×	✔	✔	✔
During familiarization, proportion of total LT to Expected > proportion of total LT to Distractor						
Any cueing (N = 20)	✔	✔	×	×	✔	✔
Any orienting OR reaction time effect during short-delay or long-delay trials						
Differential exposure (N = 13)	✔	✔	×	✔	✔	✔
During familiarization, proportion of total LT to Expected > proportion of total LT to Distractor						

✔ = significant effect, × = no effect, - = not tested

Table 2.1. Summary of analyses conducted for Study 1.

sample of infants as well as the Full Cueing and Any Cueing subgroups. Finally, these two sub-groups were further divided to examine infants who showed both significant effects of cueing as well as differential exposure to the expected and distractor dyads during familiarization.

Familiarization

Overall Spatial Cueing Effects. Mean proportion of orienting and reaction time differences scores for the overall sample are presented in Figure 2.2. One-sample t-tests indicated that infants were significantly more likely to orient to the cued location when the cue-target delay was short ($M_{Orienting}$ = 0.5695, SD = 0.2018; $t(40) = 2.206$, $p = 0.033$). However, infants' proportion of orienting to the non-cued location during long-delay trials was not different from chance ($M_{Orienting}$ = 0.5415, SD = 0.2014; $t(40) = 1.32$, p = 0.194). Infants' reaction times followed a similar pattern. The mean reaction time difference score was significantly less than zero during short-delay trials ($M_{RT\ difference}$ = -36.82 ms, SD = 74.67 ms; $t(39) = -3.119$, $p = 0.003$), indicating a facilitation of eye movement latencies towards the cued location. In contrast, the mean reaction time difference score was not significantly different from zero for long-delay trials ($M_{RT\ difference}$ = 11.70 ms, SD = 103.10 ms; $t(40) = 0.726$, $p = 0.472$), indicating that there was no reaction time benefit for targets appearing in either the cued or non-cued locations. Thus, as an overall group, when the cue-target delay was short, infants demonstrated the expected facilitation of orienting and reaction time towards targets appearing in the cued location. However, when the cue-target delay was long, infants showed no evidence of

the expected IOR effect on orienting or reaction time for targets appearing in the non-cued location.

Infants were grouped based on whether they showed the expected facilitation and inhibition of return effects. Infants were identified as showing facilitated orienting if their proportion of orienting to the cued location following the short cue-target delay was greater than one standard error above chance (i.e., threshold = 0.5320). Infants were considered to show facilitated reaction times if their mean reaction time difference score was less than one standard error below chance (i.e., threshold = -11.81 ms), since a significantly negative difference score indicates a reaction time benefit for the cued location. Based on these thresholds, 25 infants (61%) showed facilitated orienting to targets appearing in the cued location and the same number of infants showed facilitated response times for these targets. Similarly, infants were identified as showing IOR effects on orienting if their proportion of orienting to the non-cued location following the long cue-target delay was greater than one standard error above chance (i.e., threshold = 0.5310). Infants were considered to show IOR effects on reaction times if their mean reaction time difference score was greater than one standard error above chance (i.e., threshold = 16.10 ms), since a significantly positive difference score indicates a reaction time benefit for the non-cued location. Twenty-five infants (61%) showed the expected inhibition of return effects on orienting, while 17 infants (41.5%) showed the expected inhibitory effects on their reaction times.

Exposure to Target Dyads. When considering all familiarization trials, there was no difference in the amount of exposure the infants experienced for the expected and

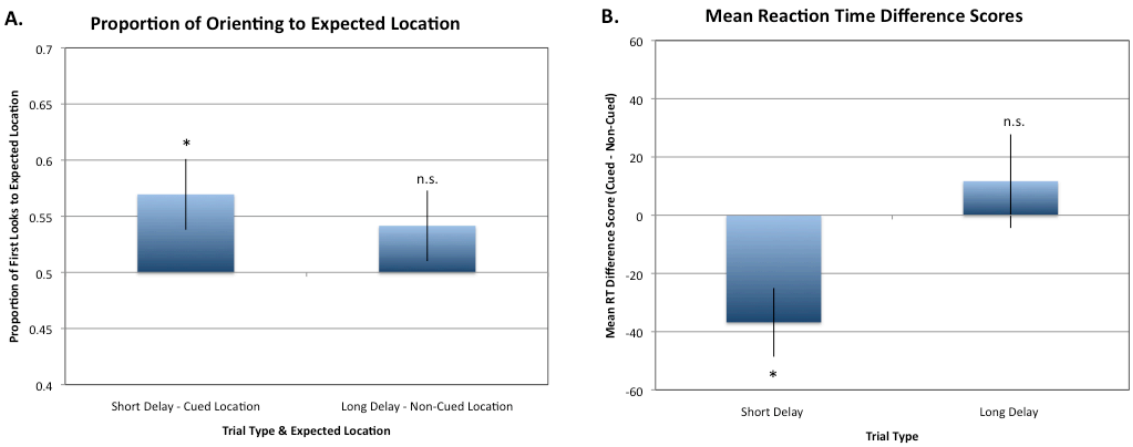


Figure 2.2. Infants' mean proportion of orienting and reaction time difference scores for short- and long-delay trials

distractor dyads (Figure 2.3; $M_{Difference}$ = -0.0256, *SEM* = 0.0269; $t(40) = 0.951$, $p = 0.347$). However, trials that were scored as invalid would not be expected to elicit cueing effects, and thus would be unlikely to modulate exposure to the two targets. When only valid trials were assessed, infants on average spent a greater proportion of time ($M = 0.4715$, $SD = 0.0993$) attending to the expected dyad compared to the distractor dyad ($M = 0.4430$, $SD = 0.1097$); however this difference was not significant ($t(40) = 0.962$, $p = 0.342$). Only valid trials were considered in all subsequent analyses.

Effects of Spatial Cueing on Exposure. Because there were individual differences in infants' sensitivity to spatial cueing, infants were further sub-grouped based on the efficacy of the cue. The first "Full Cueing" sub-group (n = 24) included infants who showed both orienting and reaction time effects during short-delay trials (i.e., facilitation effects) *or* during long-delay trials (i.e., IOR effects). Infants in this group spent a significantly greater proportion of time attending to the expected dyad ($M = 0.4959$, $SD = 0.0972$) compared to the distractor dyad ($M = 0.4185$, $SD = 0.1074$; $t(23) = 2.098$, $p = 0.047$). In addition, there were a significant number of infants in this group who spent more time looking at the expected dyad than the distractor dyad (17 vs. 7 infants; $\chi^2(1, N = 24) = 4.167$, $p = 0.041$). The second "Any Cueing" sub-group (n = 39) was more liberal and included infants who showed any cueing effect (i.e., orienting *or* reaction time) at either delay length (i.e., facilitation or IOR). Two infants in this group showed cueing effects that were the exact opposite of those predicted (e.g., facilitation of responses to the cued location following a *long* cue-target delay and inhibition of responses to the cued location following a *short* cue-target delay); these infants were

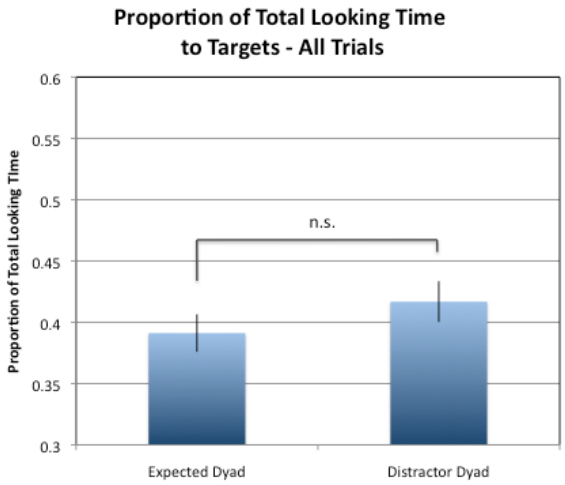


Figure 2.3. Mean proportion of overall looking time to the expected and distractor dyads across all familiarization trials.

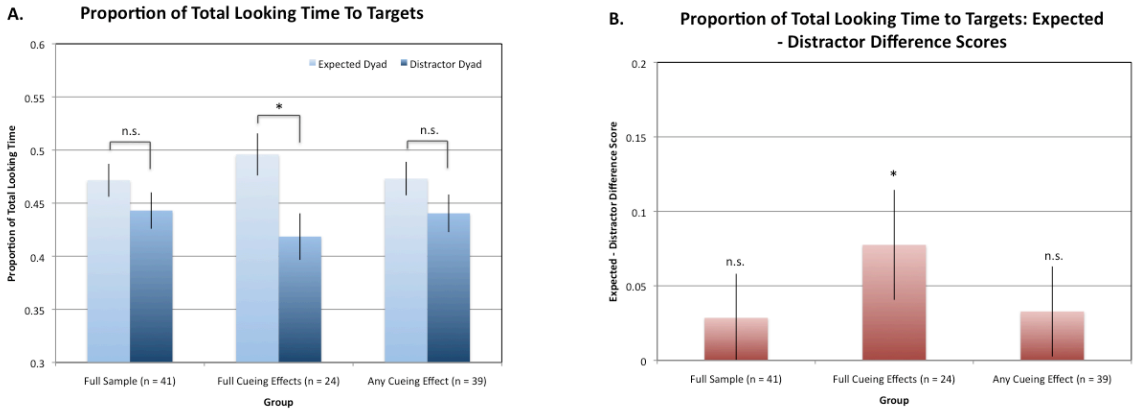


Figure 2.4. Effects of spatial cueing on proportion of overall looking time to the expected and distractor dyads across valid familiarization trials. (A) Paired comparisons. "Full cueing" refers to infants who showed both orienting and reaction time effects for either facilitation or IOR. "Any cueing" refers to infants who showed any orienting or reaction time effects for either facilitation or IOR. (B) Differential exposure assessed by computing the difference in proportion of looking to the expected and distractor dyads across valid familiarization trials.

excluded from any analyses involving this second sub-group. Though infants in this group spent slightly more time looking at the expected dyad (M = 0.4731, SD = 0.0985) than the distractor dyad (M = 0.4404, SD = 0.1105), this difference was not significant ($t(38) = 1.084$, $p = 0.285$). These results suggest that spatial cueing most effectively manipulated exposure to the two targets when infants showed both orienting and reaction time effects.

Test

Initial looking time measure. ***Effects of differential exposure on test performance.*** As discussed earlier, one of two measures of learning during the test was infants' cumulative duration of looking during the initial test trial of each test condition (expected dyad, distractor dyad, and novel dyad conditions). One trial of each condition was presented before any test conditions were repeated; thus, looking times were always drawn from the first three trials of the test session. As such, this measure is least susceptible to concerns about further learning that might occur during the test session itself. In order to determine whether differential exposure to the targets during familiarization affected infants' looking times during test, we identified infants who spent more time looking at the expected dyad than the distractor dyad during familiarization (i.e., difference in mean look duration to expected and distractor dyads > 0; n = 25). A repeated-measures ANOVA indicated that this group of infants showed a significant difference in initial looking times across the three test conditions (Figure 2.5; $F(2, 48) = 3.466$, $p = 0.039$). Follow-up paired t-tests indicated these infants looked significantly longer at the expected dyad (M = 6259.94 ms, SD = 2354.76 ms) compared to the

distractor dyad (M = 4638.33 ms, SD = 2850.22 ms; $t(24) = 2.2$, $p = 0.038$) and the novel dyad (M = 5033.11 ms, SD = 2049.38 ms; $t(24) = 2.421$, $p = 0.023$). There was no difference in looking times to the distractor and novel dyads ($t(24) = -0.596$, $p = 0.556$). These results provide evidence that differential selective attention during familiarization is reflected in infants' responses during the initial test trials. Furthermore, the results show that infants who experienced more exposure to the expected dyad during familiarization responded to the distractor dyad and a completely new dyad in a similar manner.

Novelty/Familiarity preferences. As an overall group, infants showed no significant differences in looking times during the initial test trials (Greenhouse-Geisser correction, $F(1.62, 64.89) = 1.666$, $p = 0.201$). However, it is possible that no differences were detected because of individual differences in infants' preferences for novel and familiar items. If some infants prefer novel items, we would expect them to look longer at the novel test dyad than the original expected dyad. Similarly, if infants prefer familiar items, we would expect them to look longer at the expected dyad compared to the novel dyad. When all infants are grouped together, regardless of novelty/familiarity preferences, these differences in looking times would average out and mask any differences between the novel and expected conditions. Furthermore, the critical test item is the distractor dyad. If infants learned the expected and distractor dyads to the same extent, we predict that they will respond to these two dyads similarly at test. If infants learned the expected dyad to a greater extent than the distractor dyad, we would expect infants to respond to the distractor dyad in a manner that is more similar to their

responses to the novel dyad. Thus, it is crucial to determine both how infants respond to the expected versus novel dyads, and more importantly, how they respond to the distractor dyad *relative* to the other two conditions.

Thus, we further sub-grouped infants based on their novelty/familiarity preferences to determine whether these preferences were obscuring potential effects in the larger group. To determine novelty vs. familiarity preference, we computed difference scores based on mean looking times across all test trials for the expected dyad and novel dyad conditions. We also computed this difference a second time based on their median looking times for the expected and novel conditions. For both measures, negative scores indicated preferential looking to the novel item, while positive scores indicated preferential looking to the familiar item (i.e., the expected dyad). Infants were identified as preferring novelty or familiarity only if their preference scores were consistently negative or positive for both the mean and median looking time measures. Based on this classification, 13 infants (31.7%) infants were identified as preferring novelty, 20 infants (48.8%) were identified as preferring familiarity, and 8 infants (19.5%) showed inconsistent preferences depending on the mean or median looking times. These inconsistent infants were excluded from any analyses that accounted for novelty/familiarity preferences.

Figure 2.6 illustrates the value of considering infants' novelty/familiarity preferences. While the overall sample showed no differences in initial look durations at test, infants who demonstrated an overall familiarity preference showed a trend for differential looking across test conditions ($F(2,38) = 2.738$, $p = 0.077$). Specifically, these

infants looked longer during the initial presentation of the expected dyad (M = 6416.67 ms, SD = 2478.72 ms) than during the initial presentations of the distractor (M = 4993.33 ms, SD = 3228.92 ms; $t(19) = 2.084$, $p = 0.051$) or novel dyads (M = 5248.33 ms, SD = 2347.54 ms; $t(19) = 2.542$, $p = 0.021$). However, infants in this group showed no difference in initial look durations to the distractor and novel dyads ($t(19) = -0.334$, $p = 0.742$). Infants who showed an overall novelty preference showed no differences in the initial looking time measure ($F(2,24) = 0.665$, $p = 0.529$). One drawback associated with taking these preferences into account is the marked reduction in sample size, especially once sub-groups based on cueing efficacy are involved. Because of the small number of infants who demonstrated novelty preferences, subsequent analyses only assessed infants who showed familiarity preferences (n = 20), unless otherwise noted.

Spatial Cueing Effects. Among infants identified as preferring familiarity, those who showed either facilitative or inhibitory cueing effects on *both* orienting and reaction time during familiarization (i.e., Full Cueing; n = 13) showed no difference in looking times across the initial test trials (Figure 2.7; $F(2,24) = 0.913$, $p = 0.415$). When this group was further limited to only examine infants for whom these cueing effects successfully modulated attention during familiarization (i.e., proportional looking to expected dyad > proportional looking to distractor dyad), the infants showed substantial differences in looking times during the initial test trials (expected dyad: M = 5800 ms, SD = 2576.14 ms; distractor dyad: M = 3729.17 ms, SD = 2764.94 ms; novel dyad: M = 4687.5 ms, SD = 2079.22 ms). However, these differences were not statistically significant ($F(2,14) = 1.851$, $p = 0.194$), possibly due to the small sample size (n = 8).

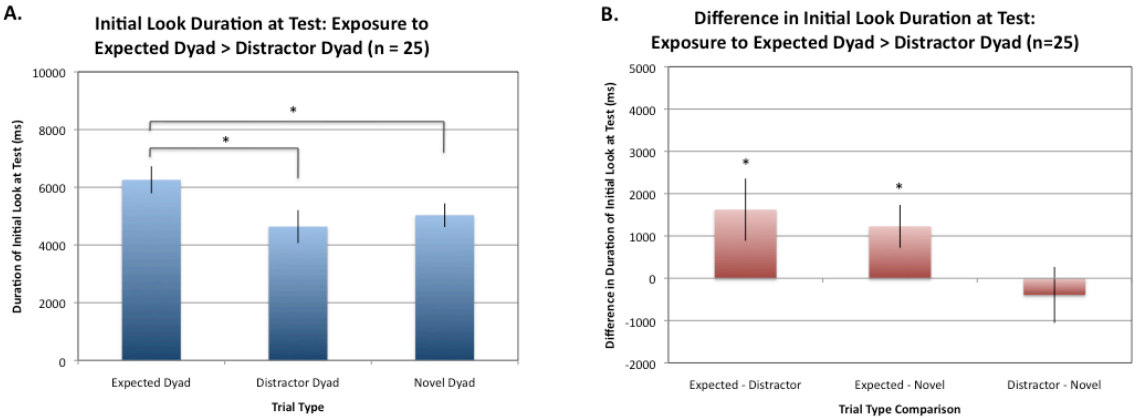


Figure 2.5. Initial looking times at test for infants who spent a greater proportion of familiarization time attending the expected dyad than the distractor dyad. (A) Paired comparisons. (B) Differences in initial look duration across test items.

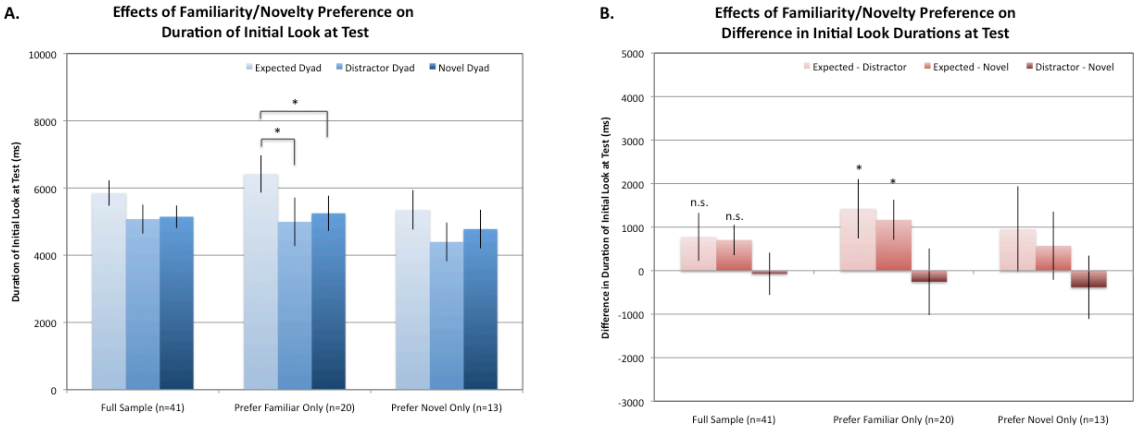


Figure 2.6. Initial looking times at test before and after taking infants' novelty/familiarity preferences into account. (A) Paired comparisons. (B) Differences in initial look duration across test items.

These results provide some evidence that infants who were sensitive to cueing and, as a result, experienced differential exposure during familiarization, treated the expected and distractor dyads differently at test.

The more inclusive Any Cueing group of infants (n = 20) also showed a trend for a significant difference in initial looking times across test conditions (Figure 2.7; $F(2,38) = 2.738$, $p = 0.077$). Subsequent paired t-tests showed that these infants looked significantly longer towards the expected dyad ($M = 6416.67$ ms, $SD = 2478.72$ ms) than to the distractor dyad ($M = 4993.33$ ms, $SD = 3228.92$ ms; $t(19) = 2.084$, $p = 0.051$) or towards the novel dyad ($M = 5248.33$ ms, $SD = 2347.54$ ms; $t(19) = 2.542$, $p = 0.02$). Infants' looking times towards the distractor and novel dyads were not significantly different ($t(19) = -0.334$, $p = 0.742$). Thus, these infants showed preferential looking towards the expected dyad over both the distractor and novel dyads, which were not different from each other. This pattern of results mimics that seen for infants who showed differential exposure during familiarization, regardless of cueing effects. Furthermore, infants who showed both cueing effects and differential exposure to the expected dyad (n = 13) showed a significant difference in initial look durations across the three test items ($F(2,24) = 3.835$, $p = 0.036$). These infants showed the same pattern of effects, with preferential looking to the expected dyad ($M = 6464.10$ ms, $SD = 2458.06$ ms) compared to both the distractor dyad ($M = 4130.77$ ms, $SD = 3195.84$ ms; $t(12) = 2.838$, $p = 0.015$) or the novel dyad ($M = 4935.90$ ms, $SD = 2128.97$ ms; $t(12) = 2.304$, $p = 0.04$), but no difference in initial looking to the distractor and novel dyads ($t(12) = -0.774$, $p = 0.454$). Overall, these results suggest that infants who experienced any effect of cueing on their

attention learned the expected dyad to a greater extent than the distractor dyad, particularly if these cueing effects enhanced exposure to the expected dyad during familiarization.

Mean looking time measure. ***Effects of differential exposure on test performance.*** Infants' experiences during familiarization were also reflected in their mean looking times over the course of all test trials. As discussed earlier, the effects of differential exposure on test performance should be most clearly demonstrated by selecting infants who spent a greater proportion of the familiarization phase attending to the expected dyad over the distractor dyad, regardless of novelty/familiarity preferences (n = 25). For this group of infants, a repeated measures ANOVA indicated that there was a significant difference in their mean looking times across test conditions (Figure 2.8; $F(2,48) = 4.197$, $p = 0.021$). Subsequent paired t-tests further indicated that, across all test trials, infants in this group looked longer towards the expected dyad ($M = 4508.54$ ms, $SD = 1515.06$ ms) than they did to either the distractor dyad ($M = 3911.84$ ms, $SD = 1297.39$ ms; $t(24) = 2.64$, $p = 0.014$) or the novel dyad ($M = 3907.80$ ms, $SD = 1530.55$ ms; $t(24) = 2.634$, $p = 0.015$). There was no difference in infants' looking times towards the distractor and novel dyads ($t(24) = 0.016$, $p = 0.988$). Thus, for this group of infants, the pattern of results for the mean looking times measure – preferential looking to the expected dyad over both the distractor and novel dyads – was identical to the pattern of results based on the initial looking time measure.

Spatial cueing effects. The pattern of results based on this measure changed dramatically when other subgroups of infants were considered. Results indicated that

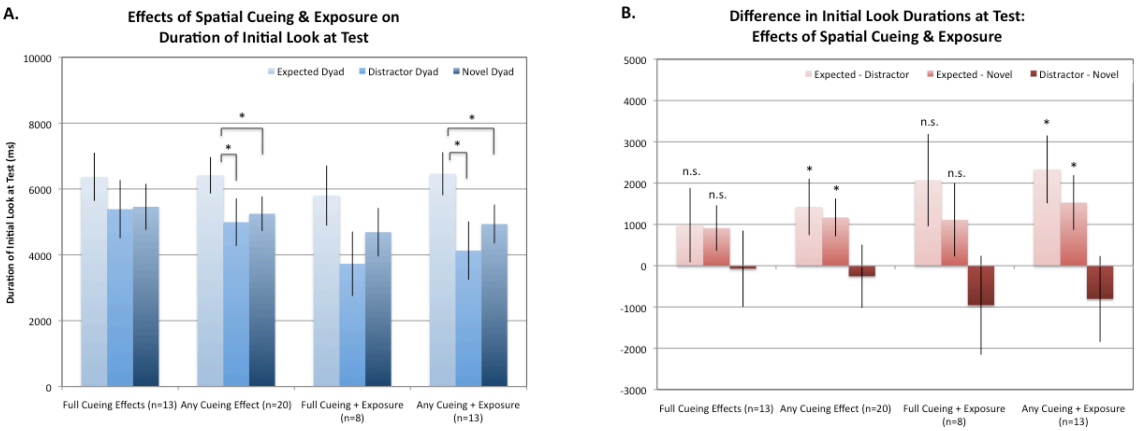


Figure 2.7. Effects of spatial cueing and differential exposure on initial look durations at test. (A) Paired comparisons. (B) Differences in initial look duration across test items.

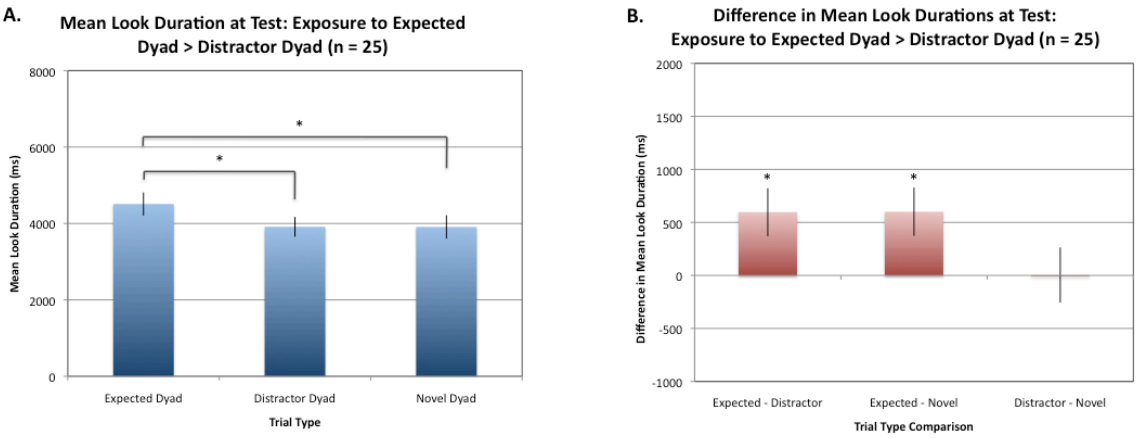


Figure 2.8. Mean looking times at test for infants who spent a greater proportion of familiarization time attending the expected dyad than the distractor dyad. (A) Paired comparisons. (B) Differences in mean look duration across test items.

infants in the Full Cueing sub-group (n = 13) also showed a significant difference in mean looking times across test conditions (Figure 2.9; $F(2, 24) = 8.82$, $p = 0.001$), but the paired comparisons revealed a very different pattern of looking times. For this group, there was no difference in mean looking times for the expected ($M = 4661.29$ ms, $SD = 1363.46$ ms) and distractor dyads ($M = 4403.30$ ms, $SD = 1759.36$ ms; $t(12) = 0.75$, $p = 0.468$). However, infants looked longer during both of these conditions compared to the novel dyad condition ($M = 3481.81$ ms, $SD = 951.37$ ms; expected vs. novel: $t(12) = 6.171$, $p < 0.001$; distractor vs. novel, $t(12) = 2.82$, $p = 0.015$). Thus, this pattern is the opposite of that seen for the initial looking time measure; in this case, infants responded similarly to the expected and distractor dyads and preferred both over the novel dyad.

Interestingly, a slightly different pattern emerged for infants whose cueing effects on *both* orienting and reaction time successfully modulated attention during familiarization (e.g., proportional looking to expected dyad > proportional looking to distractor dyad; n = 8). This group of infants also showed a significant difference in mean looking times across test conditions (Greenhouse-Geisser correction, $F(1.13, 7.93) = 12.043$, $p = 0.001$), with a different pattern of results emerging from the follow-up paired comparisons. These comparisons indicated that infants' mean looking times to the expected dyad ($M = 4346.43$ ms, $SD = 1619.24$) were longer than their looking times to both the distractor dyad ($M = 3519.64$ ms, $SD = 1106.36$; $t(7) = 2.727$, $p = 0.029$) and the novel dyad ($M = 3157.94$ ms, $SD = 1106.36$ ms; $t(7) = 4.071$, $p = 0.005$). In addition, infants looked significantly longer towards the distractor dyad compared to the novel dyad ($t(7) = 4.093$, $p = 0.005$). Thus, in this case, the results revealed a step-wise pattern

in which infants looked longest towards the expected dyad, looked the least towards the novel dyad, and spent an intermediate amount of time looking at the distractor dyad.

Infants in the Any Cueing sub-group (n = 20) showed a significant difference in mean looking times across test conditions (Figure 2.9; $F(2,38) = 20.408$, $p < 0.001$). Follow-up paired comparisons indicated that infants' mean looking times were longer for the expected dyad (M = 4713.73 ms, SD = 1314.04 ms) compared to the novel dyad (M = 3386.75 ms, SD = 1066.12 ms; $t(19) = 8.28$, $p < 0.001$), but were no different from their mean looking times toward the distractor dyad (M = 4358.53 ms, SD = 1314.04; $t(19) = 1.456$, $p = 0.162$). In addition, infants showed preferential looking to the distractor dyad compared to the novel dyad ($t(19) = 4.20$, $p < 0.001$). These results again reveal a pattern that is the opposite of the results seen with the initial looking time measure. In this case, infants responded to the expected and distractor dyads similarly, rather than treating the novel and distractor dyads in a similar manner.

Once again, a different pattern of results emerged when the Any Cueing sub-group was further divided to only include infants who had also experienced differential exposure to the expected dyad during familiarization (n = 13). These infants showed a significant difference in mean looking time to the three test items ($F(2,24) = 25.057$, $p < 0.001$) and follow-up paired comparisons revealed that these infants showed a step-wise pattern of preferential looking. Specifically, these infants spent longer on average looking at the expected dyad (M = 4652.50 ms, SD = 1539.52) compared to the distractor dyad (M = 3884.92 ms, SD = 1400.27 ms; $t(12) = 3.505$, $p = 0.004$) and the novel dyad (M = 3206.35, SD = 1214.62 ms; $t(12) = 6.323$, $p < 0.001$). In addition, these infants showed

preferential looking to the distractor dyad compared to the novel dyad ($t(12) = 4.286$, $p = 0.001$). Thus, these infants discriminated between all of the test items and spent the most time looking at the expected dyad, the least time looking at the novel dyad, and an intermediate amount of time looking at the distractor dyad.

Continuous analyses. The extent of differential exposure to the expected and distractor dyads was quantified by subtracting the proportion of total looking time devoted to the distractor dyad from the proportion of looking time devoted to the expected dyad. Positive difference scores reflected greater exposure to the expected dyad during the familiarization phase. Similarly, the extent of discrimination between the expected and distractor dyads at test was computed by subtracting infants' duration of looking to the distractor dyad from their duration of looking to the expected dyad. These difference scores were computed for both the initial looking time and mean looking time measures.

Differential exposure during familiarization was significantly correlated with the extent to which infants discriminated the expected and distractor dyads at test, for both the initial looking time measure ($r = 0.331$, $p = 0.035$) as well as the mean looking time measure ($r = 0.44$, $p = 0.004$). These positive relationships indicate that infants who demonstrated greater selective attention to the expected dyad during familiarization also showed greater discrimination between the two dyads during the test. Interestingly, this relationship was even stronger when differential exposure was based on all familiarization trials, rather than only the valid familiarization trials (initial looking time: $r = 0.478$, $p = 0.002$; mean looking time: $r = 0.568$, $p < 0.001$). This result suggests that

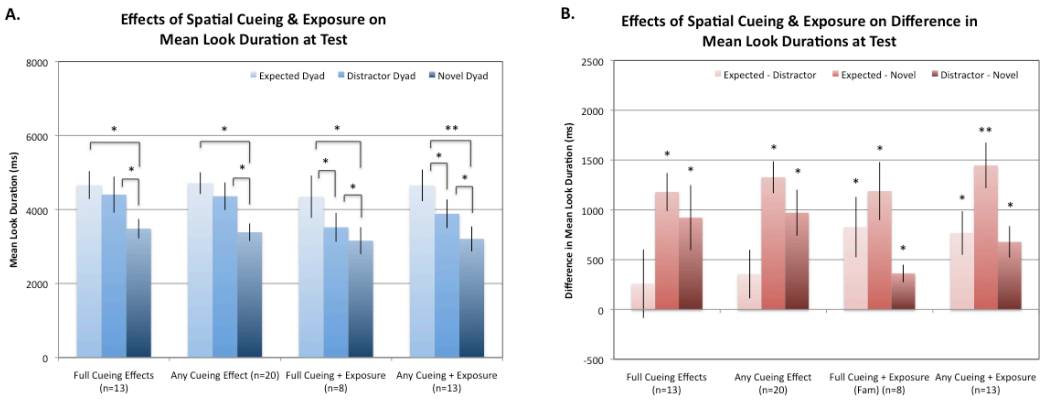


Figure 2.9. Effects of spatial cueing and differential exposure on mean look durations at test. (A) Paired comparisons. (B) Differences in mean look duration across test items.

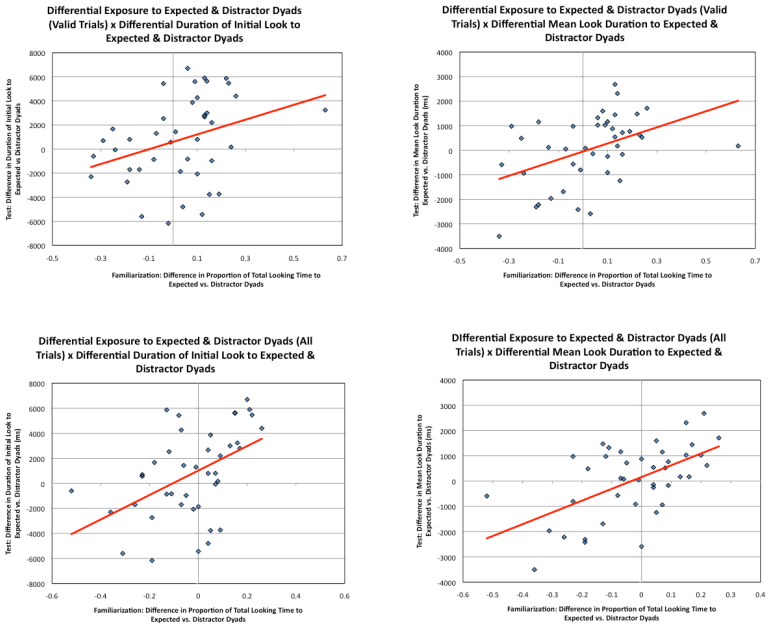


Figure 2.10. Relationship between the extent of differential exposure to expected and distractor dyads and extent of discrimination between the expected and distractor dyads at test. A) and B) Differential exposure based on valid familiarization trials only; discrimination based on initial looking time measure (A) and mean looking time measure (B). C) and D) Differential exposure based on all familiarization trials; discrimination based on initial looking time measure (C) and mean looking time measure (D).

infants' true experiences during familiarization, including trials that were scored as invalid, were most closely related to their looking behaviors at test.

In contrast, the magnitude of spatial cueing effects during familiarization was not related to infants' later discrimination between the expected and distractor dyads. Infants' initial duration of looking to the expected and distractor test items was not related to the extent of cueing effects on orienting, for either short-delay (e.g., facilitation; $r = -0.032$, $p = 0.843$) or long-delay (e.g., IOR; $r = -0.227$, $p = 0.154$) trials. A similar non-significant relationship was evident between the facilitation of orienting measure and infants' mean duration of looking during the test ($r = -0.085$, $p = 0.595$). However, the correlation between the extent of inhibitory cueing effects on orienting and infants' mean duration of looking to the expected and distractor dyads approached significance ($r = -0.298$, $p = 0.059$). None of the cueing effects on reaction time were significantly related to infants' behaviors at test, for either the initial looking time measure (facilitation: $r = -0.061$, $p = 0.709$; inhibition of return: $r = -0.175$, $p = 0.273$) or the mean looking time measure (facilitation: $r = -0.101$, $p = 0.536$; inhibition of return: $r = -0.114$, $p = 0.476$).

Discussion

The results of Study 1 provided several important and intriguing findings. First, as an overall group, infants showed facilitation effects on both orienting and reaction time, but no inhibition of return effects on either measure. This lack of inhibitory effects was surprising given that inhibition of return effects were robust in several pilot studies that utilized identical cueing parameters. However, the task used in this study differed from those used in the pilot studies in terms of the number and variety of stimuli presented in

any given trial. While the pilot tasks involved identical bilateral targets, the task design for Study 1 involved a total of four target shapes with four unique colors. These additional stimuli were crucial for the learning component of the task; however, introducing these new stimuli increased the number of items competing for infants' attention during familiarization. Though the cue remained effective for many infants, the lack of inhibition of return effects for the overall group may be attributable to the additional factors involved in competitive allocation of selective attention.

A second finding from this study is that spatial cueing of attention modulated information gathering during the familiarization phase. There was no significant difference in exposure to the two target dyads for the overall group of infants, which again likely reflects the many factors driving attention allocation. However, infants who were especially sensitive to the cue experienced differential exposure to the expected dyad over the distractor dyad. This effect was significant only for infants who showed full cueing effects on both orienting and reaction time measures, suggesting that spatial cueing competes with other attention processes among infants who are not as sensitive to the cue.

Perhaps the clearest finding to emerge from this study is that infants' experience during familiarization impacts their learning of the available predictable information. Though both target dyads could theoretically be learned equally, differential exposure during familiarization due to infants' sensitivity to salient cues clearly affected their responses to the two target dyads during the test phase. Specifically, infants who spent more time looking at the expected dyad during familiarization treated the distractor dyad

as though it was a novel stimulus, both when it was first presented at test and over the course of the entire test phase. Furthermore, the extent of differential exposure during familiarization was related to the extent to which infants treated the distractor dyad as a novel stimulus at test. This relationship was even stronger when considering infants' true experience during familiarization (i.e., all trials), rather than only those trials that would be expected to elicit cueing effects (i.e., valid trials). Thus, these results provide direct evidence that preferential allocation of attention to one of two competing sets of stimuli impacts the degree to which those stimuli are learned.

One of the primary goals of this study was to assess whether the effects of spatial cueing on reflexive orienting can bias attention to an extent that supports preferential learning of information that is the focus of the attention bias. Infants who showed cueing effects on their reflexive orienting behaviors did show different initial looking preferences for the target dyads at test, suggesting that the cueing may have modulated processing of the two dyads during familiarization. Infants who showed some sensitivity to cueing for either orienting or reaction time measures responded to the distractor as a novel item when it was first presented at test. However, infants who showed full cueing effects during familiarization did not show differential looking during the initial test trials, even when the cueing effectively biased exposure to the expected dyad over the distractor dyad. This pattern of test results does not match the pattern of exposure experienced by these two groups, as it was the full cueing group who experienced greater exposure to the expected dyad during familiarization. Given that infants' looking times at test were quite variable, it is possible that the relatively small number of infants showing

the full cueing effects was insufficient to detect looking preferences across test conditions. These non-corresponding patterns make it difficult to identify direct links between cueing effects, differential exposure during familiarization, and preferential looking at test. Nonetheless, these results provide preliminary evidence demonstrating that infants whose reflexive attention is sensitive to spatial cues also discriminate between targets that appeared in the location of the cueing bias and those that appeared elsewhere.

Overall, the results based on the initial looking time measure support the hypothesis that spatial cueing can impact selective attention, which then influences the extent to which infants learn predictable information. However, this positive finding was dependent on the specific measure of infants' looking behavior at test. Infants' sensitivity to the spatial cues also affected their looking preferences over the entire test phase, though in a very different manner. When considering all test trials, infants who showed full cueing or any cueing effects during familiarization did not discriminate between the expected and distractor dyads and preferred both over the novel dyad. One possibility is that this change in behavior from the initial test trials reflects the additional exposure to the distractor dyad that occurred over the course of the test. Alternatively, the contrasting results from these two measures (i.e. initial look at test and mean looking at test) may reflect the infants' relative treatment of the distractor dyad in comparison to the expected and novel dyads. Infants' initial looks at test suggest that their looking preferences reflect the *relative* novelty of the distractor dyad compared to the expected dyad. Yet, the distractor dyad was not truly novel since infants did have some previous exposure to it,

though to a lesser degree than the expected dyad. This previous experience with the distractor dyad may affect looking behavior over the entire test, since the distractor dyad was *relatively* familiar compared to the novel dyad.

This interpretation garners further support when examining the looking preferences of infants who showed sensitivity to spatial cueing and experienced differential exposure to the target dyads during familiarization. These infants showed a step-wise pattern of looking preferences, in which they preferred the expected dyad over the distractor dyad and preferred the distractor dyad over the novel dyad. This result suggests that the differential exposure during familiarization created a distinction between the two target dyads that was strong enough to be upheld throughout the test phase. However, this distinction weakened over time; by the end of the test, these infants no longer considered the distractor dyad to be novel, as it was relatively familiar compared to the novel dyad. Yet they continued to treat the distractor dyad as distinct from the expected dyad, since it was relatively novel compared to the expected dyad. It is possible that the distinction between the expected and distractor dyads would have continued to shrink if the test phase was extended with additional trials.

Overall, the results of Study 1 demonstrated that spatial cueing can bias infants' reflexive attention and that attention biases towards one of two competing sets of stimuli can affect the way that information is gathered and processed. Theuring et al. (2007) suggested that the effects of gaze cueing on object processing may be very short-lived, as the effects described in their study were evident for only the first test trial and disappeared by the second test trial. The results of the present study are concordant with

Theuring et al. (2007) to a degree, since infants' looking behavior towards the expected and distractor dyads were distinctly different during the initial test trials compared to the overall test. However, infants who both showed the typical cueing effects and experienced greater exposure to the expected dyad during familiarization maintained their distinction between the expected and distractor dyads over the course of the entire test phase. This suggests that the effects of preferential attention allocation during familiarization are not necessarily short-lived; instead, infants' looking behavior during test trials is heavily influenced by the nuances of their experiences during familiarization.

Above all, this study highlights the extreme complexity of the processes driving selective attention. Spatial cueing is one of many factors that mediate competitive allocation of attention. Only a subset of infants in this study showed sensitivity to spatial cueing, and only a subset of those infants also experienced differential exposure to the target dyads during familiarization. For the infants who did not show these effects, any number of additional factors may have been involved in allocating selective attention to the available stimuli. Nonetheless, this study offers the first evidence showing that non-social spatial cues can bias selective attention and influence learning of predictable information. Just as there are numerous factors contributing to selective attention, there are many, many factors that organize information gathering and learning during early infancy. Study 1 highlights the intriguing possibility that at least some aspects of this organization can be provided by environmental stimuli and constraints on infant learning do not have to be wholly endogenous.

Chapter 3

Study 2A: Stability of Spatial Cueing Effects

The previous chapter described some of the potential functional implications of reflexive orienting for infants' learning of predictable information. However, not all infants showed the expected cueing effects, even though the infants were well over the age (~6 months) when such effects can typically be elicited. In Study 1, 61% of the sample of 7-month-olds showed facilitation of orienting and 63% of the sample showed facilitation of reaction time towards the cued location during short-delay trials. Similarly, 61% of the sample showed the expected inhibition of return effects on orienting, while only 42% showed the expected inhibition of return effect on reaction time during long-delay trials. This distribution is relatively consistent with data from several pilot studies that were conducted prior to the current work. These pilot studies utilized the same spatial cueing task with the same age group, though the precise parameters of the task varied by study. The proportions of infants who showed the expected cueing effects across these three pilot studies are displayed in Table 3.1. These distributions clearly indicate that while the majority of an infant sample may demonstrate the expected cueing effects, there is always a subgroup of infants (approximately 30 – 40% of the sample) who do not show the expected effects.

This observation raises the question of whether infants' responses during the spatial cueing task reflect stable individual differences or are instead due to a high degree of context-dependence during testing (e.g., alertness, motivation, physical condition, and/or mood (Ruff & Rothbart, 1996)). The extent of stability in early attention processes has been of interest to researchers for several decades; however, the vast majority of this

	Facilitation of Orienting	Facilitation of Reaction Time	Inhibition of Return Orienting	Inhibition of Return Reaction Time
Study 1	0.61	0.63	0.61	0.42
Pilot 1	0.50	0.64	0.86	0.65
Pilot 2	0.74	0.78	0.48	0.56
Pilot 3	0.38	0.69	0.76	0.56
Mean	**0.56**	**0.69**	**0.68**	**0.55**
Range	**0.38 - 0.74**	**0.63 - 0.78**	**0.48 - 0.86**	**0.42 - 0.65**

Table 3.1. Proportion of total sample of 7-month-olds who demonstrated expected facilitation and inhibition of return effects during Study 1 and three pilot studies.

research has examined the consistency of sustained or focused attention behaviors, rather than selective orienting or reflexive attention *per se*. These studies have found moderate stability in measures of sustained attention over the course of several months. Caregiver ratings of their infants' duration of sustained orienting to a single object, as measured by the Infant Behavior Questionnaire (Rothbart, 1981), are moderately consistent from 3 – 9 months of age and show strong stability when considered across 6-, 9-, and 12-months of age (Ruff & Rothbart, 1996). Using a visual paired-comparison task, Colombo, Mitchell, and Horowitz (1988) found moderate stability in infants' attention from 4 – 7 months of age, with respect to the number of unique looks made by individual infants, the amount of time needed to reach an exposure criterion, and infants' preferential looking to a novel item. The amount of time needed to reach an exposure criterion and the proportion of looking time devoted to a novel stimulus were also shown to be moderately stable across 6-, 7-, and 8-months of age (Rose & Feldman, 1987). Additional studies, however, have found little stability in sustained attention measures over longer periods of time. For

example, Courage, Howe, and Squires (2004) re-examined a sample of 8 – 12-month-old infants who had previously been identified as long- or short-lookers based on their behavior during visual attention task at 3.5 months of age (Courage & Howe, 2001). There was no evidence for a relationship between infants' peak look durations at 3.5 months and the corresponding measures of peak look duration at 8-12 months (Courage, et al., 2004). Furthermore, only half of the infants retained their classification as a short- or long-looker at 8- 12 months of age, suggesting that there is little stability in infants' overall patterns of attention over more extended periods of time (Courage, et al., 2004, p. 24). Taken together, these studies suggest that there may be moderate stability in measures of sustained attention over the first year of life, but the degree of this stability depends on the measures and age groups of interest.

Additional studies have investigated the stability of infants' sustained attention over the course of several weeks rather than months. As with the studies described above, these studies provide either conflicting or modest results. For example, 12-month-olds' initial look durations and overall durations of looking during a visual paired-comparison task were highly correlated with the same measures obtained three weeks after the initial test (Fenson, Sapper, & Minner, 1974). In contrast, Ritz, Woodruff, and Fagen (1984) found no evidence for stability in 4-month-olds' habituation rates when the infants completed a second habituation task one week after the initial testing. This lack of evidence for stability prompted the authors to argue that measures of attention in infancy merely reflect "infants' processing abilities to that stimulus on the particular day of testing" (Ritz, et al., 1984, p. 286). While these two studies represent extreme outcomes,

most studies have found only modest reliability when the same measures of sustained attention were obtained over a short time period. For example, 5-month-olds tested on identical habituation tasks twice over 10 days showed moderate stability in quantitative measures of habituation and the majority of individual infants showed reliability in their overall habituation patterns (Bornstein & Benasich, 1986). Colombo, Mitchell, O'Brien, and Horowitz (1987) tested infants on a habituation task twice over 1-2 weeks at ages 3-, 4-, 7-, and 9-months. While infants' initial look durations during habituation were consistent within all four age groups, other measures of habituation (e.g., peak look duration) were reliable at some ages but not others, and there was no evidence of stability in measures of dishabituation at any age (Colombo, et al., 1987). Finally, measures of attention derived from the visual paired-comparison task (e.g., number of unique looks, amount of time needed to reach exposure criterion, and preferential looking to novel items) showed significant reliability when the task was administered twice to a group of 4-month-olds and twice to a separate group of 7-month-olds (Colombo, et al., 1988). Thus, these visual paired comparison measures show both short-term (e.g., weeks) and long-term (e.g., months) consistency. Though this work suggests a moderate degree of stability in infants' sustained attention processes, these varying results again highlight the complexity of examining stability of attention during the first year of life.

A small number of studies have examined the stability of attention processes that are involved in infants' reactions to external stimuli. As Ruff and Rothbart (1996) explained, "individuals vary on how much stimulation or change in stimulation is required to elicit a reaction, how long a response takes to develop, and the vigor of the

response" (p. 176). Moreover, these indices of reactivity are related to the selective aspects of infant attention, including disengagement from previously attended stimuli, orienting attention to a new stimulus, and re-engaging attention to the new stimulus (Hood, 1995; Posner & Petersen, 1990). The few studies addressing the stability of these selection processes have focused on disengagement and orienting processes. Butcher, Kalverboer, and Geuze (2000), for example, conducted a longitudinal study examining infants' latency to disengage attention from a central stimulus from 6 weeks to 6 months of age. As part of this study, the authors measured the stability of attention disengagement by focusing on test sessions that occurred after 12 weeks of age, when all of the infants showed successful disengagement skills. This analysis revealed very little stability in infants' latencies to disengage across sessions (Butcher, et al., 2000). In contrast, studies utilizing the visual expectation paradigm have found a reasonable degree of stability in infants' latencies to re-orient attention. In this paradigm, infants learn a predictable sequence of stimuli that requires re-orienting attention from a central stimulus to a stimulus presented in the periphery. Haith and McCarty (1990) found that 3.5-month-olds' latencies to shift attention to the peripheral stimuli were highly consistent when repeatedly tested over the course of several days. Similar results were found when a separate group of infants were tested on the same paradigm at 4 months and again at 6 months of age (Canfield, Wilken, Schmerl, & Smith, 1995). Interestingly, though both studies found strong evidence for stability in the latency measure, they saw very little stability in the number of trials in which infants correctly anticipated the appearance of the peripheral stimuli (Canfield, et al., 1995; Haith & McCarty, 1990). Thus, as is the

case with studies examining stability of sustained attention, measures of stability in selective attention appear to be highly variable depending on the specific processes that are examined.

Though the disengagement and visual expectation paradigms described above assessed orienting, only one study to date has used the spatial cueing task to specifically examine the stability of infants' reflexive orienting responses. This investigation was part of a larger longitudinal study that followed the development of inhibition of return effects on orienting from 6 weeks to 6 months of age (Butcher, Kalverboer, & Geuze, 1999). As in Butcher et al. (2000), the researchers examined the stability of these inhibition of return effects by focusing on the test sessions that occurred after the majority of infants showed the expected effects. This analysis revealed a high degree of stability in IOR effects on infants' reaction times, but found less stability in the frequency of IOR orienting effects, which was measured as infants' preferential orienting to cued versus non-cued targets (Butcher, et al., 1999). The authors attributed the lack of stability in orienting preferences to infants' idiosyncratic looking asymmetries, and suggested that the mechanisms driving response selection may be more variable than those mediating the efficiency of response execution (Butcher, et al., 1999).

Overall, results from this body of work suggest a limited to moderate degree of stability in sustained and orienting attention processes during early infancy. Yet questions of stability in early attention processes remain critical given additional evidence for a relationship between individual differences in these early attention components and variations in cognitive development during later childhood. Indeed, many studies have

demonstrated the predictive value of looking time measures for subsequent measures of cognitive development (Ruff & Rothbart, 1996). Relatively short durations of sustained attention during infancy have been related to more advanced motor development, higher levels of interest in novel toys, improved concept formation, and higher IQ scores during later childhood (Bornstein & Sigman, 1986; Fagan, 1984; McCall & Carriger, 1993). Similarly, measures of orienting reaction time and anticipation obtained using the visual expectation paradigm have been linked to performance on childhood IQ tests (Benson, Cherny, Haith, & Fulker, 1993; Canfield, et al., 1995; DiLalla, et al., 1990). Thus, there is clear evidence that these early attention processes have meaningful relationships with broader aspects of cognitive development. As such, examining the stability of these attention processes is crucial for understanding processes of cognitive development. For example, attention behaviors that are more stable over time may have more meaningful implications for the ways that infants interact with the world and take in new information, while those that are highly context-dependent may have less functional impact on learning and cognitive development. Alternatively, individual infants who demonstrate a high degree of stability for a specific aspect of attention (e.g., orienting) may be on a developmental trajectory that is qualitatively different from those who demonstrate reliable consistency for other dimensions of attention (e.g., sustained attention).

The results of Study 1 showed that reflexive orienting elicited during the spatial cueing task can have meaningful implications for infants' learning of predictable information. However, these results were far from uniform – not all infants showed the expected cueing effects, and not all infants showed the same influence of cueing effects

on learning. The goal of Study 2 is to further explore this variability by assessing whether individual infants' reflexive orienting behaviors are consistent over the course of one month. Examining the variability in infants' responses over this time period will also help identify the extent to which measures of early reflexive orienting are context-dependent.

All infants in this study were tested at an age (7 months) when, based on previous empirical literature, we would expect them to have developed the attention systems mediating inhibition of return. One issue that arises when considering the stability of behavior over time is whether we should expect the behavior to look the same if the underlying processes haven't changed (i.e., homotypic continuity) or if stability in the underlying processes can also be manifested through overt behaviors that change over time (i.e., heterotypic continuity). Repeated testing over a relatively short time period of one month allowed for a more straightforward prediction of homotypic stability, though this approach did not eliminate the possibility of heterotypic stability. Finally, this approach also allowed for more detailed inspection of behavioral changes, which can potentially provide insight into the mechanisms that contribute to development of the underlying cognitive processes.

Method

Participants

Seventy-four 7-month-old infants (36 M, 38 F) participated in three testing sessions at the University of Minnesota over the course of approximately one month. One of these infants completed only two of the three test sessions and a second infant completed only the first test session. As in the previous study, infants were recruited from

an existing database of volunteers from the Minneapolis-St. Paul metro area and parents were interviewed prior to enrollment to ensure that their infant was eligible to participate in the study. Exclusion criteria were the same as in the previous study (<37 weeks gestation, birth weight < 5 lbs, exposure to drugs or alcohol in utero, major prenatal or birth complications, extended stay in the neonatal intensive care unit (NICU) following birth, or any serious health problems at the time of screening).

Infants were seen for their first testing session within one week of their 7-month birthday. The second session was at least one week after the infants' first visit and similarly, the final test session was conducted at least one week after the infants' second test session. All test sessions had to be completed before the infant turned 8 months, 1 week old. Mean ages at test and the mean number of days between sessions are listed in Table 3.2. Parents gave informed consent in accordance with the University of Minnesota IRB at the beginning of every test session. The first session took approximately 45 minutes to complete, while the second and third sessions each lasted approximately 30 minutes. Participants received a gift at each session as a thank-you for volunteering.

Materials

The room setup, stimulus presentation software, testing conditions, and video recording equipment were identical to those used in the previous study.

Stimuli

Stimuli for the spatial cueing task consisted of brightly colored shapes appearing on a black background. Task stimuli included a central fixation, a peripheral cue, and a target shape. The central fixation stimulus was either a blue cross or a red star, which

	Valid N (Missing)	Mean Age (Months, Days)	Age Range (Months, Days)	Mean # Days Between Sessions	Range - # Days Between Sessions
Session 1	65 (9)	7, 1	6, 22 - 7,9 (16 days)	n/a	n/a
Session 2	66 (8)	7, 11	7,0 - 7, 23 (23 days)	10.04	6 - 22
Session 3	65 (9)	7, 21	7, 7 - 8,7 (30 days)	10.01	3 - 31

Table 3.2. Mean ages and mean number of days between Study 2 test sessions.

were presented in the center of the screen and loomed in and out (min size = 1.25", max size =3.5") in order to sustain infants' attention. The two fixation shapes were evenly distributed across trials. The cue was a 2" bright yellow ring that appeared 16 inches to the left or right of the central fixation. The target stimuli were identical 3.5" green hearts, which were presented simultaneously as static images on the left and right sides of the screen (see Figure 3.1). These stimuli were consistent across all infants and all three testing sessions.

This study also used the same audiovisual attention-getter stimulus (i.e., a blue and white, checkered sphere that loomed in and out against a grid-like background composed of white dots) that had been used in Study 1.

Procedure

Infants were seated on their parents lap, about 48 inches from the screen, for the duration of the task. The task began with the attention-getter stimulus presented in the center of the screen. The experimenter monitored the infant's eyes and pressed a key to begin the first trial when she determined that the infant was looking at the center of the screen.

A schematic depiction of the task is presented in Figure 3.1. Every trial began with presentation of the fixation stimulus in the center of the screen. After 1000 ms, the cue stimulus appeared on either the left or right side of the fixation and remained on the screen for 100 ms. The cue presentation was followed by a short (33 ms) or long (600 ms) delay, during which the central fixation stimulus remained on the screen. At the end of this delay, the central fixation stimulus disappeared and the target shape simultaneously appeared on both the left and right sides of the screen. Thus, one of the green hearts appeared in the location in which the cue had appeared and an identical green heart appeared in the opposite, non-cued location. The target shapes remained visible for up to 1500 ms or until the infant looked away for more than 500 ms. The audiovisual attention-getter was presented after the targets disappeared in order to refocus the infant's attention towards the center of the screen before beginning the next trial.

As in the previous study, the experimenter monitored the infant's eye movements throughout the task and used key presses to indicate when the infant was looking center, left, right, or away from the screen. The experimenter was kept blind to the specific images that were presented during each trial. The computer program scored trials as invalid if the infant looked away before target onset or if the infant failed to make an eye movement towards a target within the 1500 ms time window following target onset. Trials that were scored as invalid were replaced with a new trial using the same cue location and delay length. Trials continued until the infant completed a maximum of 48 valid trials, (24 trials for each of the cue – target delay lengths) or until the infant became

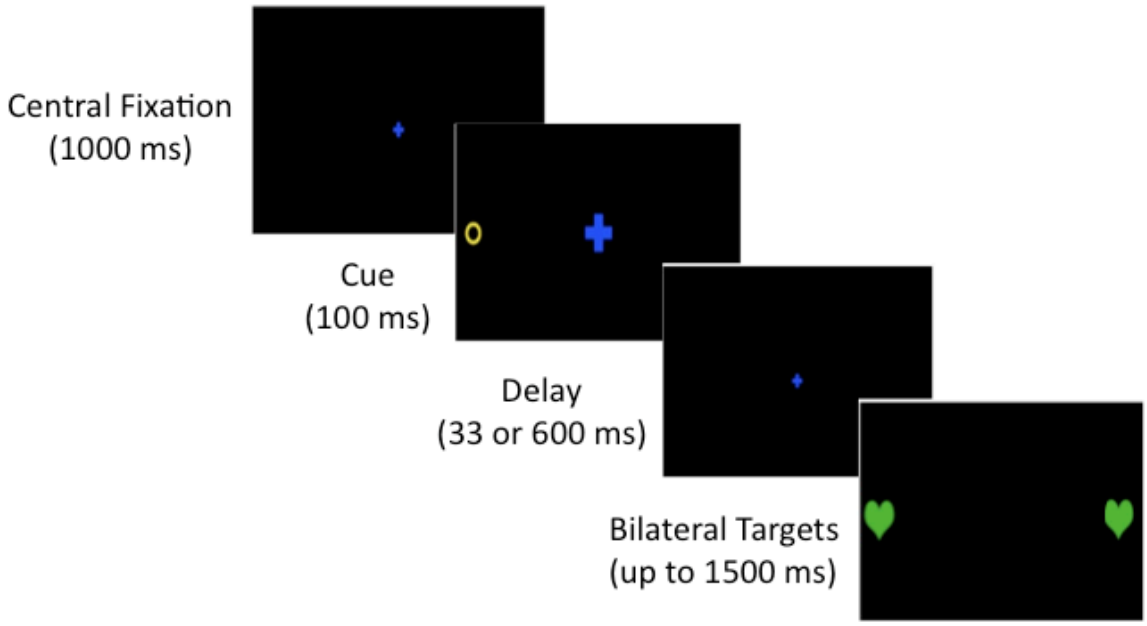


Figure 3.1. Schematic of spatial cueing task used in Study 2.

too bored and/or fussy to continue. The data were usable even if the infant did not complete all 48 trials and were included in subsequent analyses.

Data Coding and Processing

Infants' responses were hand-coded by trained research assistants for the direction and timing of every eye movement made by the infant during the task. Possible eye movement directions included the center, left, and right sides of the screen. Eye movements made to any other location were coded as a look away from the screen.

The coded data were used to determine the direction and latency of the infant's first eye movement following onset of the target shapes. As in the previous study, individual trials were discarded if the infant looked away from the screen before looking at one of the target shapes ("Look-away" trials), if the infant broke fixation from the central stimulus prior to target onset ("Fixation-break" trials), or if the infant never looked away from the central stimulus within the 1500 ms time window ("Center-only" trials). Additional trials were also excluded due to technical/experimenter errors.

After excluding these trials, the latencies of the infant's first look after target onset were filtered to exclude especially fast or slow eye movements. Latencies less than 200 ms was filtered out, as these likely reflected anticipatory looks rather than eye movements initiated following target onset. Latencies that were greater than two standard deviations above the infant's mean latency were considered to be especially slow and were also filtered out. The final sample only included infants who had at least four valid trials at each delay length (33 and 600 ms) after accounting for trial exclusion and latency filtering.

The latency values for the remaining valid trials provided a measure of cueing effects on the infant's response time towards targets appearing in the cued and non-cued locations. As in the previous study, mean latency difference scores were computed for each delay length by subtracting the infant's mean latency to look towards the non-cued location from the infant's mean latency to look towards the cued location. Use of these difference scores allowed for an assessment of *relative* reaction time benefits for targets appearing in the cued and non-cued locations, with positive scores indicating a reaction time benefit for looks to the non-cued location and negative score indicating a reaction time benefit for looks to the cued location.

The coded data files were also used to determine the direction of the infant's first look for every trial. This information was used to calculate the proportion of trials in which the infant's initial eye movements were directed to the cued or non-cued locations. This information provided a measure of cueing effects on the infant's orienting responses (e.g., the likelihood that the infant's first look is to the cued location).

Orienting and reaction time measures were computed in the same manner as in the previous study. Specifically, valid trials were sorted into four different categories based on delay length and the infant's response: 1) trials in which there was a short cue – target delay and the infant first looked to the expected (i.e., cued) location, 2) trials in which there was a short cue – target delay and the infant first looked to the unexpected (i.e., non-cued) location, 3) trials in which there was a long cue – target delay and the infant first looked to the unexpected (i.e., cued) location, and 4) trials in which there was a long cue – target delay and the infant first looked to the expected (i.e., non-cued)

location. Proportion of orienting scores were computed for each of these four categories. Mean latency difference scores were also computed for each delay length by subtracting the infant's mean latency to look towards the non-cued location from the infant's mean latency to look towards the cued location. Use of these difference scores allowed for an assessment of *relative* reaction time benefits for targets appearing in the cued and non-cued locations. A positive difference score indicates a reaction time benefit for looks to the non-cued location, while a negative difference score indicates a reaction time benefit for looks to the cued location. Overall, we expected that infants would display a reaction time benefit and higher proportion of orienting towards the cued location when the delay was short. At the long delay length, we expected infants to display a reaction time benefit and higher proportion of orienting towards the non-cued location.

The testing session, data coding, and data processing were conducted in an identical manner for the infants' second and third sessions.

Results

Task Completion

On average, infants completed 54 trials of the spatial cueing task at their first session (SD = 12.66), 56 trials at their second session (SD = 17.77), and 55 trials at their final session (SD = 16.84). Thus, as a group, there were no differences in task duration across the three test sessions ($F(2, 144) = 0.327$, $p = 0.722$). However, the extent to which data from individual infants were excluded varied across the three sessions. Session 1 data from five infants were excluded (valid n = 69) because they did not reach the minimum criterion of 8 valid trials after individual trial exclusions and latency

filtering was complete. Similarly, Session 2 data were excluded for five infants (valid n = 69) and Session 3 data were excluded for nine infants (valid n = 65).

Mean percentages of valid (i.e., not excluded or filtered) and invalid trials for the remaining infants are listed in Table 3.3. There was a significant reduction in the proportion of valid trials collected during three test sessions ($F(2,118) = 7.036$, $p = 0.001$). Paired t-tests indicated that there was a significant drop in valid trials between Sessions 1 and 2 ($t(65) = 3.065$, $p = 0.003$) and between Sessions 1 and 3 ($t(60) = 3.706$, $p < 0.001$), but no difference in the percentage of valid trials between Sessions 2 and 3 ($t(61) = 1.026$, $p = 0.309$). This reduction was largely driven by an increase in the proportion of trials that were excluded because the infants looked away from the screen before fixating a target shape ($F(2,118) = 7.52$, $p = 0.001$). The increasing percentage of these look-away trials corresponded to the reduction in valid trials, with a significant increase in look-away trials between Sessions 1 and 2 ($t(65) = -2.874$, $p = 0.005$) and between Sessions 1 and 3 ($t(60) = -3.646$, $p = 0.001$), but no difference between Sessions 2 and 3 ($t(61) = -1.094$, $p = 0.278$). In contrast, there were no differences across sessions in the percentage of trials that were excluded due to breaks in fixation prior to target onset ($F(2,118) = 0.286$, $p = 0.752$), failure to make an eye movement away from the central stimulus (Greenhouse-Geisser correction, $F(2,118) = 2.703$, $p = 0.084$), or experimenter error ($F(2,118) = 0.384$, $p = 0.682$).

With respect to individual infants' performance, there was a significant relationship between the total number of trials completed at Sessions 1 and 2 ($r = 0.468$, $p < 0.001$) as well as between the total number of trials completed at Sessions 2 and 3 (r

	Percentage of Total Trials (Mean/SD)		
	Session 1	Session 2	Session 3
Valid Trials	61.97 (14.5)	54.96 (16.2)	52.58 (17.9)
Look-away Trials	27.3 (14.1)	33.9 (15.9)	37.1 (17.6)
Fixation-break Trials	8.2 (7.4)	9.4 (7.3)	8.8 (6.8)
Center-only Trials	1.5 (3.7)	1.1 (2.5)	0.5 (1.1)
Experimenter Error	0.7 (1.4)	0.9 (1.8)	0.9 (1.9)

Table 3.3. Average percentage of valid and invalid trials for each test session.

0.468, $p < 0.001$). Similar correlations were also evident for the percentage of valid trials across sessions (Sessions 1 – 2: $r = 0.307$, $p = 0.012$; Sessions 2 – 3: $r = 0.344$, $p = 0.006$). Furthermore, across sessions, individual infants tended to have similar proportions of trials excluded due to looks away from the screen (Sessions 1 – 2: $r = 0.327$, $p = 0.007$; Sessions 2 – 3: $r = 0.276$, $p = 0.03$) and fixation breaks prior to target onset (Sessions 1 – 2: $r = 0.245$, $p = 0.047$; Sessions 2 – 3: $r = 0.332$, $p = 0.008$). In contrast, the proportions of trials excluded due to central fixations only (Sessions 1 – 2: $r = 0.057$, $p = 0.649$; Sessions 2 – 3: $r = 0.116$, $p = 0.369$) or experimenter error (Sessions 1 – 2: $r = 0.128$, $p = 0.306$; Sessions 2 – 3: $r = 0.08$, $p = 0.633$) were not consistent across sessions.

Infants' age at the time of testing did not relate to the total number of trials completed (Session 1: $r = -0.163$, $p = 0.164$; Session 2: $r = 0.03$, $p = 0.803$; Session 3: $r = 0.038$, $p = 0.751$) or the percentage of valid trials infants provided at each session

(Session 1: r = -0.147, p = 0.229; Session 2: r = 0.023, p = 0.853; Session 3: r = 0.178, p = 0.156). The amount of time between Sessions 1 and 2 did not affect the total number of completed trials (r = 0.029, p = 0.809) or the percentage of valid trials (r = 0.183, p = 0.133) during Session 2. The amount of time between the second and third sessions did not impact the total number of trials that infants completed during the third session (r = 0.041, p = 0.734) but was related to the percentage of valid trials infants provided during Session 3 (r = 0.276, p = 0.026). Infants who experienced a longer delay between the second and third sessions provided more valid trials during the third session.

Missing data. As described earlier, spatial cueing effects on infants' first look latencies were assessed based on the difference between infants' reaction times towards the cued location and their reaction times towards the opposite, non-cued location. As in Study 1, some infants demonstrated "perfect" cueing effects on their orienting behaviors, which precluded assessing relative reaction time benefits for looks towards the cued and non-cued locations. These infants' orienting data were included in the previously discussed analyses examining the direction of their first looks; however, they were treated as missing data points for the subsequent reaction time analyses. For Session 1, all infants provided reaction time data for trials with the short delay, but four infants did not provide reaction time data for trials with the long delay length. Similarly, during Session 2, reaction time data for short-delay trials were available for all infants, whereas three infants did not provide reaction time data for long-delay trials. Finally, Session 3 reaction time data were missing from three infants for short-delay trials, but reaction time data for long-delay trials were available from all infants. Reaction time data were never missing

from the same infant for more than one session. Final sample sizes for short-delay trials from Sessions 1, 2, and 3 were n = 69, n = 69, and n = 62, respectively. Final samples sizes for long-delay trials from Sessions 1, 2, and 3 were n = 65, n = 66, and n = 65, respectively.

One infant had an extreme outlying reaction time difference score for short-delay trials from Session 3 that was greater than six standard deviations above the group mean. This infant's data were excluded for all Session 3 reaction time analyses.

Spatial Cueing Effects

Facilitation (short-delay trials). ***Session 1***. Mean proportion of orienting and reaction time difference scores at each test session are presented in Figure 3.2. As a group, infants' proportion of first looks directed towards the cued location was not different from chance ($M_{Orienting}$ = 0.52, SD = 0.15, $t(68)$ = 1.02, p = 0.311) during trials with the short delay length. However, infants were faster to orient to the cued locations during these trials ($M_{RT\ Difference}$ = -53.02 ms, SD = 94.05 ms, $t(68)$ = -4.683, $p < 0.001$). Infants were grouped based on whether their orienting behavior was influenced by the spatial cue. Infants were considered to show facilitated orienting if their proportion of orienting towards the expected side was greater than one standard error above chance. Similarly, infants were considered to show facilitation of reaction time if their mean RT difference scores were less than one standard error below zero, since significantly negative difference scores indicate a reaction time benefit towards the cued location. Thirty-six infants (52.2%) showed facilitated orienting towards the cued location, which was a chance-level distribution ($\chi^2(1,N = 69) = 0.13$, p = 0.718). In contrast, 49 infants

(71%) showed facilitation of reaction time towards the cued location following the short delay, reflecting a significant proportion of infants who showed facilitated reaction times ($\chi^2(1,N = 69) = 12.188$, $p < 0.001$). Thus, during Session 1, infants did not show the expected facilitation in orienting following the short delay, but did show the expected facilitation of reaction time during short-delay trials.

Session 2. Similar to the results from the first session, infants' proportion of first looks towards the cued location was at chance levels when the cue-target delay was short ($M_{Orienting} = 0.4973$, $SD = 0.15$, $t(68) = -0.144$, $p = 0.886$). Furthermore, a marginally significant number of infants (42 infants, 60.9%; $\chi^2(1,N = 69) = 3.261$, $p = 0.071$) did *not* show the typical facilitation of orienting towards the cued location. Of these 42 infants, 7 infants (16.7%) showed no orienting preference, while 35 (83.3%) showed a preference for the *non-cued* location. Thus, these infants demonstrated an inhibition of return effect on their orienting behavior during the short-delay trials. However, infants showed significant facilitation of reaction time to the cued location during short-delay trials ($M_{RT\ Difference} = -29.18$ ms, $SD = 86.57$ ms, $t(68) = -2.8$, $p = 0.007$). Thirty-nine infants (56.5%) showed facilitated reaction times during these trials, though this distribution was not different from chance ($\chi^2(1,N = 69) = 1.174$, $p = 0.279$). Thus, as in Session 1, infants demonstrated the expected facilitative cueing effects on reaction time, while their orienting behaviors began to shift towards a preference for the opposite location, even during trials with the short delay.

Session 3. The effects of cueing on infants' orienting behavior shifted substantially by the third session. During this session, infants did not show facilitated

orienting following the short delay length; instead, their proportion of orienting to the cued location was significantly *less* than chance ($M_{Orienting}$ = 0.45, *SD* = 0.18, *t*(64) = -2.108, *p* = 0.039), indicating that infants were more likely to orient to the *non-cued* location. The number of infants who demonstrated facilitated orienting towards the cued location (25 infants; 38.5%) was less than the number of infants who did not (40 infants, 61.5%; $\chi^2(1,N = 65) = 3.462$, *p* = 0.063). Thus, though most infants did not demonstrate the expected facilitation at the cued location, as a group, they instead began to demonstrate an inhibition of return effect on their orienting following the short delay. Furthermore, during this final session, infants no longer showed significant facilitation of reaction time to look to the cued location during short-delay trials ($M_{RT\ difference}$ = -12.25 ms, *SD* = 96.86 ms, *t*(60) = -0.988, *p* = 0.327) and only half of the sample (31 infants, 50.0%) demonstrated facilitative cueing effects on reaction time. Thus, unlike during Sessions 1 and 2, there was no evidence the expected facilitative cueing effects on the direction or speed of infants' orienting behaviors.

Inhibition of return (long-delay trials). ***Session 1.*** During trials with the long delay length, infants were more likely to direct their first look to the non-cued location than to the cued location ($M_{Orienting}$ = 0.64, *SD* = 0.19, *t*(68) = 5.928, *p* < 0.001). Similarly, infants demonstrated faster reaction times towards the non-cued locations during these trials ($M_{RT\ Difference}$ = 64.49 ms, *SD* = 126.47 ms, *t*(64) = 4.111, *p* < 0.001). As with the measures of facilitation discussed above, infants were grouped based on whether they showed the expected inhibition of return effects on orienting and/or reaction time. Infants were considered to show inhibitory effects on orienting if their proportion of

orienting to the non-cued location was greater than one standard error above chance. Infants were considered to show inhibitory effects on reaction time if their mean reaction time difference scores were greater than one standard error above zero, since significantly positive difference scores indicate a reaction time benefit towards the non-cued location. During trials with the long delay, a significant number of infants (47 infants; 68.1%) showed IOR effects on orienting ($\chi^2(1,N = 69) = 9.058$, $p = 0.003$). A marginally significant number of infants (40 infants, 61.5%) demonstrated inhibition of return effects on reaction time during these trials ($\chi^2(1,N = 65) = 3.462$, $p = 0.063$). Overall, Session 1 results provided evidence of inhibitory cueing effects on both orienting and reaction time measures.

Session 2. Inhibition of return effects during the second session were very similar to those seen during Session 1. Infants continued to demonstrate a significant orienting preference towards the non-cued location ($M_{Orienting} = 0.59$, $SD = 0.19$, $t(68) = 4.088$, $p < 0.001$). Forty-one infants (59.4%) showed this orienting preference; however, this number could be explained by chance ($\chi^2(1,N = 69) = 2.449$, $p = 0.118$). In addition, infants showed significant inhibitory effects on reaction time ($M_{RT\ Difference} = 23.15$ ms, $SD = 80.59$ ms, $t(65) = 2.334$, $p = 0.023$). However, the number of individual infants showing these effects (39 infants; 59.1%) was not different from chance ($\chi^2(1,N = 66) = 2.182$, $p = 0.14$). Thus, as in Session 1, the latency of infants' first looks reflected inhibitory cueing effects on both orienting and reaction time, though the number of infants demonstrating these effects was reduced from Session 1.

Session 3. Inhibition of return effects on infants' orienting behavior began to decline by Session 3. Infants no longer showed a significant orienting preference for the non-cued location ($M_{Orienting}$ = 0.53, SD = 0.16, $t(64) = 1.293$, $p = 0.201$). Though 36 infants (55.4%) continued to demonstrate the inhibition of return effect on orienting, this distribution was not different from chance ($\chi^2(1,N = 65) = 0.754$, $p = 0.385$). In contrast, the inhibition of return effect on infants' reaction times continued to be nearly significant during Session 3 ($M_{RT\ Difference}$ = 20.93 ms, SD = 93.22 ms, $t(63) = 1.796$, $p = 0.077$). Thirty-eight infants (58.5%) showed inhibition of return effects on reaction time during the final session, though this distribution was not significant ($\chi^2(1,N = 65) = 1.862$, $p = 0.172$). Thus, as a group, inhibition of return effects on infants' orienting and reaction times were substantially weaker and less prevalent than those seen during the first two sessions.

Links between facilitation and inhibition of return effects. There was no evidence for a link between facilitation and inhibition of return effects at any of the three sessions. Specifically, infants' proportion of first looks to the cued location during short-delay trials was not significantly related to their proportion of first looks to the non-cued location during long-delay trials. This result was seen for Session 1 ($r = -0.123$, $p = 0.315$), Session 2 ($r = -0.081$, $p = 0.506$), and Session 3 ($r = -0.176$, $p = 0.163$). Similarly, there was no relationship between the extent of facilitative and inhibitory effects on infants' reaction times during Session 1 ($r = -0.086$, $p = 0.494$), Session 2 ($r = -0.015$, $p = 0.904$), or Session 3 ($r = -0.164$, $p = 0.207$)[1]. Because there was no evidence for a

[1] Mean reaction time difference scores were reverse-coded for short-delay trials in order to be on the same scale as the long-delay trials.

relationship between facilitative and inhibitory cueing effects at any session, these effects were considered separately for all subsequent analyses.

Change in cueing effects over time. ***Facilitation (Short delay).*** Infants' proportions of orienting to the cued location and mean reaction time difference scores were entered into separate repeated-measures ANOVAs with Session as the within-subjects factor. Results indicated that there was a significant change in infants' proportion of orienting to the cued location over the course of the three sessions ($F(2,118) = 3.295$, $p = 0.04$). Follow-up paired comparisons indicated that infants were more likely to orient to the cued location during Session 1 ($M_{Orienting} = 0.52$, $SD = 0.15$) compared to Session 3 ($M_{Orienting} = 0.45$, $SD = 0.18$; $t(60) = 1.99$, $p = 0.041$). There were no differences in infants' orienting from Session 1 to Session 2 ($t(65) = 1.053$, $p = 0.296$) or from Session 2 to Session 3 ($t(61) = 1.457$, $p = 0.15$). However, recall that the proportion of orienting measure was different from chance only during Session 3, when infants were *less* likely to orient to the cued location. Thus, the change in the proportion of orienting measure across Session 1 to Session 3 reflects this shift from a null effect in the first and second sessions to a significant orienting preference towards the non-cued location during the final session.

In contrast, there was no main effect of Session on infants' mean reaction time difference scores (Greenhouse-Geisser correction, $F(1.54, 87.85) = 2.39$, $p = 0.11$). However, recall that these difference scores were significantly below chance at the first and second sessions, reflecting a reaction time benefit for targets appearing in the cued location. Thus, infants were faster to respond to targets appearing in the cued location at

these sessions, but there was no change in the extent of this reaction time benefit across sessions.

Inhibition of Return (Long delay). Results of a second set of repeated-measures ANOVAs indicated that there was a significant change in infants' proportion of orienting to the non-cued location across the three sessions ($F(2,118) = 8.227$, $p < 0.001$). Follow-up paired t-tests indicated that infants' orienting preference towards the non-cued location was greater during Session 1 ($M_{Orienting} = 0.64$, $SD = 0.19$) than Session 3 ($M_{Orienting} = 0.53$, $SD = 0.16$; $t(60) = 3.951$, $p < 0.001$) and greater during Session 2 ($M_{Orienting} = 0.59$, $SD = 0.19$) than Session 3 ($t(61) = 2.657$, $p = 0.01$). In addition, there was a nearly significant difference in the orienting measures from Sessions 1 and 2, with infants showing a greater orienting preference towards the non-cued location during Session 1 ($t(65) = 1.792$, $p = 0.078$). Also recall that these proportion of orienting measures were significantly above chance during Sessions 1 and 2, but not Session 3. Thus, the extent of infants' orienting preferences for the non-cued location gradually decreased over the three sessions and reached null levels by the final session.

Results also indicated a significant change in infants' mean reaction time difference scores over the course of the three sessions (Greenhouse-Geisser correction, $F(1.61,88.45) = 4.048$, $p = 0.004$). Paired t-tests revealed significant differences between Session 1 ($M_{RT\ Difference} = 64.49$ ms, $SD = 126.47$ ms) and Session 2 ($M_{RT\ Difference} = 23.15$ ms, $SD = 80.59$ ms; $t(60) = 2.264$, $p = 0.027$) as well as between Sessions 1 and 3 ($M_{RT\ Difference} = 20.93$ ms, SD = 93.22 ms; $t(57) = 2.335$, $p = 0.023$). There was no significant change in reaction time difference scores between Sessions 2 and 3 ($t(60) = -1.17$,

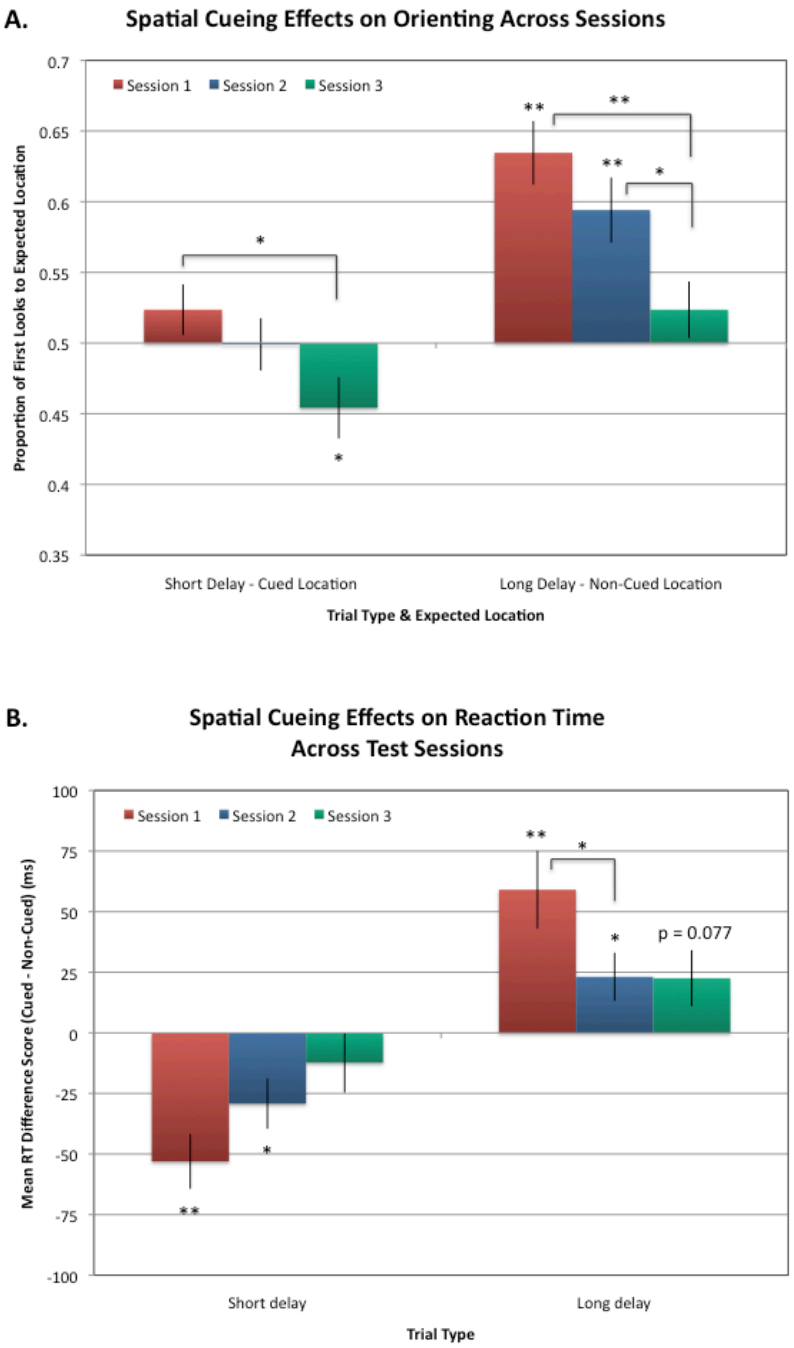


Figure 3.2. Spatial cueing effects on (A) infants' proportion of orienting to the expected location, and (B) reaction time benefits for the cued and non-cued locations

P = 0.246). As discussed earlier, these mean reaction time difference scores were above chance during all three sessions. Thus, as a group, infants showed the greatest reaction time benefit for targets appearing in the non-cued location during Session 1. Though the extent of this reaction time benefit decreased with subsequent sessions, infants continued to demonstrate an IOR effect on reaction time during the second and third sessions.

Stability of cueing effects. ***Facilitation (short-delay trials).*** *Proportion of orienting.* The stability of individual infants' responses to spatial cueing was assessed by determining whether the magnitude of the cueing effects observed during early sessions predicted infants' sensitivity to cueing at subsequent sessions. Regression coefficients for these analyses are reported in Table 3.4. Results indicated that the Session 1 proportion of orienting measure was a significant predictor of infants' proportion of orienting to the cued location during Session 2 (R^2 = 0.156, F(1,65) = 4.924, p = 0.03). Considered independently, Session 1 orienting did not have predictive value for Session 3 orienting behavior (R^2 = 0.008; F(1,57) = 0.456, p = 0.502), and continued to be a poor predictor when the Session 2 orienting measure was added (t(56) = -0.047, p = 0.963). However, when controlling for Session 1, the Session 2 orienting measure explained unique variance in infants' Session 3 orienting behavior (R^2 = 0.164; ΔR^2 = 0.156, F(1,56) = 10.469, p = 0.002).

Reaction time. Infants' reaction time benefit for the cued location during Session 1 was a poor predictor of the same measure during Session 2 (R^2 = 0.016, F(1,64) = 1.02, p = 0.316). In contrast, the reaction time measure from Session 1 did predict the Session 3 measure of reaction time (R^2 = 0.11, F(1,55) = 6.808, p = 0.012). However, this was a

negative relationship; infants who showed stronger reaction time benefits during the first session showed weaker facilitation of reaction time during the final session. The addition of the Session 2 reaction time measure to the model explained additional variance in the Session 3 reaction time measure, above the contribution of the Session 1 variable (R^2 = 0.16, ΔR^2 = 0.05, $F(1,54) = 3.219$, $p = 0.078$). Furthermore, there was a positive relationship between the Session 2 and Session 3 reaction time measures, indicating that infants who show strong facilitation of reaction time during the second session continued to show strong facilitation during the final session. Thus, these results reveal opposite patterns of reaction time facilitation between the first and third sessions, but similar facilitation patterns between the second and third sessions.

Inhibition of return (long-delay trials). *Proportion of orienting.* Regression coefficients for analyses of inhibition of return effects during the long-delay trials are also listed in Table 3.4. Results indicated that infants' proportion of orienting to the non-cued location during Session 1 was a nearly significant predictor of the same measure during Session 2 ($R^2 = 0.057$, $F(1,64) = 3.934$, $p = 0.055$). Furthermore, considered on its own, the Session 1 proportion of orienting measure continued to be a trend-level predictor of the proportion of orienting measure during Session 3 ($R^2 = 0.047$, $F(1,57) = 2.826$, $p = 0.098$). Controlling for the Session 1 orienting measure, the Session 2 orienting measure contributed a marginally significant portion of additional variance in explaining Session 3 orienting ($R^2 = 0.099$, $\Delta R^2 = 0.052$, $F(1,56) = 3.241$, $p = 0.077$).

Reaction time. Inhibition of return effects on reaction times during Session 1 did not predict cueing effects during Session 2 ($R^2 = 0.045$, $F(1,60) = 0.121$, $p = 0.729$).

When considered independently, the Session 1 reaction time measure was also a poor predictor of the same measure obtained during Session 3 (R^2 = 0.003, F(1,53) = 0.689). In contrast, the Session 2 reaction time measure accounted for a significant proportion of unique variance in the Session 3 reaction time (R^2 = 0.097, ΔR^2 = 0.093, F(1,52) = 5.379, p = 0.024).

Summary. *Session 1 – Session 2.* Overall, these results revealed modest stability in the orienting measures across the first two tests sessions. Session 1 measures of both facilitated orienting and inhibition of return effects on orienting were significant predictors of the same measures obtained during Session 2. However, the facilitation of orienting measure accounted for a larger proportion of variance (R^2 = 0.16) of Session 2 performance than the IOR measure of orienting (R^2 = 0.06). In contrast, neither the facilitation nor the IOR effects on reaction time during Session 1 predicted infants' performance on the same measures during Session 2.

Session 1 – Session 3. The relationships between cueing effects during Session 1 and Session 3 were not straightforward. The measure of IOR effects on orienting during Session 1 was a significant predictor of the same measure during Session 3, though the Session 1 measure accounted for only a small amount of variance (R^2 = 0.05) in the corresponding Session 3 measure. The measure of facilitated reaction time during Session 1 was also a significant predictor of the same measure during Session 3; however, the facilitation of reaction time measure from Session 1 was negatively related to the corresponding measure from Session 3, indicating that infants who showed strong

Session 2 Measures								
	Facilitation of Orienting		Facilitation of RT		IOR - Orienting		IOR - RT	
	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Predictor								
Session 1 Measure	0.071*	0.267*	0.016	0.125	0.057$^+$	0.238$^+$	0.002	0.045
n	65		65		65		60	
Session 3 Measures								
Step 1	0.015		0.11*		0.051$^+$		0.004	
Session 1 Measure		0.124		-0.332*		0.225$^+$		-0.059
Step 2	0.141*		0.05$^+$		0.049$^+$		0.091*	
Session 1 Measure		0.037		-0.35*		0.163		-0.085
Session 2 Measure		0.385*		0.224$^+$		0.231$^+$		0.303*
Total R^2	0.156*		0.16*		0.10$^+$		0.094$^+$	
n	59		56		59		55	

*$p < 0.05$, $^+p < 0.10$

Table 3.4. Regression coefficients for analyses of stability of spatial cueing measures across repeated test sessions.

facilitation of reaction time during the initial session demonstrated substantial attenuation of the effect by the final session. The measures of facilitated orienting and IOR effects on reaction time during Session 1 did not predict infants' performance on the corresponding measures from Session 3.

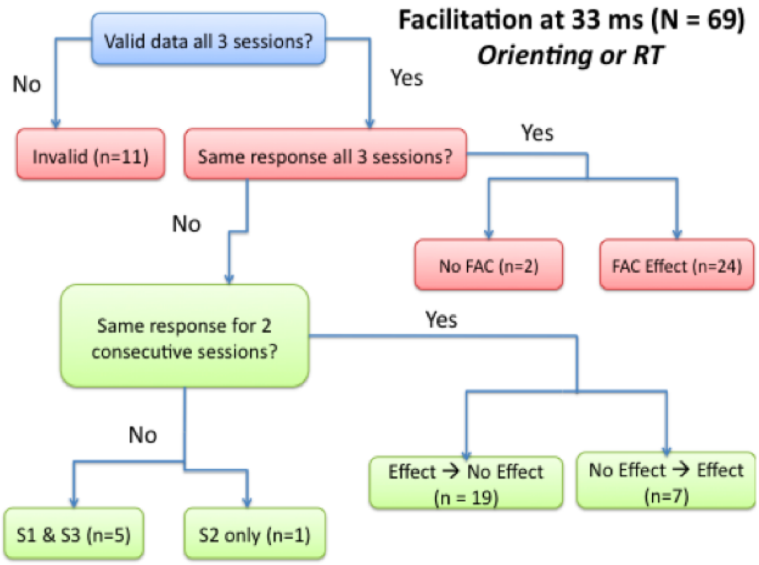
Session 2 – Session 3. Infants' responses to spatial cueing were most stable across Sessions 2 and 3. The extent of facilitation during Session 2 was a significant predictor of facilitation effects during Session 3, for both the orienting and reaction time measures. However, the orienting measure of facilitation accounted for a larger amount of variance in the corresponding Session 3 measure ($R^2 = 0.16$) compared to the reaction time measure of facilitation ($R^2 = 0.05$). Similarly, the extent of inhibition of return effects during Session 2 significantly predicted the extent of these effects during Session 3, for both the orienting and reaction time measures. Furthermore, both of these Session 2 measures accounted for a similar amount of variance in their corresponding Session 3 measures (IOR orienting effects: ($R^2 = 0.05$); IOR reaction time effects: ($R^2 = 0.09$).

Qualitative assessment. In addition to these quantitative measures, the stability of infants' responses to spatial cueing was also assessed qualitatively by determining whether individual infants showed the expected effects at each session, regardless of the magnitude of the effect. As discussed earlier, infants were identified as showing orienting and/or reaction time effects if their scores fell more than one standard error from chance. Based on this initial classification, infants were further grouped depending on whether they showed the same overall responses at three consecutive sessions, two consecutive sessions, or at non-consecutive sessions. Infants were considered to show an overall

facilitation or inhibition of return effect if they had significant scores for either the orienting or reaction time measure.

A summary of this qualitative assessment is displayed in Figure 3.3. For the assessment of facilitation effects, 11 infants did not have valid data for all three sessions and were excluded from this assessment. Of the remaining group, 26 infants (44.8% of valid sample) showed the same response at all three sessions; 24 of these infants showed an overall facilitation effect at each session and 2 infants showed no evidence of facilitation at any of the sessions. Twenty-six infants (44.8%) showed the same response at two consecutive sessions. Nineteen of these infants showed an overall facilitation effect at the first and second sessions but no longer showed a facilitation effect during the final session. Seven infants showed the opposite pattern, with no facilitation effect during the first session but significant facilitation effects during the second and third sessions. Finally, 6 infants (10.3%) showed significant facilitation effects at non-consecutive sessions; 5 of these infants showed an overall facilitation effect during the first and third sessions, but not the second session, and 1 infant showed a facilitation effect during the second session only.

For the inhibition of return assessment, 9 infants did not provide usable data from all three sessions and were excluded from the assessment. Of the remaining group, 30 infants (53.6% of valid sample) showed an overall inhibition of return effect at every session. Eighteen infants (32.1%) showed inhibition of return effects at two consecutive sessions. Eleven of these infants showed significant effects at the first two sessions but no longer showed an effect at the third session. Seven infants showed significant inhibition



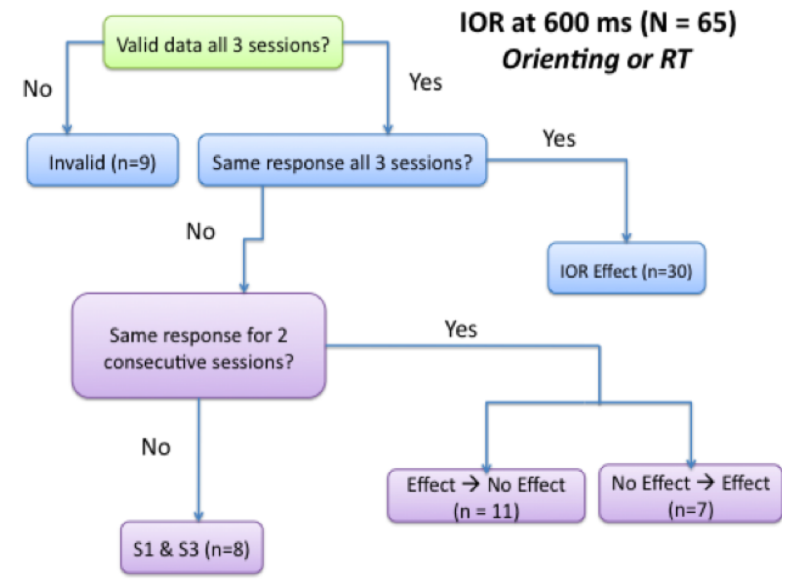


Figure 3.3. A schematic depiction of the qualitative assessment of stability. Infants were grouped based on whether they showed the same facilitation/IOR effects at consecutive sessions

of return effects during the second and third sessions only. Finally, 8 infants (14.3%) showed inhibition of return effects at non-consecutive sessions; all 8 of these infants showed significant inhibition of return effects during the first and third sessions, but not during the second session.

Discussion

The primary goal of Study 2A was to assess the extent of stability in 7-month-old infants' reflexive orienting behaviors over repeated experiences with the spatial cueing task. Overall, the results demonstrated only moderate consistency across these repeated measures. As a group, the extent of facilitative and inhibitory effects on infants' orienting and reaction times declined over the three test sessions. Furthermore, there was dramatic reduction in the magnitude of these effects between the first two sessions but less change across Sessions 2 and 3. These results suggest that as an overall group, infants' attention behaviors were less stable between the first two sessions and then stabilized between the final sessions.

With respect to individual infants' behaviors, the results suggested little to moderate stability of cueing effects across the three sessions. In general, orienting measures showed more stability than the reaction time measures, and Session 2 measures tended to be better than Session 1 measures as predictors of the Session 3 results. However, though these quantitative measures imply little stability in infants' reflexive orienting, qualitative assessments of infants' behaviors suggest a greater extent of stability over time. Specifically, there was much stronger evidence for stability when infants were grouped based on whether they did or did not show the expected effects at

each session. Based on this approach, approximately half of the sample showed consistent facilitation and inhibition of return effects at all three sessions and a substantial number of infants showed consistent effects across the first two sessions. Thus, conclusions regarding the stability of spatial cueing effects on infants' orienting behaviors are highly dependent on quantitative versus qualitative definitions of stability.

These varying results lead to questions regarding whether the quantitative or qualitative approach is a more appropriate assessment of stability. As discussed earlier, assessing continuity of complex cognitive functions is especially challenging because it is unclear whether the associated behaviors should look the same if the underlying processes haven't changed, or if there can be stability in the underlying processes despite changing behaviors. In this study, the contrast between the quantitative and qualitative assessments of stability highlights this complexity. The quantitative assessment accounts for the magnitude of individual infants' responses to cueing over time, but does not account for whether individual infants continue to show significant facilitation and/or inhibition of return effects over time. For example, individual infants may demonstrate a dramatic reduction in the magnitude of facilitative and inhibitory effects yet continue to show significant effects at each time point. Similarly, other infants may show a high degree of stability in the magnitude of facilitation and inhibition of return effects, but these effects may never reach significance. Thus, quantitative assessments are likely more appropriate when considering the stability of precise response variables, whereas qualitative assessments may be more appropriate when examining the stability of individual infants' propensities for specific kinds of behavior.

There are a number of factors that may have contributed to changes in infants' behaviors over the repeated test sessions. Perhaps one of the most obvious considerations is that development continues even over relatively short periods of time. Even though the sessions occurred only ten days apart on average, the passage of any time makes it difficult to know what developmental processes occurred during that time that could contribute to the observed changes in infants' behaviors. In a similar vein, it is possible that learning processes led to changes in behavior, since repeated testing on an identical task necessarily involves prior experience with the same task. The effects of this prior experience could certainly affect performance during subsequent test sessions, and potentially to a different extent for different infants.

Methodologically, the specific task parameters used in this study also could have affected the observed changes in infants' sensitivity to spatial cueing. Because attention processes are so sensitive to context, spatial cueing effects, and especially inhibition of return effects, are highly dependent on the specific timing parameters that are used. In particular, cue – target delays that are too long or too short fail to yield any observable effects of cueing on reflexive orienting. Extensive piloting was done prior to the current set of studies to identify the optimal timing parameters for this age group. However, the efficacy of the timing parameters is partially dependent on an individual's speed of information processing; thus it is extremely difficult to identify parameters that will be optimal for every individual in a sample of participants. Furthermore, whether the timing parameters are optimal for an individual infant can change over time as he/she develops more rapid processing speeds. For some infants, the parameters used in the current study

may have remained optimal over the entire month of testing, which would contribute to greater stability of behavior over time. However, for other infants, the timing parameters that were used may have been optimal for only a limited number of test sessions.

This important role of timing parameters might also help explain the inconsistent facilitation of orienting effects observed in this study. Though infants showed weak facilitation of orienting to the cued location during the first two sessions, by the final session infants showed a significant bias to orient towards the *non-cued* location during short-delay trials. Thus, as a group, infants were demonstrating inhibition of return effects on orienting during the short-delay trials of Session 3. This evidence for inhibition of return effects during these trials suggests a previously effective short delay length during earlier sessions became a relatively long delay length by the final session. This shift in the relative duration of the delay lengths may have contributed to changes in infants' processing speeds that could have occurred over the month of testing.

Finally, it is possible that the observed changes in behavior reflect a high degree of context dependence that may be inherent to lab-based experimental testing, and infant testing in particular. In particular, the quantitative assessment of stability suggests that infants' attention behaviors may be highly dependent on the context of their daily experiences. Yet the qualitative approach suggested a fair amount of stability in infants' overall sensitivity to cueing information. Thus, one of the challenges for understanding developing attention in infancy will be to identify how much of observed behavior reflects true individual differences versus intra-individual differences that are highly context-dependent.

Chapter 4
Study 2B: Individual Differences in Spatial Cueing Effects and Responses to Novelty

The results described in the previous chapters highlight the wide range of individual differences seen within a limited age group, over a relatively short period of time, and across repeated measures of performance in a single attention task. These individual differences include variation in the extent to which spatial cueing influences infants' orienting behavior during a single test session, as well as variation in the degree to which individual infants show consistent effects of spatial cueing across multiple test sessions. The primary questions that follow from these results surround the potential factors that may contribute to these individual differences. Within single test sessions, why do some infants show a high degree of sensitivity to the cue while others do not? Across sessions, why do some infants show consistent responses during the spatial cueing task while the orienting behaviors of other infants are highly variable across time? The next two chapters (Studies 2B and 2C) will address these questions by identifying behavioral and biological factors that may be related to these observed variations in infants' reflexive orienting.

The facilitation and inhibition of return effects elicited by spatial cueing have been replicated many times (Berlucchi, 2006; Klein, 2000; Lupianez, et al., 2006) and a number of authors have considered how these behavioral effects reflect the functioning of underlying selective attention processes. Facilitation has predominantly been interpreted as a benefit in stimulus detection that arises from covert shifts of attention prior to target onset (Posner & Cohen, 1984). From this perspective, target detection is facilitated by

spatial cues because the focus of spatial attention is deployed to the location of the upcoming target stimulus, which supports enhanced stimulus detection and processing following target onset. With respect to individual differences, some researchers have suggested that sensitivity to peripheral spatial cues may have an inverse relationship with an individual's tendency to sustain visual fixation to an engaging stimulus for a prolonged period of time (McConnell & Bryson, 2005). Though inhibition of return effects are also linked to covert shifts of attention, most researchers discriminate between facilitation and inhibition of return based on Posner and colleagues' proposal that inhibition of return uniquely reflects a bias towards novelty that is inherent to the human attention system (Handy, et al., 1999; Ivanoff & Klein, 2001; Lupianez, et al., 2006; Posner & Cohen, 1984; Posner, et al., 1985; Posner, et al., 1997; 1998). Specifically, these authors assert that inhibition of return "works in conjunction with the saccadic system to ensure that eye movements are made more frequently to novel locations than to locations that have just been examined" (Posner, et al., 1997, p. 331). Several other authors have expanded on this idea to argue that this bias to selectively attend to novel information is essential for efficient visual search (Boot, McCarley, Kramer, & Peterson, 2004; Klein, 1988; Macinnes & Klein, 2003; McCarley, Wang, Kramer, Irwin, & Peterson, 2003; Posner & Cohen, 1984; Posner, et al., 1985; Wright & Richard, 1998).

If this interpretation of inhibition of return as a manifestation of the attention system's bias for novelty is accurate, it is possible that variations in individuals' sensitivity to spatial cueing may be related to other aspects of responding to novelty. Several researchers have proposed models for an integrated motivation and affective

system that mediates approach and exploration of novel information (Depue & Iacono, 1989; Derryberry & Reed, 1994; Gray, 1987, 1991; Panksepp, 1982, 1986; Schneirla, 1959; Tucker & Williamson, 1984). Though the specifics of these models differ, they all converge on the idea that individuals vary in their sensitivity to rewards, reactivity to novel stimuli, and propensity to engage in approach behaviors.

These models have received support from studies identifying neural systems that are involved in reward processing, positive affect, and motor approach behaviors. These studies have generally highlighted the role of the limbic system and prefrontal cortex in mediating these cognitive, affective, and behavioral processes (Rothbart, Ahadi, & Hershey, 1994). In particular, positive affect and motor approach are both associated with neural activity in the left hemisphere (R. J. Davidson, 1992; R. J. Davidson & Fox, 1982; Putnam & Stifter, 2002). In addition, regions of the orbitofrontal cortex and amygdala that are involved in reward processing are also heavily interconnected with dopaminergic systems in ventral striatum that are critical for facilitating motor behavior (Everitt, Morris, O'Brien, & Robbins, 1991; Robbins, Cador, Taylor, & Everitt, 1989; Rothbart, Derryberry, & Posner, 1994).

Developmental observations also point to a constellation of positive reactivity and approach behaviors that emerge early in infancy. By 2 -3 months of age, positive reactivity is expressed through “limb cycling,” smiling, laughter, and positive vocalizations; by 6 months of age this repertoire of behaviors expands to include positive facial expressions and motor approach to rewarding stimuli (Rothbart, 1988, 2007). In addition, orienting of attention becomes heavily influenced by novelty by 7 months of

age, and novelty affects infants' physical approach to objects by 8 months of age (Rothbart, 1988).

Rothbart and colleagues have quantified these behaviors by developing temperament measures that identify individual infants' tendencies for emotional, motor, and attention responses to stimulation (e.g., reactivity) as well as their tendencies to engage in behaviors such as motor approach or attention orienting that modulate reactivity (Gartstein & Rothbart, 2003; Rothbart, 1988; Rothbart & Derryberry, 1981). Studies using these measures have shown that infants' individual profiles of positive reactivity and approach behaviors develop early in infancy (Nigg, 2000; Rothbart, Ahadi, et al., 1994), are consistent during infancy and early childhood (Calkins, Fox, & Marshall, 1996; Rothbart, 1986, 1988; Rothbart, Derryberry, & Hershey, 2000; Rothbart & Mauro, 1990; Ruff & Rothbart, 1996) and are related to approach, impulsivity, and attention focusing behaviors at 7 years of age (Derryberry & Reed, 1994; Rothbart, Derryberry, & Hershey, 1993). Many studies have reported specific associations between infants' expressions of positive affect and their motor approach to engaging stimuli (Fox & Davidson, 1984; Izard, 1977; Putnam & Stifter, 2002; Rothbart, 1988; Rothbart, et al., 2000). Several of these studies have used a motor approach paradigm initially developed by Rothbart (1988), which measures infants' latency to grasp high- and low-intensity toys, and have consistently reported positive associations between rapid motor approach and parental reports of positive emotionality (Putnam & Stifter, 2002; Rothbart, 1988; Rothbart, et al., 2000).

This research provides compelling evidence of an integrated motor approach and positive affect system that is functioning even in early infancy and likely contributes to individual differences in cognitive and behavioral responses to novel information. Thus, given the premise that orienting behavior during the spatial cueing task reflects attention biases towards novelty, it is possible that some infants' orienting biases reflect a heightened sensitivity to novelty that is mirrored by broader differences in approach behaviors and positive affect. Study 2B aims to empirically examine the interpretation of inhibition of return as a reflection of novelty biases by relating infants' orienting behavior during the spatial cueing task to measures of motor approach to novelty, dishabituation of attention to novelty, and parental report of positive reactivity and approach behaviors. Doing so will clarify whether variations in infants' reactivity and approach to novelty may contribute to the individual differences in reflexive attention orienting observed during the spatial cueing task.

Method

Participants

The following tasks were conducted with the same sample of seventy-four 7-month-old infants (36 M, 38 F) described in the previous chapter. All of the behavioral tasks were completed during the infants' first testing session, after infants completed the spatial cueing task.

Behavioral Measures

Approach Latency. ***Materials.*** Infants were seated in a highchair with an attached 12" x 24" oblong tray. Parents sat in a chair behind the highchair and were asked

to avoid interacting with their child while he/she played with the toys. An opaque curtain separated the infant and the experimenter and the television was covered in the same opaque fabric to limit distractions. The experimenter presented toys through a small opening (12" x 18") in the curtain. Infants' responses were recorded using a standard digital video camera.

Stimuli. Stimuli consisted of the four toys presented in Figure 4.1. Two of these toys – a rattling ball and a shiny cowbell decorated with stickers – were considered to be typical toys, as we assumed that they would likely be relatively familiar to the infants. Two additional toys were constructed in the lab to be relatively novel to the infants. One of these toys, the "Rattle-Bag," was a square bag made of synthetic fabric with a raised texture and red and black patterns. The Rattle-Bag had several adornments (e.g., two bows and a single handle) and was stuffed with foam filling and small bells. The second novel toy, the "Pop-Shaker," consisted of two plastic frozen popsicle-handles that were linked by braided plastic lanyards with small bells attached. All four toys made a rattling or clanking noise when shaken.

Procedure. The typical toys were always presented first to allow the infants a "warm-up" period before interacting with the novel toys. Toy presentation was counterbalanced within these two categories. At the beginning of each presentation, the experimenter moved the toy through the opening in the curtain, shook the toy to attract the infants' attention, and placed it in the center of the tray. Infants were given approximately one minute to examine each toy. Infants did not have any interaction with the experimenter or their caregiver before they touched the toy for the first time. After

Figure 4.1. Typical toys (A) and novel toys (B) used as stimuli for the motor approach task in Study 2B.

this initial contact, infants were assisted if the toy fell on the floor or rolled out of their reach.

Data Coding and Processing. The first 30 seconds of each toy presentation were hand coded to determine infants' latencies to grasp the toy for the first time. The beginning of each trial was identified as the time at which the toy made contact with the tray. Trained coders scored the time at which the infant made his/her first contact with the toy. These time-stamps were used to compute the infant's latency to approach each toy. In addition, infants' mean approach latencies were calculated for the typical and novel toy categories.

Dishabituation to Novel Faces. ***Materials.*** As for the spatial cueing task, all stimuli were presented on the 42" television screen using Macromedia Director. During the task, the room was dark and the experimenter's computer was separated from the infant and the television screen by the opaque curtain. The experimenter viewed the infant's responses on a remote screen using a standard Sony digital camera with infrared "night vision" capabilities.

Stimuli. Two smiling female faces were selected from the MacBrain Face Stimulus Set (Tottenham, 1998). The two faces were selected to be as dissimilar as possible (e.g., short brown hair versus long blonde hair). The faces were always presented on a black background. One face was used as the habituation stimulus and the second face was used as the novel test stimulus. Habituation and test faces were counterbalanced across infants.

In addition to the face stimuli, an "attention-getter" stimulus was used between every trial to re-orient infants' attention to the center of the screen. This attention-getter consisted of a cartoon movie accompanied by a repetitive, auditory stimulus. A second attention-getter stimulus was used to re-engage infants' attention between the habituation and test portions of the task. This second attention-getter consisted of a separate short cartoon video clip that was presented in the center of the screen.

Procedure. The experiment began with the attention-getting stimulus appearing in the center of the screen. The researcher pressed a key to begin the first habituation trial when she determined that the infant was looking at the center of the screen. During each trial, the habituation face was presented for up to 15 seconds. The researcher used key presses to indicate when the infant was looking at the center of the screen or looking away from the screen. If the infant had multiple short (i.e., < 1000 ms) looks away from the screen over the course of the trial, the computer program computed the infant's cumulative looking over the entire trial. Trials ended when the infant's cumulative look duration exceeded 15 seconds or when the infant looked away for more than 1000 ms.

The habituation criterion was based on a sliding window design. Habituation was achieved when the infant's average look duration over three consecutive trials was less than 50% of the average look duration for the first four trials of the experiment. Infants had a maximum of 21 trials to reach habituation. The program advanced to the second attention-getting stimulus once infants successfully habituated or reached the maximum number of trials. This attention-getter remained on screen for 15 seconds in order to re-engage the infant's attention.

The experimenter pressed a key to begin the test phase when she determined that the infant was looking at the center of the screen. There were six test trials (3 habituation face, 3 novel face), with only one of the two faces presented in any single trial. The order of face presentation was randomized across infants. During each trial, the experimenter indicated when the infant was looking at the screen versus looking away from the screen. Trials lasted up to 10 seconds or until the infant looked away for more than 800 ms. If the infant had multiple short (i.e., < 800 ms) looks away over the course of the trial, the program computed the infant's cumulative duration of looking for the entire trial. The original attention-getting stimulus was presented after every trial in order to re-orient the infant's attention to the center of the screen.

Data Coding and Processing. All test trials were hand-coded to determine the amount of time each infant spent looking at the novel and familiar faces. The coded data were then used to compute the infant's mean look duration across the three novel face test trials, their mean look duration across the three familiar face test trials, as well as their mean look duration across all six of the test trials. In addition, a looking time difference score was calculated by subtracting the infant's mean look duration to the familiar face from the mean look duration to the novel face (Novel LT – Familiar LT). This difference score quantified the extent to which the infant dishabituated to the novel face, as well as the infant's preference for either the novel or familiar face. Positive difference scores reflect longer looking times to the novel face (i.e., novelty preference) while negative difference scores reflect longer looking times to the familiar face (i.e., familiarity preference). The absolute value of this difference score quantified the extent

of discrimination between the faces without taking the infant's novelty/familiarity preference into account.

Infant Behavior Questionnaire. The revised version of the Infant Behavior Questionnaire (Gartstein & Rothbart, 2003) was sent to parents at the time of recruitment (typically 1 – 2 weeks prior to their first appointment). Parents completed the questionnaire on their own time and returned it at the first test session. The questionnaire asks parents to use a 1 – 7 (never – always) scale to rate the frequency of specific behaviors displayed by their infants over the week prior to the time the questionnaire was completed. Parents' responses were scored using a template provided with the questionnaire. The IBQ-R includes 15 temperament dimensions: Activity Level, Distress to Limitations, Fear, Duration of Orienting, Smiling & Laughter, High-Intensity Pleasure, Low-Intensity Pleasure, Soothability, Falling Reactivity, Cuddliness, Perceptual Sensitivity, Sadness, Approach, and Vocal Reactivity. For the purposes of this study, only the Smiling & Laughter and Approach dimensions were examined. These dimensions are defined as "smiling or laughter from the child in general caretaking and play situations" and "rapid approach, excitement, and positive anticipation of pleasurable activities," respectively.

Results

Analysis Plan

Data from the motor approach task, the dishabituation to faces task, and the Infant Behavior Questionnaire were analyzed both categorically and as continuous variables. For the categorical analyses, infants were grouped based on whether they showed

significant orienting or reaction time effects during the spatial cueing task. The criterion for identifying these categories was the same as described in the previous chapters. Infants were considered to show a significant effect if their scores on the orienting or reaction measures were greater than one standard error above chance. Facilitation of orienting and reaction times during the short-delay trials were considered separately from inhibition of return effects on orienting and reaction times, since data from Study 2A suggest that these effects are independent of each other. For the continuous analyses, infants' reaction time difference scores during short-delay trials were reverse-scored for ease of interpretation.

Approach Latency

Task Completion. All infants completed all four of the motor approach trials. However, data from three infants could not be coded due to technical errors with the recording equipment. An additional five infants were excluded because they had especially long latency values (i.e., > 3 standard deviations above the group mean) for at least one approach trial. All analyses of approach latencies were based on the remaining sample of 66 infants.

As discussed in the previous chapter, not all infants provided usable spatial cueing data from Session 1. Of the sample of 66 infants described above, 5 infants did not provide usable data for any of the spatial cueing measures. An additional 3 infants did not provide data for the reaction time measure during long-delay trials. Thus, analyses concerning both spatial cueing performance and approach latencies were based on a final

sample of 61 infants, except for analyses involving the reaction time measure from long-delay trials, which was based on a final sample of 58 infants.

Overall group performance. All approach latency values were square root transformed to account for substantial positive skew in the distribution. Infants' latencies to approach the novel and typical toys are presented in Figure 4.2. Paired t-tests indicated that as a group, infants were faster to approach the novel toys (M = 40.48 ms, SD = 14.12 ms) compared to the typical toys (M = 46.08 ms, SD = 17.24 ms; $t(65) = 2.571$, p = 0.012). In addition, a repeated-measures ANOVA indicated that there were significant differences in approach latencies for the individual toys (Greenhouse-Geisser correction, $F(2.59, 168.35) = 4.962$, $p = 0.004$). Post-hoc paired comparisons revealed that infants were significantly faster to approach the Pop-Shaker (a novel toy; M= 36.52 ms, SD = 1.81 ms) compared to all other toys (M_{Ball} = 41.85 ms, SD = 2.25 ms, $t(65) = 2.279$, p = 0.026; M_{Bell} = 47.24 ms, SD = 2.83 ms, $t(65) = 3.66$, $p = 0.001$; M_{Bag} = 42.41 ms, SD = 2.24 ms, $t(65) = 2.736$, $p = 0.008$). There were no other significant differences in approach latencies across individual toys, suggesting that the overall difference in approach to novel versus typical toys was likely driven by infants' faster approach to the Pop-Shaker.

On a descriptive level, of the two typical toys, infants were slower to approach the Bell; of the two novel toys, infants were faster to approach the Pop-Shaker, suggesting that the Pop-Shaker was the optimal novel toy. An Approach to Novelty Bias score was generated in order to assess the extent to which individual infants' responses to the toys

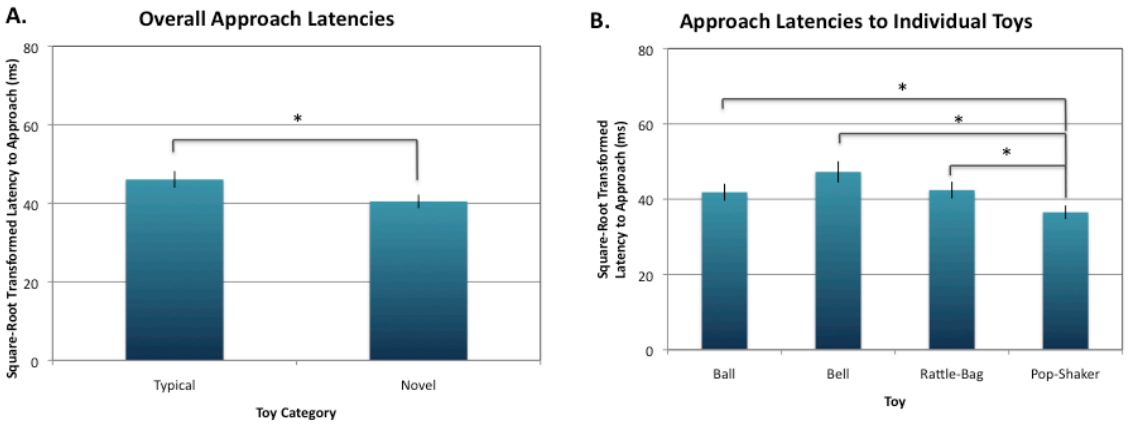


Figure 4.2. Mean approach latencies to (A) typical vs. novel stimuli categories and (B) individual toys.

were similar regardless of novelty, or if they were biased to specifically respond rapidly to novel stimuli. This score was computed by subtracting infants' approach latencies to the optimal novel toy (i.e., the Pop-Shaker) from their approach latencies to the least stimulating toy overall (i.e., the Bell). Infants with negative Approach to Novelty Bias scores were considered to preferentially approach the typical toys. In contrast, infants with positive Approach to Novelty Bias scores were considered to preferentially approach the novel toys, since their rapid responses were specifically elicited by the Pop-Shaker. Forty-four infants (66.7%) showed preferential approach to the novel toy and 21 infants (31.8%) showed preferential approach to the typical toy, reflecting a significant bias towards novelty among the overall sample ($\chi^2(1,N = 65) = 8.138$, $p = 0.004$). One infant (1.5%) had identical approach latencies to the Bell and the Pop-Shaker.

Spatial cueing effects. ***Categorical analyses.*** *Facilitation of orienting (short-delay trials).* Thirty-one infants showed a significant bias of orienting to the cued location during short-delay trials of the spatial cueing task while 30 infants did not. Mean approach latencies to the novel and typical toys were entered into a 2 x 2 mixed-model ANOVA with facilitation of orienting as the between subjects factor and toy category as the within-subjects factor. Results indicated a significant main effect of toy category ($F(1,59) = 6.059$, $p = 0.017$) with faster approach latencies to the novel toys ($M = 40.48$ ms, $SD = 14.12$ ms) than the typical toys ($M = 46.08$ ms, $SD = 17.24$ ms). There was no main effect of facilitation of orienting ($F(1,326) = 0.527$, $p = 0.471$); however, there was a significant toy category x facilitation interaction ($F(1, 59) = 8.088$, $p = 0.006$). Follow-up group comparisons indicated that infants who showed significant facilitation of

orienting during the spatial cueing task were faster to approach the novel toys (M = 35.49 ms, SD = 12.58 ms) compared to infants who did not show the facilitative cueing effect on orienting (M = 44.17 ms, SD = 14.15 ms; $t(59) = 2.536$, $p = 0.014$). In addition, follow-up paired comparisons indicated that infants who showed significant facilitation of orienting had faster mean approach latencies to the novel toys (M = 35.49 ms, SD = 12.57 ms) than to the typical toys (M = 47.25 ms, SD = 18.28; $t(30) = 3.157$, $p = 0.004$). This group also included a significant distribution of infants who were biased to rapidly approach the optimal novel toy (21 biased to novel toy versus 9 biased to typical toy; $\chi^2(1,N = 30) = 4.8$, $p = 0.028$). Infants who did not show significant orienting effects during the spatial cueing task showed no difference in mean approach latencies to the novel (M = 44.17 ms, SD = 14.15 ms) and typical toys (M = 43.32 ms, SD = 16.11 ms; $t(29) = -0.362$, $p = 0.720$). In addition, this group of infants showed a chance-level distribution of infants who were biased to rapidly approach the optimal novel toy (19 biased to novel toy vs. 11 biased to typical toy; $\chi^2(1,N = 30) = 2.133$, $p = 0.144$).

Facilitation of reaction time (short-delay trials). During the Session 1 spatial cueing task, 42 infants showed a significant reaction time benefit for targets appearing in the cued location during the spatial cueing task while 19 infants did not. Again, there was a main effect of toy category ($F(1,59) = 7.962$, $p = 0.006$) among these infants, with faster responses to the novel toys (M = 40.48 ms, SD = 14.12 ms) than the typical toys (M = 46.08 ms, SD = 17.24 ms). In addition, there was a nearly significant main effect of facilitation of reaction time ($F(1,59) = 3.693$, $p = 0.059$), as infants who showed facilitation of reaction time were faster to approach the *typical* toys (M = 42.03 ms, SD =

15.53 ms) compared to infants who did not show facilitated reaction times (M = 52.6 ms, SD = 18.92 ms).

Though the interaction term did not reach significance, the pattern of within-group results was informative. Among the infants who showed significant facilitation of reaction time during the cueing task, there was no difference in approach latencies to the novel (M = 38.93 ms, SD = 14.3 ms) versus typical toys (M = 42.03 ms, SD = 15.53 ms; $t(41) = 0.151$, $p = 0.256$). In contrast, infants who did not show a significant facilitation effect on reaction time were significantly faster to approach the novel toys (mean = 41.58 ms, SD = 13.39 ms) compared to the typical toys (M = 52.6 ms, SD = 18.92 ms; $t(18) = 2.463$, $p = 0.024$). Both groups of infants showed a trend or a significant distribution of infants who were classified as biased to approach novelty (Facilitation of RT: 26 biased to novelty vs. 15 biased to typical, $\chi^2(1,N = 41) = 2.951$, p = 0.086; no RT effect: 14 biased to novelty vs. 5 biased to typical, $\chi^2(1,N = 19) = 4.263$, $p = 0.039$).

Inhibition of return effects on orienting (long-delay trials). Results of a mixed-model ANOVA with toy category and IOR orienting effect factors indicated that there was a significant main effect of toy category ($F(1,59) = 4.292$, $p = 0.043$). Again, infants were faster overall to approach the novel toys (M = 40.48 ms, SD = 14.12 ms) than the typical toys (M = 46.08 ms, SD = 17.24 ms). The results revealed no differences in approach latencies across infants who showed inhibitory cueing effects on orienting (n = 42) and those who did not (n=19; $F(1,59) = 0.522$, $p = 0.473$). The interaction term was not significant ($F(1,59) = 0.087$, $p = 0.77$); however, once again the results of within-group comparisons were informative. In particular, infants who showed inhibitory

orienting effects during the spatial cueing task were faster to approach the novel toys compared to the typical toys (M_{Novel} = 38.73 ms, *SD* = 13.24 ms, $M_{Typical}$ = 44.76 ms, *SD* = 17.7 ms; $t(41) = 2.036$, $p = 0.048$). Those who did not show IOR effects on orienting were equally fast to approach the novel and typical toys (M_{Novel} = 42.03 ms, *SD* = 15.58 ms, $M_{Typical}$ = 46.56 ms, *SD* = 16.52 ms, $t(18) = 1.186$, $p = 0.251$). Infants in both groups were more likely to be identified as biased to rapidly approach the novel toy (IOR orienting effect: 25 vs. 12, $\chi^2(1,N = 42) = 4.568$, $p = 0.033$; no orienting effect: 12 vs. 4, $\chi^2(1,N = 19) = 4.0$, $p = 0.046$).

Inhibition of return effects on reaction time. A final mixed-model ANOVA included IOR reaction time effects as the between-subjects factor and toy category as the within-subjects factor. Again, there was a significant main effect of toy category ($F(1,56) = 5.296$, $p = 0.025$), with faster approach latencies to the novel toys (*M* = 40.48 ms, *SD* = 14.12 ms) than the typical toys (*M* = 46.08, *SD* = 17.24 ms). There were no overall differences in approach latencies for infants who showed IOR effects on reaction time (n = 35) compared to those who did not (n = 23).

Again, though the interaction between toy category and inhibitory reaction time effects was not significant ($F(1,56) = 1.266$, $p = 0.265$), the within-subject comparisons were revealing. Infants who showed IOR effects on reaction time showed faster approach latencies to the novel toys (*M* = 38.66 ms, *SD* = 13.39 ms) than the typical toys (*M* = 47.15 ms, *SD* = 19.31 ms; $t(34) = 2.417$, $p = 0.021$). This group also included a significant number of infants who were identified as biased to approach the novel toys (26 vs. 6 biased to approach typical, $\chi^2(1,N = 35) = 12.5$, $p < 0.001$). In contrast, infants

who did not show IOR effects on reaction time during the spatial cueing task showed no difference in approach latencies to the novel (M = 41.37 ms, SD = 15.55 ms) versus typical toys (M = 44.29 ms, SD = 13.83; $t(22) = 0.988$, $p = 0.334$). Furthermore, this group consisted of a chance-level distribution of infants who showed approach biases to the novel versus typical toys (11 vs. 7, respectively; $\chi^2(1,N = 23) = 0.889$, $p = 0.346$).

Continuous analyses. *Facilitation (short-delay trials).* Infants' proportions of orienting to the cued location during short-delay trials were negatively correlated with overall mean latencies to approach the novel toys (r = -0.247, $p = 0.055$) and latencies to approach the Bag (r = -0.262, $p = 0.041$). Thus, infants who were more likely to orient to the cued location following a short delay were also faster to approach novel toys, particularly the Bag. No other approach variables were significantly correlated with either the orienting or reaction time measures of facilitation.

Inhibition of return (long-delay trials). Infants' proportions of orienting to the non-cued location during long-delay trials were not correlated with any of the approach measures. However, infants' mean reaction time difference scores were significantly negatively correlated with mean approach latencies to the novel toys (r = -0.258, $p = 0.051$) and with approach latencies to the Pop-Shaker (r = -0.353, $p = 0.007$). These results indicate that infants who showed a larger IOR effect on reaction time were faster to approach the novel toys, and the Pop-Shaker in particular. In addition, infants' mean reaction time difference scores were highly correlated with their Approach to Novelty Bias scores (Figure 4.4; r = 0.388, $p = 0.003$). This positive relationship indicates that stronger IOR

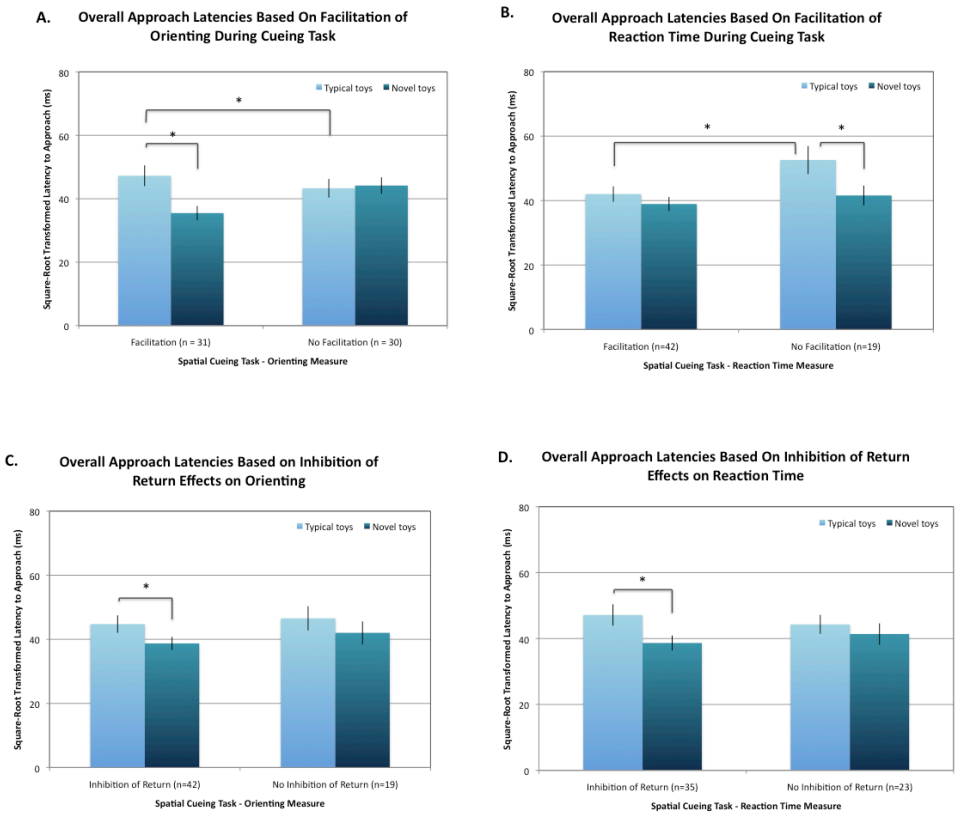


Figure 4.3. Latency to approach the typical vs. novel toys for infants who did/did not show (A) facilitation of orienting, (B) facilitation of reaction time, (C) IOR effects on orienting, and (D) IOR effects on reaction time.

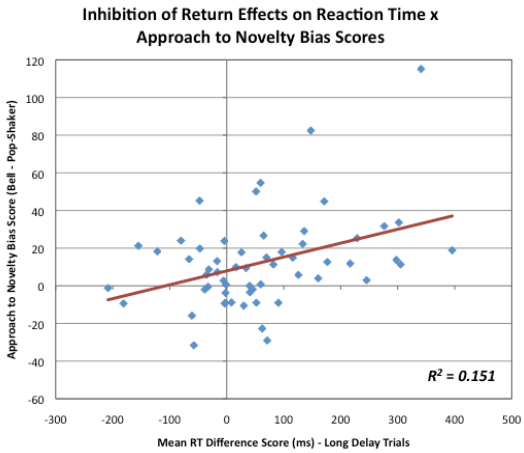


Figure 4.4. Relationship between the extent of IOR effects on reaction time and infants' Approach to Novelty Bias scores

effects on reaction time were associated with an increasing bias to approach the optimal novel toy.

Summary. In sum, infants who showed facilitative cueing effects on orienting were faster to approach novel toys compared to those who did not show these effects. In addition, these infants were faster to approach the novel toys compared to the typical toys, and were likely to be biased to rapidly approach the optimal novel toy. Infants who showed facilitative cueing effects on reaction time had faster approach latencies for the two typical toys compared to those who did not show these reaction time effects. However, infants who showed reaction time effects during spatial cueing showed no difference in approach latencies to the novel and typical toys, suggesting that these infants showed rapid approach behaviors in general, rather than specifically in response to novel stimuli.

With respect to inhibition of return, infants who showed inhibitory cueing effects showed approach latencies that reflected a heightened sensitivity to the novel toys. Specifically, the extent of inhibition of return effects on infants' reaction times was related to infants' preferential approach to the optimal novel toy (i.e., the Pop-Shaker). Furthermore, infants who showed IOR reaction time effects were faster to approach the optimal novel toy compared to infants who did not show similar cueing effects. Infants who showed IOR effects on reaction time, as well as those who showed orienting effects, were faster to approach the novel toys compared to the typical toys. In contrast, infants who did not show these cueing effects showed no differences in approach latencies to the novel and typical toys. Finally, infants who did show IOR effects were significantly more

likely to be identified as being biased to rapidly approach the optimal novel toy, whereas infants who did not show these effects were equally divided between approach biases towards the novel toy versus approach biases towards the typical toy.

Dishabituation to Novel Faces.

Task Completion. Nine infants became fussy during testing and did not complete the entire task. Of the remaining sample, 7 infants were excluded because they failed to habituate within the criterion of 21 trials. An additional 3 infants were excluded due to technical errors and one infant did not complete the task because her mother became ill during testing. Thus, all analyses involving data from this task were based on a sample of 54 infants.

In addition to these exclusions, 2 infants did not provide usable data for any of the spatial cueing measures. An additional 3 infants had missing data for the reaction time measure during long-delay trials. Thus, analyses considering both spatial cueing data and dishabituation to faces data were based on a sample of 51 infants; analyses specific to IOR effects on reaction time were based on a sample of 48 infants.

Overall group performance. On average, infants required 12.8 trials (SD = 5.1 trials) and an overall exposure time of 90.72 s (SD = 0.005 s) to reach the habituation criterion. The mean duration of infants' initial look during habituation was 10.96 s (SD = 3.43 s) and their overall mean look duration during habituation was 6.91 s (SD = 2.32 s). At test, infants showed a significant preference for the novel face ($M_{LookTime}$ = 5.23 s, SD = 1.96 s) compared to the familiar face ($M_{LookTime}$ = 4.48 s, SD = 2.08 s; $t(53) = 2.714$, p = 0.009). In addition, individual infants' Novel – Familiar faces difference scores indicated

that a significant number of infants preferred the novel face over the familiar face (36 vs. 18; $\chi^2(1,N = 54) = 6.0$, $p = 0.014$).

Infants' experiences during the habituation phase were related to their looking behaviors at test. Specifically, the number of trials needed to reach habituation criterion was marginally correlated with infants' mean duration of looking during test trials ($r = 0.218$, $p = 0.113$) and significantly positively correlated with their mean duration of looking to the novel face ($r = 0.281$, $p = 0.039$), as well as with the extent to which they discriminated between the novel and familiar faces (i.e., absolute Novel – Familiar difference score; $r = 0.287$, $p = 0.035$). The same measures were also positively correlated with the total exposure time required to reach habituation criterion (mean look duration: $r = 0.286$, $p = 0.036$; mean looking to novel: $r = 0.341$, $p = 0.012$; discrimination: $r = 0.341$, $p = 0.012$). Thus, infants who experienced a more prolonged habituation phase showed longer looks at test, particularly to the novel face, and enhanced discrimination between the novel and familiar faces.

Spatial cueing effects. ***Categorical analyses.*** *Facilitation of orienting (short-delay trials).* Of the current sample, 23 infants showed significant facilitation of orienting to the cued location, while 28 infants did not show a significant orienting effect. There were no differences in habituation measures across these two groups. However, infants mean look durations at test were marginally different across these groups, with shorter look among infants who showed facilitated orienting ($M_{LookTime}$ = 4.4 s, SD = 1.65 s) compared to infants who did not show facilitation of orienting ($M_{LookTime}$ = 5.21 s, SD = 1.77 s; $t(49) = 1.682$, $p = 0.099$). A similar group difference was evident for infants' mean

look durations to the familiar test face (Facilitation of orienting: $M_{LookTime}$ = 3.84 s, *SD* = 1.61 s, No orienting effect: $M_{LookTime}$ = 5.1 s, *SD* = 2.26 s; $t(38.82) = 2.162$, $p = 0.037$).

Within-group comparisons indicated that infants who showed facilitation of orienting during the spatial cueing task spent more time looking at the novel face ($M_{LookTime}$ = 4.96 s, *SD* = 2.13 s) than the familiar face ($M_{LookTime}$ = 3.84 s, *SD* = 1.61 s; $t(27) = 3.198$, $p = 0.004$). In addition, this group included a significant number of infants who preferred the novel face (21 vs. 7; $\chi^2(1,N = 28) = 7.0$, $p = 0.008$). In contrast, infants who did not show facilitation of orienting did not discriminate between the two faces (novel face: $M_{LookTime}$ = 5.36 s, *SD* = 1.8 s; familiar face: $M_{LookTime}$ = 5.05 s, *SD* = 2.25 s; $t(22) = 0.741$, $p = 0.467$) and individual infants' preferences for the novel and familiar faces were distributed at chance levels in this group (13 vs. 10; $\chi^2(1,N = 23) = 0.391$, $p = 0.532$).

Facilitation of reaction time (short-delay trials). There were no group differences in habituation or test measures across infants who showed facilitation of reaction time during the cueing task (n = 36) and those who did not (n = 28). However, within-group comparisons indicated that infants who showed facilitated reaction times spent more time looking at the novel face ($M_{LookTime}$ = 5.23 s, *SD* = 2.08 s) compared to the familiar face ($M_{LookTime}$ = 4.45 s, *SD* = 2.12 s; $t(35) = 2.426$, $p = 0.021$). In addition, a significant proportion of these infants preferred the novel face (26 vs. 10; $\chi^2(1,N = 36) = 7.11$, $p = 0.008$). Infants who did not show a facilitation effect on reaction time did not discriminate between the two test faces (novel face: $M_{LookTime}$ = 4.94 s, *SD* = 4.23 s; familiar face: $M_{LookTime}$ = 4.23 s, *SD* = 1.74 s; $t(14) = 1.301$, $p = 0.214$). This group

included equal numbers of infants who preferred the novel and familiar faces (8 vs. 7; $\chi^2(1,N = 15) = 0.067$, $p = 0.796$).

Inhibition of return effects on orienting. Infants who showed significant inhibitory effects on orienting (n = 35) required less total exposure time to reach habituation (M = 81.73 s, SD = 44.33 s) compared to those who did not show IOR effects on orienting (n = 16; M = 109.63 s, SD = 70.44 s; $t(49) = 1.722$, $p = 0.09$). In addition, these infants also showed a trend for significantly lower discrimination scores, regardless of preference (i.e., absolute Novel-Familiar difference score; M = 1.56 s, SD = 0.92 s) relative to infants who did not show an IOR orienting effect (M = 2.25 s, SD = 1.31 s; $t(21.97) = 1.917$, $p = 0.068$).

Within-group comparisons indicated that infants who showed an IOR effect on orienting spent more time looking at the novel face ($M_{LookTime}$ = 5.03 s, SD = 2.01 s) than the familiar face ($M_{LookTime}$ = 4.42 s, SD = 1.89 s; $t(34) = 2.071$, $p = 0.046$). This group consisted of a marginally significant proportion of infants who preferred the novel face (23 preferred novel face vs. 12 preferred familiar face; $\chi^2(1,N = 35) = 3.457$, $p = 0.067$). Infants who did not show IOR orienting effects also showed a trend for longer looking to the novel face ($M_{LookTime}$ = 5.4 s, SD = 1.94 s) compared to the familiar face ($M_{LookTime}$ = 4.3 s, SD = 2.42 s; $t(15) = 1.807$, $p = 0.091$). However, individual infants in this group were equally distributed across preferences for the novel and familiar faces (11 vs. 5, respectively; $\chi^2(1,N = 16) = 2.225$, $p = 0.134$).

Inhibition of return effects on reaction time. The pattern of results changed dramatically among infants who showed inhibition of return effects on reaction time

during the spatial cueing task (n = 35). These infants showed a trend for significantly less discrimination between the novel and familiar faces ($M_{Novel - Familiar\ Difference}$ = 0.3 s, *SD* = 2.08 s) compared to infants who did not show an IOR effect on reaction time (n = 23; *M* = 1.27 s, *SD* = 1.76 s; $t(45) = 1.697$, $p = 0.096$). Furthermore, within-group comparisons revealed that infants who showed inhibitory effects on reaction time did not show any preferential looking to either the novel ($M_{LookTime}$ = 4.01 s, *SD* = 1.97 s) or familiar face ($M_{LookTime}$ = 4.51 s, *SD* = 2.21 s; $t(27) = 0.766$, $p = 0.451$). This group also consisted of an equal number of infants who preferred the novel and familiar faces (15 vs. 13, respectively; $\chi^2(1,N = 28) = 0.143$, $p = 0.705$). In contrast, infants who did not show IOR effects on reaction time demonstrated preferential looking to the novel face ($M_{LookTime}$ = 5.37 s, *SD* = 1.57 s) compared to the familiar face ($M_{LookTime}$ = 4.1 s, *SD* = 1.58 s; $t(19) = 3.226$, $p = 0.004$). Furthermore, a significant number of infants showed a preference for the novel face (16 vs. 4; $\chi^2(1,N = 20) = 7.2$, $p = 0.007$).

Continuous analyses. *Facilitation (short-delay trials).* Infants' proportions of orienting to the cued location during short-delay trials were negatively correlated with their average look duration at test ($r = -0.268$, $p = 0.057$) and their average duration of looking to the familiar face ($r = -0.326$, $p = 0.019$). Infants' reaction time difference scores from the short-delay trials of the spatial cueing task were not related to any of the measures obtained during the faces task.

Inhibition of return (long-delay trials). Infants' proportions of orienting to the non-cued location during long-delay trials of the spatial cueing task were not related to any of the measures obtained during the faces task. However, infants' reaction time

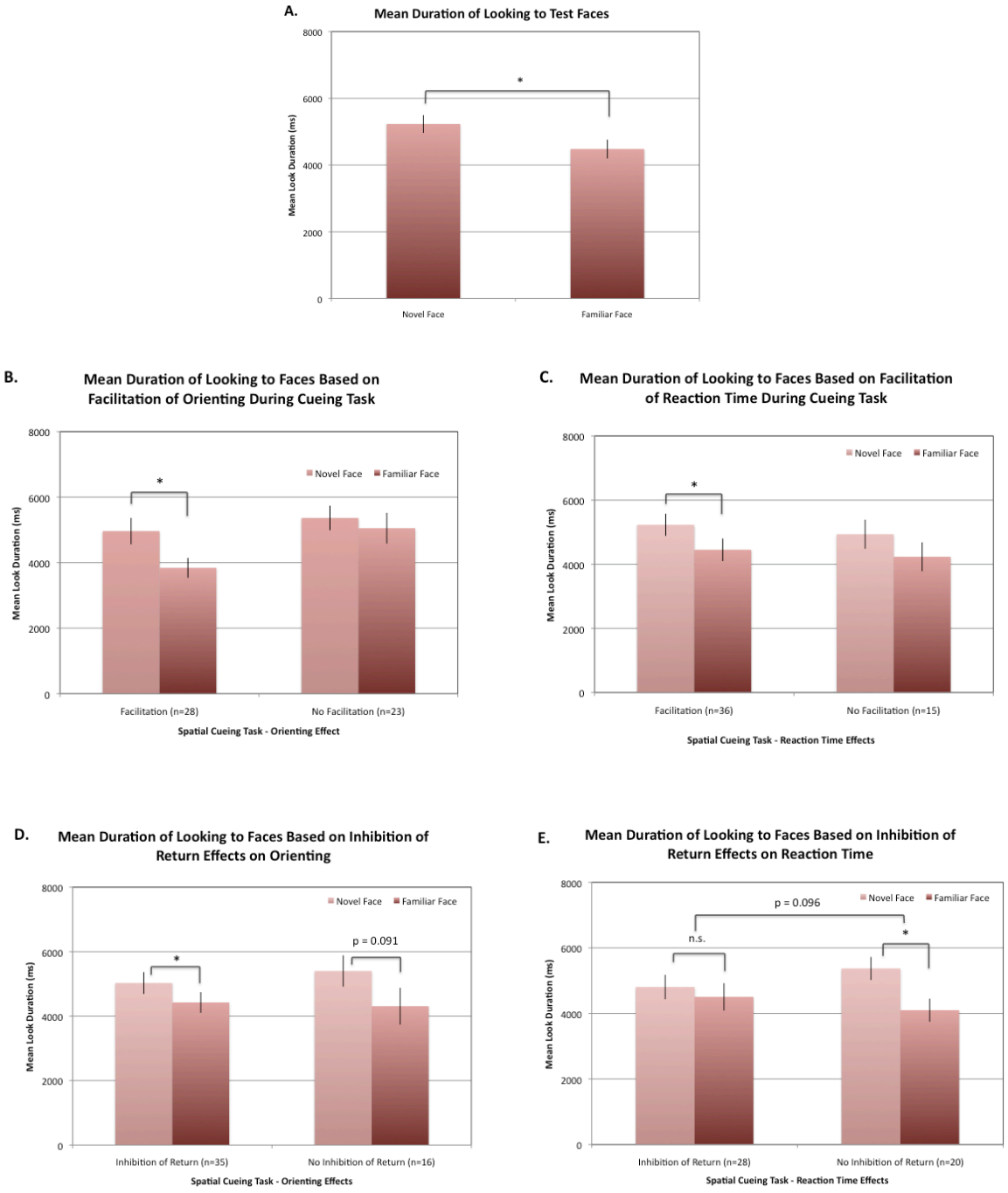


Figure 4.5. Mean duration of looking to the novel and familiar faces for (A) the overall sample, and infants who did/did not show (B) facilitation of orienting, (C) facilitation of reaction time, (D) IOR effects on orienting, and (E) IOR effects on reaction time.

difference scores from the long-delay trials were negatively correlated with the number of trials required to reach habituation criterion (r = -0.292, p = 0.044). In addition, these reaction time scores were nearly significantly negatively correlated with their dishabituation to novelty (Novel-Familiar difference) scores (r = -0.275, p = 0.058). This negative relationship indicates that infants who showed stronger IOR effects on reaction time dishabituated to the novel face to a lesser extent.

Summary. The relationship between facilitative effects during the spatial cueing task and infants' behavior during the faces task were consistent across the proportion of orienting and reaction time measures. Specifically, infants who showed facilitation of orienting or reaction time during the cueing task also showed significant looking preferences for the novel face compared to the familiar face. In addition, individual infants in both of these groups were more likely to show a novelty preference than a familiarity preference. In contrast, infants who did not show facilitation of orienting or reaction time during the spatial cueing task showed no evidence of discrimination between the two faces, and were equally distributed across novelty and familiarity preferences.

Similar results were seen among infants who showed inhibition of return effects on orienting during the spatial cueing task. These infants spent more time looking at the novel face than the familiar face and were more likely to be identified as preferring the novel face instead of the familiar face. Infants who did not show IOR orienting effects also showed a trend-level looking preference for the novel face, though equal numbers of individual infants showed novelty and familiarity preferences.

A unique pattern of results was observed among infants who showed inhibition of return effects on reaction time during the spatial cueing task. These infants dishabituated to the novel face to a lesser extent than infants who did not show the inhibitory reaction time effects. Furthermore, these infants showed no evidence of discrimination between the novel and familiar faces and were equally likely to show novelty and familiarity preferences. In contrast, the infants who did not show IOR effects on reaction time did show a significant looking preference to the novel face, and individual infants in this group were more likely to show a novelty preference rather than a familiarity preference. Thus, the relationship between inhibition of return effects on reaction time and performance on the faces task was opposite to the patterns observed for the other cueing effects.

Infant Behavior Questionnaire

Missing data. IBQ scores were not available for 4 infants because their parents were unable to complete the questionnaire in a timely manner. All analyses involving IBQ scores were based on a sample of 70 infants. Of this sample, 5 infants did not provide usable data for any of the spatial cueing measures and an additional 3 infants did not provide usable data for the reaction time measure during long-delay trials. Thus, analyses concerning IBQ scores and spatial cueing effects were based on a sample of 65 infants; analyses specifically addressing the relationship between IBQ scores and reaction time benefits during long-delay trials were based on a sample of 62 infants.

Descriptive statistics. IBQ scores for both dimensions were based on a scale of 1 (behavior never evident) to 7 (behavior always evident). Infants' mean score on the

Smiling & Laughter dimension was 4.55 (*SD* = 0.97, range = 2.33 – 6.8). Infants' mean score on the Approach dimension was 4.42 (*SD* = 0.45, range = 3.38 – 5.73). Infants' ages at the first test session were positively correlated with their scores on the Approach dimension ($r = 0.381$, $p = 0.001$). As such, age at Session 1 was used as a covariate for all analyses involving infants' scores on the Approach dimension. Age was not related to scores on the Smiling & Laughter dimension.

Spatial cueing effects. ***Group analyses.*** *Facilitation (short-delay trials).* There were no differences in Smiling & Laughter scores across infants who showed significant facilitation of orienting during the spatial cueing task and those who did not. A similar null effect was seen for infants who showed facilitation of reaction time versus those who did not. In addition, after controlling for age at Session 1, there were no differences in Approach scores across infants who showed significant facilitation effects (i.e., orienting or reaction time) and those who did not.

Inhibition of return (long-delay trials). Infants who showed significant inhibition of return effects on orienting received higher scores on the Approach dimension (*M* = 4.49, *SD* = 0.47) compared to infants who did not show these orienting effects (*M* = 4.22, *SD* = 0.40), even after controlling for age at Session 1 ($F(1,62) = 4.395$, $p = 0.04$). There were no differences in Smiling & Laughter scores across these two groups. In addition, there were no differences in ratings for the Smiling & Laughter or Approach dimensions across infants who showed IOR effects on reaction time versus those who did not.

Continuous analyses. *Facilitation (short-delay trials).* There were no significant correlations between infants' proportion of orienting to the cued location and the two

IBQ dimensions. Similarly, the extent of facilitation on reaction time was not related to either IBQ dimension.

Inhibition of return (long-delay trials). Infants' proportions of orienting to the non-cued location during long-delay trials were not related to their scores either the Smiling & Laughter or Approach dimensions. Similarly, the extent of inhibitory effects on reaction time measure was not related to either IBQ dimension.

Summary. The analyses of infants' IBQ scores yielded few significant effects. The Smiling & Laughter dimension was not related to any of the measures obtained during the spatial cueing task. However, the infants' ratings on the Approach dimension varied depending on whether they had shown significant IOR effects on orienting during the spatial cueing task. Overall, these results provide little evidence that infants' sensitivity to the effects of spatial cueing is related to increasing tendencies to approach engaging objects or events.

Relationships Across Measures of Novelty

Approach task – Dishabituation to novelty task. There were no significant relationships between any of the approach latency variables and the habituation measures obtained during the faces task[2]. However, several of the measures obtained during the test phase of the faces task were related to infants' behaviors during the approach task (see Figure 4.7). In particular, there was a significant correlation between infants' mean duration of looking to the novel face and their latencies to approach the Pop-Shaker (r =

[2] Results indicated a trend-level association between infants' latencies to approach the Bag and the duration of their first look during habituation (r = -0.261, p = 0.073).

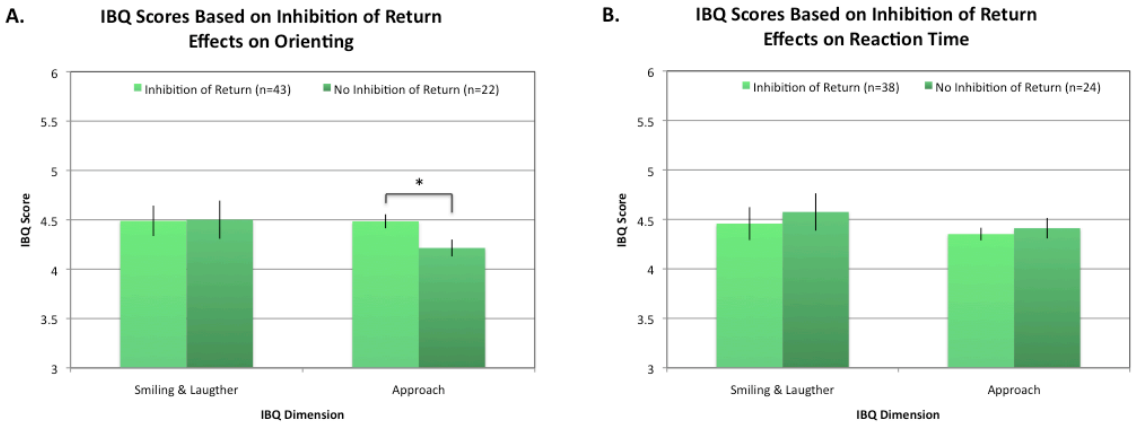


Figure 4.6. IBQ ratings of Smiling & Laughter and Approach behaviors for infants who did/did not show (A) IOR effects on orienting, and (B) IOR effects on reaction time.

0.288, $p = 0.047$). Similarly, the extent to which infants dishabituated to the novel face was related to their average approach latencies to the novel toys ($r = 0.296$, $p = 0.041$) and their approach latencies to the Pop-Shaker ($r = 0.281$, $p = 0.053$)[3]. These positive relationships indicate that infants who showed a larger preference for the novel face were *slower* to approach the novel toys overall, and the Pop-Shaker in particular. Finally, infants' Approach to Novelty Bias scores were negatively correlated with both their overall duration of looking to the novel face ($r = -0.296$, $p = 0.041$) and the extent of dishabituation to the novel face ($r = -0.269$, $p = 0.065$). These negative relationships indicate that infants who showed a larger approach bias towards the optimal novel toy spent *less* time looking at the novel face overall and showed less discrimination between the novel and familiar faces.

Approach task – IBQ ratings. There were no significant correlations between any of the approach latency variables and infants' scores on the Smiling & Laughter dimension of the IBQ. Furthermore, after controlling for age at Session 1, there were no significant relationships between infants' scores on the Approach dimension and their performance during the motor approach task.

Dishabituation to novelty task – IBQ ratings. There were no significant correlations between the habituation measures obtained during the faces task and infants' scores on the IBQ dimensions of Smiling & Laughter or Approach. However, after controlling for age, infants' scores on the Approach dimension were related to their duration of looking to the familiar face ($r = 0.297$, $p = 0.038$) and marginally related to

[3] Results also indicated trend level associations between infants' latencies to approach the Ball and their mean look duration at test ($r = 0.267$, $p = 0.066$), as well as their duration of looking to the novel face ($r = 0.257$, $p = 0.078$).

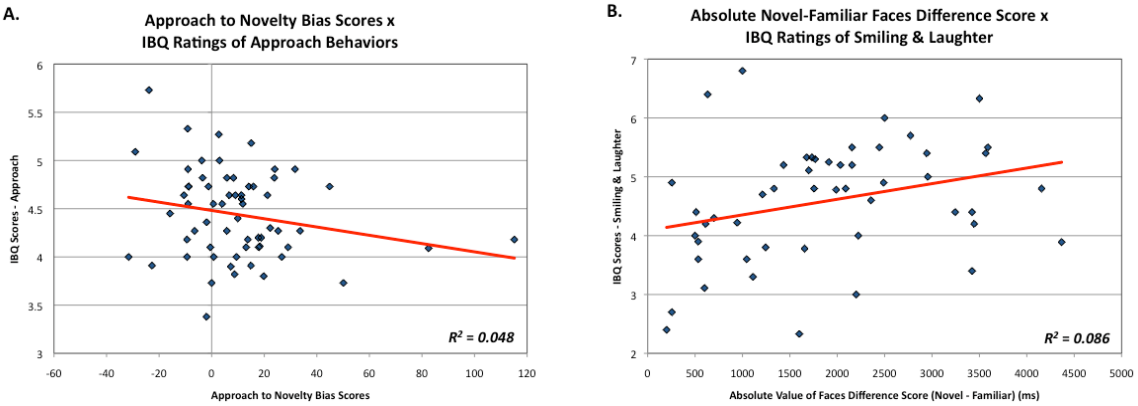


Figure 4.7. Relationship between behavior on the motor approach and dishabituation to novelty measures. Preferential looking to the novel face was related to (A) latency to approach the optimal novel toy and (B) Approach to Novelty bias scores.

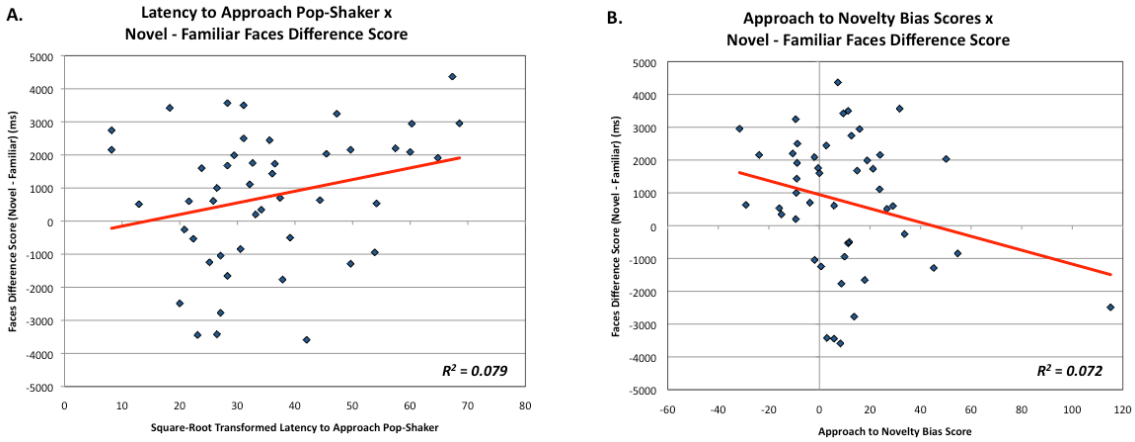


Figure 4.8. Relationships between (A) infants' Approach to Novelty bias scores and IBQ ratings of approach behaviors, and (B) the magnitude of infants' discrimination between the novel and familiar faces and IBQ ratings of positive affect.

their overall mean look durations at test ($r = 0.249$, $p = 0.084$). These positive relationships indicate that infants who were rated as showing more approach behaviors in daily life tended to spend more time looking at the test faces, and the familiar face in particular. In addition, infants' scores on the Smiling & Laughter dimension were significantly correlated with extent of discrimination between the novel and familiar faces, regardless of preference (e.g., absolute value of the Novel – Familiar difference score; $r = 0.294$, $p = 0.038$). This result suggests that infants who showed greater discrimination between the faces were also rated as demonstrating more positive affect during everyday situations.

Discussion

The results of Study 2B revealed intriguing relationships between infants' performance on the spatial cueing task and their patterns of responding to novel information. Infants who showed facilitative effects of cueing on orienting or reaction tended to be faster to approach toys during the free play task compared to infants who did not show these facilitation effects. More specifically, infants who showed facilitation of reaction time during the cueing task were faster to approach the toys overall, regardless of whether the toys were in the typical or novel categories, and also showed a preference for the novel face during the dishabituation task.

Infants who showed inhibition of return effects on orienting during the spatial cueing task tended to show responses to novelty that were similar to those seen among infants who showed facilitation effects. Specifically, these infants showed a preference for the novel face during the dishabituation task and received relatively higher scores on

the Approach dimension of the Infant Behavior Questionnaire. However, infants who showed IOR effects on reaction time during the spatial cueing task showed markedly different patterns of responding to novelty. Though these infants did not show overall faster approach latencies during the free play task, they were specifically faster to approach the novel toys, and the optimal novel toy in particular. In addition, the extent of inhibitory cueing effects on infants' reaction time was associated with the extent to which infants showed a rapid approach bias towards the optimal novel toy. However, these infants did not show a preference for the novel face during the dishabituation task and more specifically, did not show *any* significant discrimination between the novel and familiar faces. Finally, Smiling & Laughter and Approach ratings were equivalent across infants who showed IOR effects on reaction time and those who did not.

Given the initial hypothesis that inhibition of return reflects an integrated system of biased responding to novelty, these findings initially seem completely contradictory. However, closer inspection of the results suggests that the three measures used in this study may tap into different aspects of responding to novelty. In particular, infants who showed larger preferences for the novel face in the dishabituation task were *slower* to approach the novel toys in the free play task, regardless of performance during the spatial cueing task. Similarly, infants who received higher ratings on the Approach dimension of the IBQ were also slower to approach the novel toys during the free play task. Finally, in contrast with previous reports (Rothbart, 1988; Rothbart, et al., 2000), infants' Smiling & Laughter ratings were not related to their approach latencies during the free play task,

though higher ratings on this dimension were associated with increased discrimination between the novel and familiar faces during the dishabituation task.

Taken together, these results imply that the expectation for consistency across these different measures of responding to novelty was likely mistaken. In particular, these results suggest that the processes mediating motor approach to novelty are dissociable from those mediating sustained attention to novelty. Previous reports have distinguished novelty preferences for objects and locations among young infants (Harman, et al., 1994; Posner, et al., 1997; Posner, et al., 1998). Furthermore, in her initial study utilizing the motor approach paradigm, Rothbart (1988) argued that it is important to examine the different components of approach behavior that may contribute to performance on the task. For example, some infants may be slow to reach for an object simply because their motor approach behaviors are typically slow. However, an infant's latency to grasp a new toy is necessarily influenced by the amount of time he or she devotes to visually investigating the object before initiating a motor response. Thus, the motor approach task taps into both the latency to approach the toy as well as the duration of sustained attention to the toy prior to approach (Rothbart, 1988).

The results of the current study are consistent with Rothbart's distinction between sustained attention and motor approach. In this study, the free play task was intended to measure motor reactivity to novelty while the faces dishabituation task measured sustained attention to novel versus familiar faces. Infants who preferentially attended to the novel face during the dishabituation task were slower to approach the novel toys during the free play task, suggesting that they may have spent more time studying the

toys before initiating a response. With respect to performance during the spatial cueing task, infants who demonstrated larger inhibition of return effects on reaction time were faster to initiate a motor response to the novel toys during the free play task, but showed no difference in sustained attention to the novel and familiar faces during the dishabituation task. Thus, overall, these results suggest that inhibition of return may indeed reflect a bias towards processing novel information; however, this bias may be primarily manifested through motor reactivity (e.g., orienting or reaching) rather than sustained attention to novelty.

Chapter 5
Study 2C: Contributions of Genetic Polymorphisms to Individual Differences in Spatial Cueing Effects

The results of Study 2 have shown that there is a high degree of individual variability in infants' responses during the spatial cueing task, both within a single session and across multiple sessions. As discussed in the previous chapter, some of this variation in reflexive attention, particularly with respect to inhibition of return effects, may be related to individual infants' propensities to approach and explore novel information. This variability in attention orienting can also be examined at a biological level by assessing how variations in the genetic regulation of neurotransmitter systems are related to infants' developing attention processes. Specifically, the efficacy of neurotransmission can be influenced by normal variations in genes that regulate protein production and ultimately affect receptor or enzyme levels in various neural systems. An emerging methodological approach known as "cognitive genetics" now allows scientists to directly examine the relationship between this normal genetic variation and individual differences in specific cognitive processes (Bellgrove & Mattingley, 2008, p. 200).

The complexity of the human attention system suggests that it is highly unlikely that variations in any single gene mediate individual variation in attention behaviors. Nonetheless, a number of candidate genes have been identified that appear to be related to different aspects of the attention system. Not surprisingly, these candidate genes regulate neurotransmitter systems that have previously been implicated in these component systems. A large body of work has shown that selective orienting of attention is dependent on a posterior network that involves parietal cortex, particularly the

intraparietal sulcus (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Parasuraman, Greenwood, Kumar, & Fossella, 2005; Posner & Petersen, 1990). This region is heavily innervated by cholinergic neurons (Everitt & Robbins, 1997; Parasuraman, et al., 2005) and shows dense expression of nicotinic-type acetylcholine receptors (nAchRs; Mentis, et al., 2001; Parasuraman & Espeseth, 2007; Parasuraman, et al., 2005). Furthermore, modulations of cholinergic input to this region directly influence the speed of orienting among non-human primates, (M. C. Davidson & Marrocco, 2000), as well as performance on spatial cueing tasks among humans (Greenwood, Lin, Sundararajan, Fryxell, & Parasuraman, 2009; Shirtcliff & Marrocco, 2003; Witte, Davidson, & Marrocco, 1997). Additionally, patients with mild Alzheimer's disease show a deficit in attention orienting that appears to be mediated by the degradation of cholinergic inputs to the parietal cortex (Parasuraman, Greenwood, Haxby, & Grady, 1992; Parasuraman, Greenwood, & Sunderland, 2002). Healthy individuals with the ApoE-ε4 gene, which is believed to confer risk for developing Alzheimer's disease, show altered performance on spatial attention tasks that may be due to reduced cholinergic activity in parietal cortex (Bellgrove & Mattingley, 2008; Poirier, et al., 1995). Thus, abundant evidence points to a link between cholinergic transmission in parietal cortex and the functioning of spatial attention processes.

A growing body of work has expanded on this research by examining the relationship between normal variations in the *CHRNA4* gene and individual differences in selective attention. The *CHRNA4* gene affects expression of the α4 subunit of the α4/β2 nAChR, which is the most widely distributed nicotinic acetylcholine receptor in cortical

regions (Greenwood, Fossella, & Parasuraman, 2005; Parasuraman & Espeseth, 2007). This gene has several single nucleotide polymorphisms (SNPs), including the common $C^{1545}T$ polymorphism in which cytosine and thymine are exchanged (Parasuraman & Espeseth, 2007). This polymorphism has been related to individuals' performance on speed of processing, alerting/vigilance, and executive attention tasks (Reinvang, Lundervold, Rootwelt, Wehling, & Espeseth, 2009; Winterer, et al., 2007). Additional studies have specifically examined the relationship between *CHRNA4* genotype and individuals' deployment of spatial attention. One of these studies utilized a version of the spatial cueing task in which a central arrow provided valid, invalid, and neutral cues to the subsequent target location (Parasuraman, et al., 2005). The results showed that individuals with the homozygous C/C genotype were fastest to orient their attention based on a valid spatial cue but also recovered more quickly following an invalid cue (Parasuraman, et al., 2005)[4]. A follow-up study examined the effects of *CHRNA4* genotype on individuals' ability to scale the focus of spatial attention. Scaling of attention was manipulated by changing the size of the area encompassed by the cue stimulus; a cue stimulus that is distributed over a broader area provides less precise information about target location and is associated with slower target detection (Greenwood, et al., 2005). Though there was a general slowing of reaction times associated with increasing cue size, the effect was most pronounced for individuals with the C/C *CHRNA4* genotype. Together, these studies demonstrated that *CHRNA4* genotype is related to variations in selective attention and suggest that individuals with the C/C genotype show efficient orienting when provided with a precise spatial cue (Parasuraman, et al., 2005) but also

[4] This study did not vary the cue – target delay length and thus did not assess inhibition of return effects.

experience greater reaction time costs associated with imprecise cues (Greenwood, et al., 2005).

Despite the growing body of work examining the influence of *CHRNA4* on spatial attention, the precise mechanisms linking the $C^{1545}T$ polymorphism to individual differences in spatial attention remain elusive. Increased reaction time benefits among individuals with the C/C genotype may reflect increased activity at nicotinic cholinergic receptors, since these receptors mediate fast synaptic transmission in parietal cortex (Alkondon, Pereira, Eisenberg, & Albuquerque, 2000; Greenwood, et al., 2005; Parasuraman, et al., 2005). Furthermore, separate genetic polymorphisms that affect the $\alpha 4$ and $\beta 2$ subunits of the nAchR have been shown to reduce the receptor's response to extracellular calcium, which results in increased affinity of the receptor for acetylcholine (Greenwood, et al., 2009; Rodriques-Pinguet, et al., 2003). Additional work is needed in order to confidently determine the relevant mechanisms; however, these studies support the inference that the C allele of the *CHRNA4* $C^{1545}T$ polymorphism may be associated with increased affinity of the nAchR for acetylcholine.

Though the *CHRNA4* gene has received a great deal of attention as a candidate gene affecting spatial orienting, additional genetic polymorphisms have been studied with respect to other component attention processes. In particular, genetic variations affecting the regulation of dopamine neurotransmission have been explored as factors that may influence functioning of executive attention networks. The executive attention system mediates flexible allocation of attention resources based on constantly changing goals, which is crucial for efficient navigation of our everyday lives (Blasi, et al., 2005).

Anterior cortical networks involving cingulate and lateral prefrontal regions have consistently been associated with tasks that require controlled attention or detection and monitoring of conflicting goals (Blasi, et al., 2005; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Bush, Luu, & Posner, 2000; Carter, et al., 2000; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Kerns, et al., 2004; Posner & Petersen, 1990; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). These regions are characterized by dense innervation by midbrain dopamine neurons (Seamans & Yang, 2004), high levels of dopamine receptor expression (Stanwood, Washington, Shumsky, & Levitt, 2001), and enhanced activity following stimulation of dopamine neurons (McCulloch, Savaki, McCulloch, Jehle, & Sokokoff, 1982). Several studies have also linked dopamine activity in these regions with executive attention behaviors. For example, blocking dopamine function leads to deficits on tasks requiring cognitive control (Brozoski, Brown, Rosvold, & Goldman, 1979) and, conversely, concentrations of extracellular dopamine increase in dorsolateral prefrontal cortex while monkeys perform these kinds of tasks (Watanabe, Kodama, & Hikosaka, 1997). Thus, the integrity of the dopamine neurotransmitter system is crucial for efficient functioning of executive attention networks.

Catechol-O-methyltransferase (COMT) is an enzyme that catalyzes the degradation of extracellular dopamine following neurotransmission (Blasi, et al., 2005). Thus, elimination or reductions in COMT levels lead to increased levels of synaptic dopamine and corresponding increases in activity of dopaminergic neurons (Gogos, et al., 1998). This relationship between COMT levels and dopamine activity is also evident at a

behavioral level; administration of selective COMT inhibitors leads to enhanced performance in animal models of attentional set-shifting (Tunbridge, Bannerman, Sharp, & Harrison, 2004) and patients with depleted dopamine levels show improved performance on inhibitory control and working memory tasks when they receive COMT inhibitors (Gasparini, Fabrizio, Bonifati, & Meco, 1997).

The balance of COMT levels is especially important for prefrontal dopamine function because this region is characterized by a relatively high degree of extracellular diffusion and relatively low density of dopamine transporter (DAT) expression, which also functions to clear dopamine from the synapse (Sesack, Hawrylak, Matus, Guido, & Levey, 1998). As a result, genetic variations affecting the *COMT* gene likely have a greater selective effect on activity in prefrontal regions (Diamond, Briand, Fossella, & Gehlbach, 2004). One of the most extensively studied *COMT* polymorphisms is the methionine to valine missense mutation at codon 158, commonly referred to as the Val^{158}Met SNP (Blasi, et al., 2005; Mannisto & Kaakkola, 1999). For this SNP, the Met allele is associated with lower levels of COMT activity, and corresponding higher levels of dopamine neurotransmission, while the Val allele is associated with increased degradation of dopamine by COMT, and thus reduced dopamine activity (Blasi, et al., 2005; Chen, et al., 2004; Weinshilboum, Otterness, & Szumlanski, 1999). Given that higher levels of dopamine activity tend to be associated with improved performance on executive function tasks, it is unsurprising that variations in *COMT* genotype have been related to individual differences in executive function and executive attention tasks. In general, these studies have shown that an increasing dose of the Val allele is associated

with poor working memory (Diaz-Asper, et al., 2008), reduced cognitive or attention control (Barnett, Robbins, & Muller, 2007; Blasi, et al., 2005; Diamond, et al., 2004; Egan, et al., 2001; Fossella, et al., 2002; Stefanis, et al., 2005) and an increased tendency for impulsive responses (Eisenberg, et al., 1999). In addition, fMRI studies have demonstrated that individuals with the Val/Val genotype show greater BOLD responses in anterior cingulate and prefrontal regions during these kinds of tasks, despite showing equal or inferior behavioral performance (Bertolino, et al., 2006; Blasi, et al., 2005; Caldu, et al., 2007; Egan, et al., 2001; Meyer-Lindenberg, et al., 2006; Mier, Kirsch, & Meyer-Lindenberg, 2009).

In addition to its effects on executive attention, accumulating evidence suggests that dopamine functioning can influence other component attention processes, particularly spatial attention. For example, lesions of dopaminergic pathways in rats elicit behaviors that mimic the spatial biases seen in human patients who have suffered an insult to parietal cortex (Iversen, 1984). Furthermore, biases of spatial attention towards one visual hemifield can be modulated by dopaminergic agents (Maruff, Hay, Malone, & Currie, 1995); spatial biases can be induced by drugs that reduce catecholamine function (Bellgrove & Mattingley, 2008; Coull, Nobre, & Frith, 2001) and those that increase dopamine function can alleviate similar spatial biases seen among individuals with ADHD (Bellgrove, et al., 2007; Bellgrove & Mattingley, 2008).

As noted above, the dopamine transporter (DAT) also functions to remove extracellular dopamine from the synapse during neurotransmission. Because DAT serves to clear the synapse of excess dopamine, increased expression of the DAT is associated

with reduced dopaminergic signaling (Coull, et al., 2001). It is possible that the dopaminergic effects on spatial attention described above may be mediated by DAT, since the DAT-1 subtype is heavily expressed in regions that overlap with the orienting/selective attention network, including the striatum, cingulate, and posterior parietal cortex (Coull, et al., 2001; Mesulam, 1981; Posner & Petersen, 1990). The gene that codes for DAT-1 contains a 40-bp variable-number tandem repeat (VNTR) polymorphism in the 3'-untranslated region of the gene, which does not affect the protein structure of the transporter (Vandenbergh, et al., 2000) but influences the amount of DAT-1 protein that is expressed across brain regions (Fuke, et al., 2001; Heinz, et al., 2000; Mill, Asherson, Browes, D'Souza, & Craig, 2002; VanNess, Owens, & Kilts, 2005). This VNTR ranges from 3 – 13 repeats (Vandenbergh, et al., 2000) but the 9- and 10- repeats are most common (Kang, Palmatier, & Kidd, 1999) and have repeatedly been linked to different aspects of attention. The 10-repeat allele is considered a risk allele for ADHD (Bellgrove & Mattingley, 2008) and has been weakly associated with poorer performance on tasks measuring vigilance, selective attention, and executive attention (Congdon, Lesch, & Canli, 2008; Cornish, Wilding, & Hollis, 2008; Fossella, et al., 2002; Loo, et al., 2003). However, another study found that the 10/10-repeat genotype among 6-year-old children was related to superior performance on an executive attention task and higher parental ratings of effortful control (Rueda, et al., 2005). Furthermore, several functional neuroimaging studies have found that the 10/10-repeat genotype is associated with more focal activation in prefrontal regions during working memory and

reward processing tasks, which has been interpreted as more efficient neural processing (Bertolino, et al., 2006; Caldu, et al., 2007; Forbes, et al., 2009).

Despite the relatively intense focus on genetic correlates of these sustained and executive attention processes, a number of studies have specifically examined the relationship between the *DAT-1* VNTR polymorphism and spatial attention. Specifically, within a sample of 6 – 16 year-old children diagnosed with ADHD, the 10/10-repeat genotype was associated with a bias of spatial attention that favored the right visual field, whereas children with at least one 9-repeat allele showed no spatial attention biases (Bellgrove, et al., 2005). The authors interpreted this result as evidence that dopamine modulates spatial attention processes that are mediated by parietal cortex, since this kind of spatial bias is similar to the hemifield neglect evident among individuals with damage to parietal regions of cortex (Bellgrove, et al., 2005). In a follow-up study, Bellgrove et al. (2007) tested a sample of healthy 9 – 16 year-old children to examine the relationship between the *DAT-1* polymorphism and spatial attention biases elicited during a spatial cueing task. Overall, children with the 10/10-repeat genotype showed greater reaction time costs following invalid cues when compared to children with at least one 9-repeat allele. Furthermore, the 10/10-repeat group was slower to orient to validly cued targets, and the effect of invalid cues was exacerbated when the target appeared in the left visual field. These results suggest that the *DAT-1* 10/10-repeat genotype may be associated with increased left-side inattention, which may reflect a vulnerability for ADHD (Bellgrove, et al., 2007).

The contradictory behavioral findings described above reflect an uncertainty about the precise effects of the *DAT-1* polymorphism on dopaminergic functioning. Some studies have reported that the 10/10-repeat genotype is associated with higher levels of DAT expression (Heinz, et al., 2000; Mill, et al., 2002), which contributes to reductions in synaptic dopamine activity. In contrast, a growing number of studies have reported opposite effects, indicating that the 10/10-repeat genotype is associated with lower transporter density (van de Giessen, et al., 2008; van Dyck, et al., 2005; Wonodi, et al., 2009) and reduced DAT binding (Jacobsen, et al., 2000), which leads to increased dopamine activity. Miller and Madras (2002) demonstrated that these conflicting findings may be due to additional SNPs located in the 3'-untranslated region of the *DAT-1* gene. Nonetheless, the contradictory behavioral findings to this point are understandable given the ambiguity over the effects of the *DAT-1* VNTR at a molecular level.

Overall, though the precise mechanisms remain unclear, there is clear evidence that normal variations in genes that regulate neurotransmitter systems may contribute to individual differences in attention processes, including spatial attention and orienting. However, with a few exceptions (Bellgrove, et al., 2007; Cornish, et al., 2005; Cornish, et al., 2008; Diamond, et al., 2004; Rueda, et al., 2005), this work has exclusively examined the relationships between genetic polymorphisms and attention processing during adulthood or in the context of disordered attention behaviors (e.g., children diagnosed with ADHD). As a result, there is very little information regarding the nature of these relationships in the context of healthy development. To date, only one study has investigated the link between genetic polymorphisms and attention processes during

infancy. This study utilized a relatively new task, known as the Freeze-frame task, that was developed to measure aspects of inhibitory control and putative prefrontal functioning in infancy (Holmboe, Fearon, Csibra, Tucker, & Johnson, 2008). In this task, infants are encouraged to fixate on an engaging, animated central stimulus, despite the appearance of distracting stimuli in the periphery. If infants look towards the distractor stimuli, the central animation stops for a short period; thus, over time infants should learn that inhibiting eye movements to the distractors maintains a rewarding stimulus. The task includes both "boring" trials, consisting of a simple and repetitive central animation, and "interesting" trials, in which the central animation dynamically changes over time. Based on evidence that this task is a valid measure of early inhibitory control (Holmboe, et al., 2008), Holmboe, et al., (2010) conducted a follow-up study to examine the relationship between variations in dopaminergic genes and inhibitory control among 9-month-old infants. The results demonstrated that the *COMT* Val^{158}Met polymorphism was related to the proportion of looks infants made to the distractor during interesting trials, but not during boring trials. Specifically, compared to infants with the Val/Val genotype, infants with the Met/Met genotype were less distractible and more focused on the central stimulus when it was especially engaging. In addition, infants with the 10/10-repeat genotype for the *DAT-1* gene were less likely to look to the distractor stimuli than those with at least one 9-repeat allele, regardless of trial type. The results also revealed an interaction between *COMT* genotype, *DAT-1* genotype, and trial type. Infants with at least one *DAT-1* 9-repeat allele showed different levels of distractibility during the interesting trials depending on their *COMT* genotypes. Within this group, infants with the

Met/Met genotype were least distractible and most focused on the engaging central stimulus, compared to infants with either the Val/Met or Met/Met genotypes. In contrast, infants with the 10/10-repeat *DAT-1* genotype showed no differences in distractibility across the different *COMT* genotypes. These results suggest that variations in infants' *DAT-1* genotypes can modulate the impact of *COMT* genotype, and specifically, that infants with high COMT activity (i.e., Val/Val genotype) show enhanced inhibitory control if they also have the 10/10-repeat *DAT-1* genotype.

This initial infant study provided evidence that genetic polymorphisms can be related to attention behaviors during infancy, and importantly, that some of these effects are consistent with results seen among adult samples. In addition, the study highlighted the importance of examining more than one gene, since observed effects may vary depending on the context of an individual's broader genotype. However, this study focused on only one aspect of attention, inhibitory control, which is presumed to be mediated by the developing frontal cortex and may be primarily related to the executive attention system. The present study sought to expand on this work by examining the relationship between normal variations in *CHRNA4, COMT,* and *DAT-1* genotypes and infants' orienting responses during the spatial cueing task.

Method

Participants

Genotyping was conducted with the same sample of seventy-four 7-month-old infants (36 M, 38 F) described in Study 2A. Genetic samples were collected at the end of each infant's second test session. Parents provided separate informed consent for the

genotyping portion of the study. Samples were initially collected from 66 infants (34 M, 32 F; 89% of overall sample) because parents of the remaining 8 infants (2 M, 6 F) declined to provide a genetic sample. Six samples became contaminated before genotyping was complete; five of these samples were re-collected when the infants were approximately 12 months old. Thus, the final sample included genetic data from 65 infants.

Procedure

Sample collection. Samples of buccal (cheek) cells were collected from each infant using Catch-All™ collection swabs from Epicentre Biotechnologies. These soft foam swabs were gently rubbed on the inside of the infant's mouth for approximately 5 – 10 seconds on each cheek. The swabs were allowed to air dry for 10 – 15 minutes before being sealed in the sterile collection tube and frozen at -20° C. All three genetic polymorphisms were genotyped from the same buccal cell sample.

Genotyping. The *CHRNA4* $C^{1545}T$ (rs10344946) and *COMT* $Val^{158}Met$ (rs4680) SNPs were genotyped using the TaqMan SNP Genotyping Assay system from Applied Biosystems. Sequence-specific probes were provided with this system (rs1044396 probe = C__25746809_10; rs4680 probe = C__25746809_50). PCR parameters were 95/92/60° C for 40 cycles and 10 minutes, 15 seconds, and 60 seconds, respectively. Following PCR amplification, an allelic discrimination plate read was completed using the Sequence Detection Software (SDS) from Applied Biosystems.

For the *DAT-1* VNTR genotyping, PCR amplification was conducted using primers (5'-TGTGGTGTAGGGAACGGCCTGAG-3' starting at nt2691; 5'-

CTTCCTGGAGGTCACGGCTCAAGG-3' starting at nt3174 opposite strand) that have previously been identified (Barr, et al., 2001; Vandenbergh, et al., 1992). Following amplification, the PCR products were run on a 3130xl DNA sequencer from Applied Biosystems to determine sequence length.

Results

Distribution of Genetic Variants

Genotyping success rates and the distribution of allele variants for each gene are listed in Table 5.1. The allele distributions for each gene were consistent with expected frequencies derived from the Hardy-Weinberg equilibrium (*CHRNA4*: $\chi^2(2) = 0.369$, p = 0.832; *COMT*: $\chi^2(2) = 0.584$, p = 0.747; *DAT-1*: $\chi^2(2) = 0.0004$, p = 0.998). Though the heterozygous genotype was most frequent for *CHRNA4* and *COMT*, both of these genes had sufficient distribution to examine all three levels of variants. However, this was not the case for *DAT-1*, due to the low frequency of infants with the 9/9-repeat genotype. As a result, infants were grouped together if they had at least one 9-repeat allele (e.g., heterozygous 9/10- or homozygous 9/9-repeat genotypes). Thus, for the purposes of these

	CHNRA4			*COMT*			*DAT-1*		
Genotyping Success Rate (%)	96.9			98.5			92.3		
Genetic Variants	T/T	T/C	C/C	Met/Met	Met/Val	Val/Val	9/9	9/10	10/10
# of Infants	19	29	15	16	35	13	5	25	30
% of Sample	30.2	46.0	25.0	25.0	54.7	20.3	8.3	41.75	50.0

Table 5.1. Genotyping success rates and distributions of genetic variants.

analyses, the final variant distribution for *DAT-1* gene included 30 infants (50.0%) with the 10/10-repeat genotype and 30 infants (50.0%) with a non-10/10-repeat genotype.

As discussed in previous chapters, not all infants provided usable data from the spatial cueing task at Session 1, which affected the amount of data that could be analyzed with respect to infants' genotypes. Valid sample sizes after accounting for these missing data are listed for each gene in table 5.2.

The statistical analyses were substantially limited because of the low power resulting from the small number of infants in each genotype category for the three genes. This was especially true when examining interaction effects between polymorphisms of each gene. As a result, main effects were examined by conducting separate one-way ANOVAs to determine whether the extent of facilitative and inhibitory effects differed across the genetic variants. Interaction effects between genes were considered to be tentative at best due to the small sample sizes. In addition to these between-group comparisons, one-sample t-tests were conducted within each of the different genotype

	CHNRA4			*COMT*			*DAT-1*	
	T/T	T/C	C/C	Met/Met	Met/Val	Val/Val	9/10	10/10
Spatial Cueing Measure	Valid N (Missing Data)							
Short-delay Trials (Orienting & Reaction Time)	19 (0)	27 (2)	13 (2)	16 (0)	31 (4)	13 (0)	28 (2)	28 (2)
Long-delay Trials (Orienting)	19 (0)	27 (2)	13 (2)	16 (0)	31 (4)	13 (0)	28 (2)	28 (2)
Long-delay Trials (Reaction Time)	19 (0)	27 (2)	**12 (3)**	16 (0)	**29 (6)**	13 (0)	**26 (4)**	28 (2)

Table 5.2. Valid sample sizes and missing data for analyses of the relationship between genetic polymorphisms and spatial cueing measures. Note that several infants provided usable data for the majority of the spatial cueing task measures but did not provide usable data for the reaction time measure during long-delay trials.

groups to determine whether infants in any single group showed facilitative and/or inhibitory effects that were significantly different from chance.

Spatial Cueing Effects

Facilitation (short-delay trials). ***Proportion of orienting.*** Results of separate one-way ANOVAs indicated that there were no main effects of *CHRNA4* ($F(2, 56) = 0.362$, $p = 0.407$), *COMT* ($F(2, 57) = 0.79$, $p = 0.459$), or *DAT-1* ($F(1,54) = 0.07$, $p = 0.792$) genetic variants on infants' proportion of orienting to the cued location during short-delay trials. Furthermore, no single variant group for any of the three genes showed orienting effects that were significantly above chance. However, there was a significant two-way interaction between the *CHRNA4* and *DAT-1* variants (Figure 5.1; $F(2,49) = 4.09$, $p = 0.023$). Post-hoc t-tests indicated that within the *DAT-1* 10/10-repeat group, there was a trend for significantly higher orienting scores among infants who also had the *CHRNA4* C/C genotype ($M_{Orienting} = 0.64$, $SD = 0.18$) compared to those with the T/T genotype ($M_{Orienting} = 0.47$, $SD = 0.17$; $t(13) = -1.762$, $p = 0.102$). Similarly, there was a trend for higher orienting scores among infants with the C/C genotype compared to infants with the heterozygous T/C genotype ($M_{Orienting} = 0.49$, $SD = 0.14$; $t(17) = -2.016$, $p = 0.06$). Furthermore, within this *DAT-1* 10/10-repeat group, infants with the *CHRNA4* C/C genotype were the only ones whose orienting scores showed a trend for being significantly above chance ($t(5) = 1.869$, $p = 0.12$). In contrast, there were no differences across *CHRNA4* variants among carriers of the *DAT-1* 9-repeat allele. Carriers of the 9-repeat allele who also had the *CHRNA4* C-C genotype did not show a significant orienting effect ($M_{Orienting} = 0.45$, $SD = 0.20$; $t(5) = -0.661$, $p = 0.538$) while infants with

the T/T ($M_{Orienting}$ = 0.56, *SD* = 0.10) and T/C ($M_{Orienting}$ = 0.56, *SD* = 0.10) genotypes showed trends for significant orienting effects ($t(8) = 1.827$, p = 0.105; $t(11) = 2.01$, p = 0.07, respectively). Thus, infants with the *CHRNA4* C/C genotype showed opposite patterns of orienting depending on whether they also had the 10/10- or a 9-repeat version of *DAT-1*.

Reaction Time. A second set of separate one-way ANOVAs indicated that were no main effects of *CHRNA4* ($F(2,56) = 0.242$, $p = 0.786$) or *COMT* ($F(2, 57) = 0.072$, p = 0.93) variants on infants' response times to targets appearing in the cued location during short-delay trials. However, there was a trend-level main effect of *DAT-1* variant on response times to the cued location ($F(1, 54) = 3.34$, $p = 0.073$). Specifically, infants with at least one 9-repeat allele showed a greater reaction time benefit for targets appearing in the cued location ($M_{RT\ difference}$ = -74.0 ms, *SD* = 84.75 ms) compared to infants with the 10/10-repeat version of the gene ($M_{RT\ difference}$ = -31.20 ms, *SD* = 90.38 ms). None of the two-way interaction terms reached significance.

One-sample t-tests indicated that infants in all three *CHRNA4* variant groups showed reaction time difference scores that were significantly below zero (T/T: $M_{RT\ difference}$ = -53.26 ms, *SD* = 106.54 ms, $t(18) = -2.179$, $p = 0.043$; T/C: $M_{RT\ difference}$ = -54.16 ms, *SD* = 83.60 ms, $t(26) = -3.366$, $p = 0.002$; C/C: $M_{RT\ difference}$ = -74.02 ms, *SD* = 88.73 ms, $t(12) = -3.008$, p = 0.011). Thus, infants showed significant facilitation effects on reaction time regardless of their *CHRNA4* genotype. Similarly, all three *COMT* variant groups showed significant or trend-level facilitation effects on reaction time (Met/Met: $M_{RT\ difference}$ = -60.83 ms, *SD* = 122.28 ms, $t(15) = -1.99$, $p = 0.065$; Met/Val: $M_{RT\ difference}$

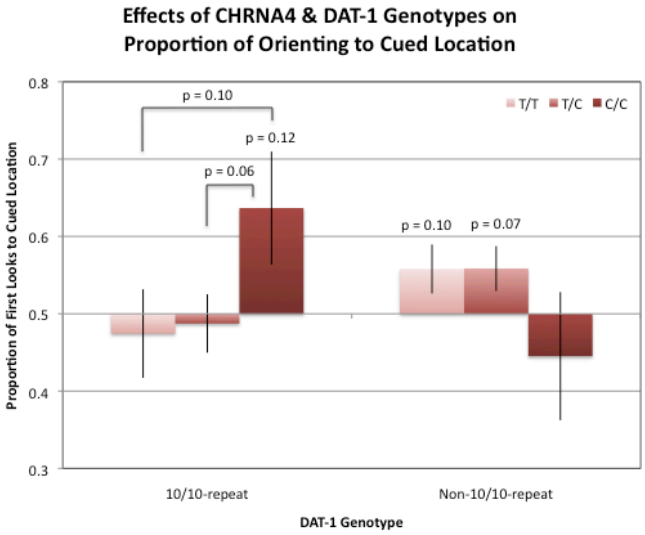


Figure 5.1. Interaction of *CHRNA4* and *DAT-1* variants on facilitation of orienting during the spatial cueing task.

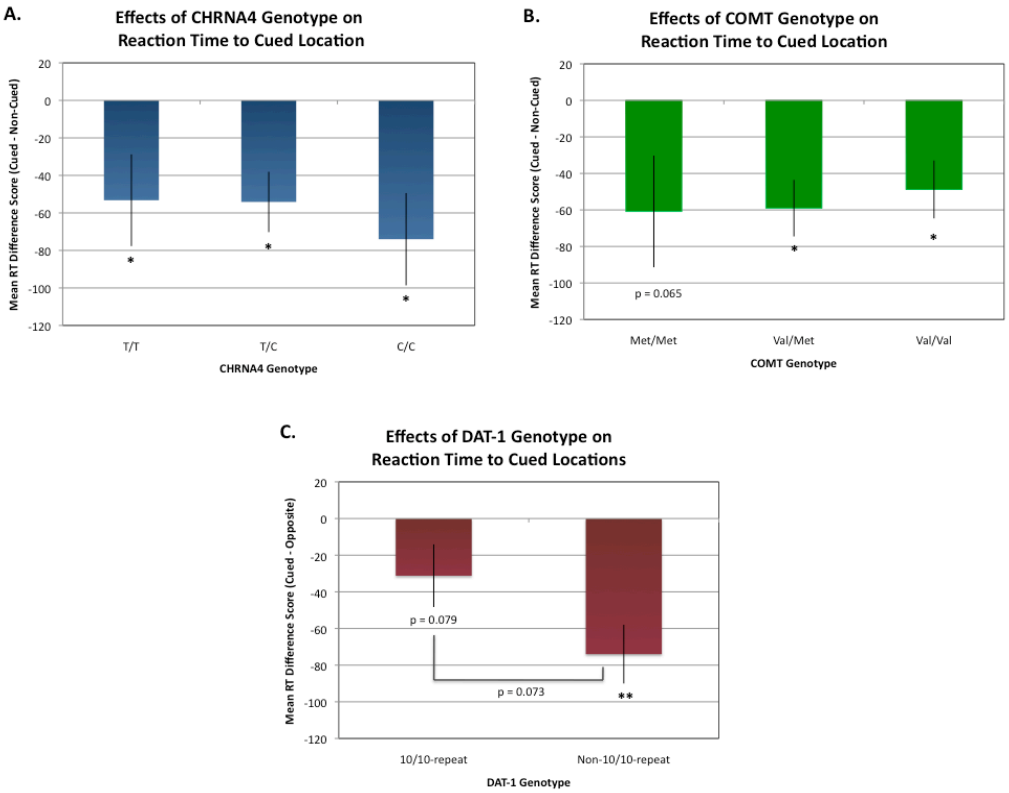


Figure 5.2. Effects of (A) *CHRNA4*, (B) *COMT*, and (C) *DAT-1* variants on facilitation of reaction time during the spatial cueing task.

= -59.04 ms, *SD* = 86.25 ms, *t*(30) = -3.811, *p* = 0.001; Val/Val: $M_{RT\ difference}$ = -48.55 ms, *SD* = 57.14 ms, *t*(12) = -3.078, *p* = 0.01). Finally, infants with the *DAT-1* 10/10-repeat genotype showed trend-level facilitation effects on reaction time ($M_{RT\ difference}$ = -31.20 ms, *SD* = 90.38 ms, *t*(27) = -1.827, *p* = 0.079) while infants with a 9-repeat allele showed highly significant facilitation effects ($M_{RT\ difference}$ = -74.0 ms, *SD* = 84.75 ms, *t*(27) = -4.62, *p* < 0.001). Taken together, these results suggest that of the three genes under consideration, *DAT-1* has the strongest effects on the extent to which spatial cueing facilitates response times to the cued location during short-delay trials.

Inhibition of return. ***Proportion of orienting.*** Separate one-way ANOVAs indicated that there were no main effects of *CHRNA4* (*F*(2,56) = 0.123, *p* = 0.884), *COMT* (*F(*2,57) = 1.685, *p* = 0.195), or *DAT-1* (*F*(1,54) = 0.359, *p* = 0.552) on infants' likelihood of orienting to the non-cued location during long-delay trials. In addition, noneof the two-way interaction terms reached significance. However, infants with all three *CHRNA4* variants showed inhibition of return orienting effects that were significantly above chance (T/T: $M_{Orienting}$ = 0.62, *SD* = 0.175, *t*(18) = 3.052, *p* = 0.007; T/C: $M_{Orienting}$ = 0.60, *SD* = 0.177, *t*(26) = 3.039, *p* = 0.005; C/C: $M_{Orienting}$ = 0.63, *SD* = 0.203, *t*(12) = 2.347, *p* = 0.037). Similarly, infants showed significant inhibitory effects on orienting regardless of their *DAT-1* genotype (10/10-repeat: $M_{Orienting}$ = 0.63, *SD* = 0.179, *t*(27) = 3.729, *p* = 0.001; non-10/10-repeat: $M_{Orienting}$ = 0.60, *SD* = 0.195, *t*(27) = 2.608, *p* = 0.015). In contrast, not all *COMT* variants were associated with significant orienting effects. Specifically, infants with at least one Val allele showed significant or trend-level inhibitory effects on orienting (Met/Val: $M_{Orienting}$ = 0.66, *SD* = 0.182, *t*(30) =

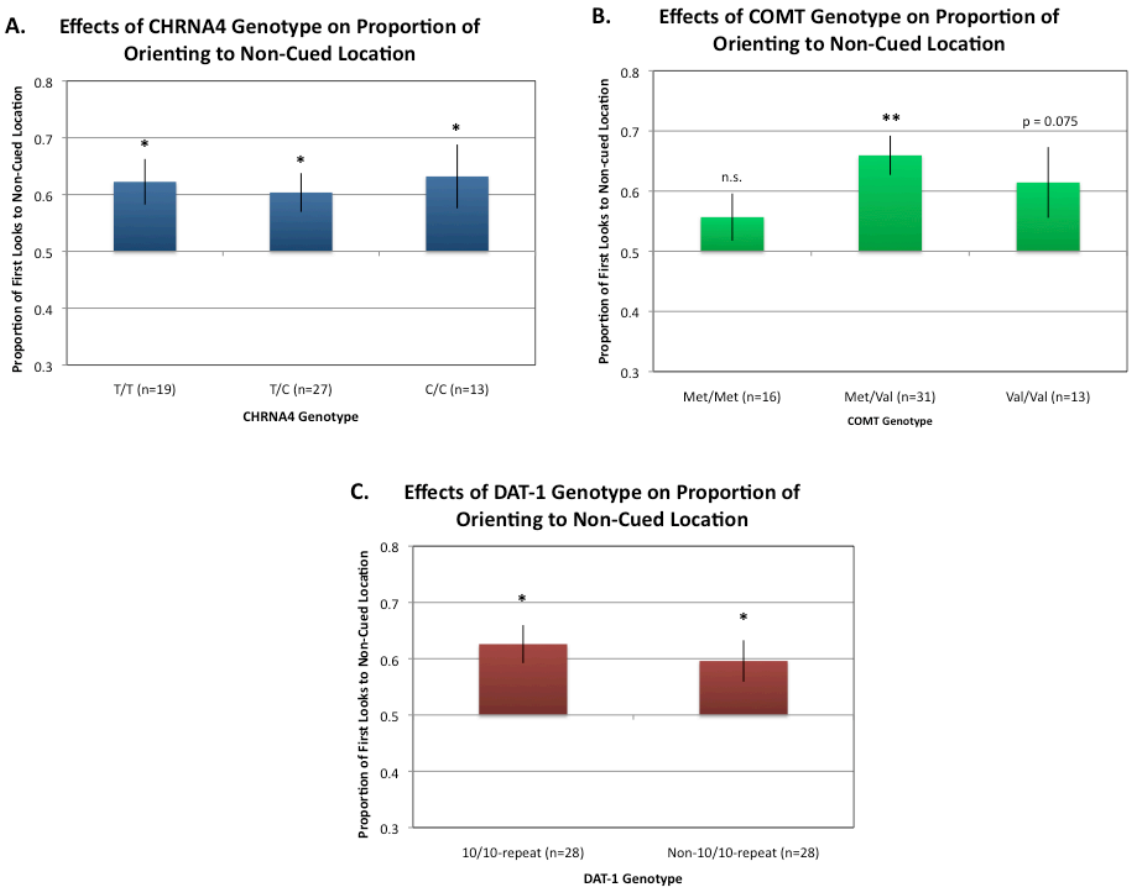


Figure 5.3. Effects of (A) *CHRNA4*, (B) *COMT*, and (C) *DAT-1* variants on IOR orienting effects.

4.844, $p < 0.001$; Val/Val: $M_{Orienting} = 0.61$, $SD = 0.212$, $t(12) = 1.946$, $p = 0.075$). In contrast, infants with the Met/Met genotype did not show a significant IOR effect on orienting ($M_{Orienting} = 0.56$, $SD = 0.157$, $t(15) = 1.446$, $p = 0.169$). Thus, although the main effect of *COMT* did not reach significance, these results suggest that infants' *COMT* genotype may influence the extent to which spatial cueing elicits inhibitory effects on orienting during long-delay trials.

Reaction time. A final set of one-way ANOVAs indicated that there were no main effects of *CHRNA4* ($F(2,55) = 1.254$, $p = 0.293$) or *DAT-1* ($F(1,54) = 0.83$, $p = 0.671$) on infants' response time to targets appearing in the non-cued location during long-delay trials. However, the main effect of *COMT* genotype on reaction time did reach trend-level significance ($F(2,55) = 2.415$, $p = 0.099$). Follow-up t-tests indicated that infants with the Met/Val genotype showed a greater reaction time benefit ($M_{RT\ Difference}$ = 94.06 ms, SD = 124.64 ms) for targets in the non-cued location compared to infants with the Met/Met genotype ($M_{RT\ Difference}$ = 10.73 ms, SD = 123.63; $t(43) = -2.153$, $p = 0.037$). No other between-group comparisons reached significance.

One-sample t-tests indicated that individual variant groups showed patterns of IOR effects on reaction time that were highly similar to those seen for infants' orienting behavior during long-delay trials. All three *CHRNA4* variants were associated with significant IOR effects on reaction time (T/T: $M_{RT\ Difference}$ = 68.70 ms, SD = 122.93 ms, $t(18) = 2.418$, $p = 0.026$; T/C: $M_{RT\ Difference}$ = 46.43 ms, SD = 116.26 ms, $t(26) = 2.053$, $p = 0.05$; C/C: $M_{RT\ Difference}$ = 115.93 ms, SD = 152.78 ms, $t(11) = 2.617$, $p = 0.024$). Similarly, infants showed significant inhibitory reaction time effects regardless of their

DAT-1 genotype (10/10-repeat: $M_{RT\ Difference}$ = 69.19 ms, *SD* = 129.43 ms, $t(27) = 2.808$, $p = 0.009$; non-10/10-repeat: $M_{RT\ Difference}$ = 56.1 ms, *SD* = 90.45 ms, $t(27) = 3.134$, $p = 0.004$). However, infants' *COMT* genotype was related to whether they showed IOR effects on reaction time. Specifically, infants with at least one Val allele showed significant IOR effects (Met/Val: $M_{RT\ Difference}$ = 94.06 ms, *SD* = 124.64 ms, $t(28) = 4.042$, $p < 0.001$; Val/Val: $M_{RT\ Difference}$ = 80.82 ms, *SD* = 123.08 ms, $t(12) = 2.353$, $p = 0.037$) whereas infants with the Met/Met genotype did not show a significant IOR effect on reaction time ($M_{RT\ Difference}$ = 10.73 ms, *SD* = 123.63 ms, $t(15) = 0.334$, $p = 0.745$). These results suggest that the Val allele supports inhibitory effects on reaction time, whereas the Met allele does not.

Finally, although none of the two-way interaction terms were significant, the patterns of reaction time results may suggest that the *CHRNA4* and *COMT* genes modulate one another. Few effects reach significance because of the very small number of infants who have each of the combinations of *CHRNA4/COMT* genotypes; thus these results must be interpreted with caution. However, the mean reaction time difference scores for these groups of infants reveal some intriguing patterns. First, recall that previous literature suggests that individuals with the *CHRNA4* T/T genotype may be least sensitive to the effects of cueing on reflexive orienting (Parasuraman, et al., 2005). Second, note that the results of the current study showed that infants with the Met/Met *COMT* genotype did not show significant inhibition of return effects on orienting or reaction time, while infants with any Val allele did show these significant effects. When the *CHRNA4* and *COMT* genes were considered in combination, infants with the

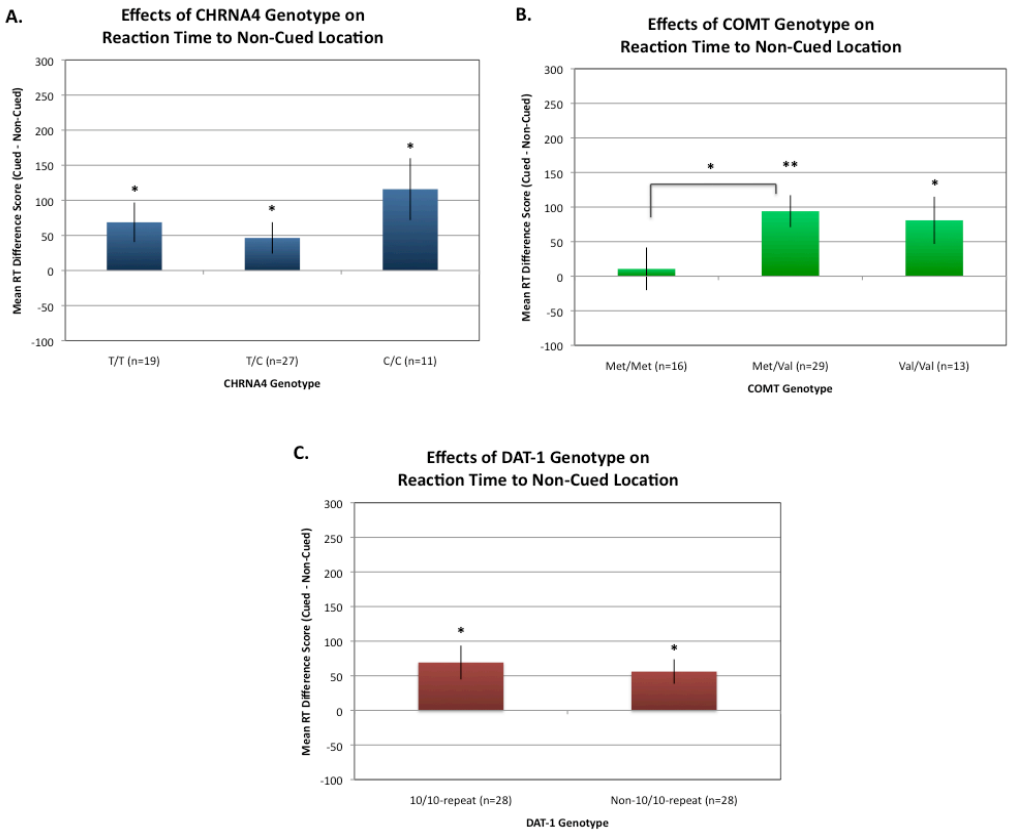


Figure 5.4. Effects of (A) *CHRNA4,* (B) *COMT,* and (C) *DAT-1* variants on IOR reaction time effects.

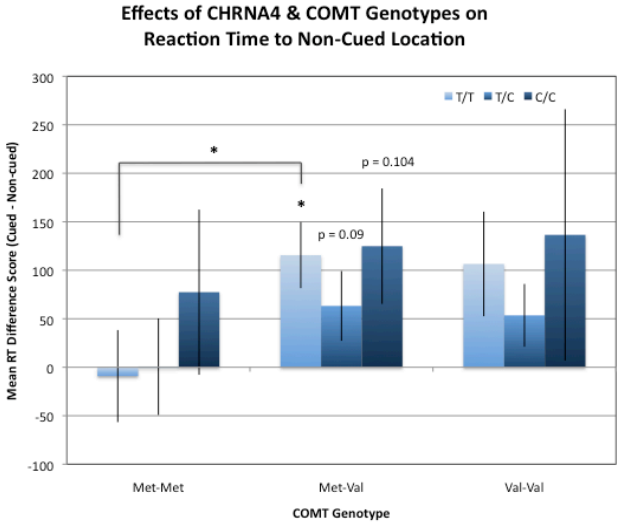


Figure 5.5. Interaction of *CHRNA4* and *COMT* on IOR reaction time effects.

combined T/T and Met/Met genotype showed no reaction time benefit for either the cued or non-cued locations (Figure 5.5; $M_{RT\ Difference}$ = -9.12 ms, *SD* = 125.62 ms, *t*(6) = -0.192, p = 0.854), which is concordant with the findings from previous literature and the initial findings from this study. However, infants who had the T/T *CHRNA4* genotype and also had at least one Val allele in their *COMT* genotype showed a substantial reaction time benefit for targets appearing in the non-cued location (T/T – Met/Val: $M_{RT\ Difference}$ = 115.61 ms, *SD* = 107.63 ms, *t*(9) = 3.397, p = 0.008; T/T – Val/Val: $M_{RT\ Difference}$ = 106.50 ms, *SD* = 76.24 ms, *t*(1) = 1.976, p = 0.298). Furthermore, this reaction time benefit was significantly greater for infants with the T/T – Met/Val genotype compared to infants with the T/T – Met-Met genotype (*t*(15) = -2.198, *p* = 0.044). These patterns suggest that the Val allele of the *COMT* gene may modify the relative insensitivity to spatial cueing that might be expected among individuals with the T/T variant of the *CHRNA4* gene. Similarly, the presence of a C/C *CHRNA4* genotype may modify the effects of having the Met/Met version of the *COMT* gene. Again, infants with the T/T – Met/Met combination of *CHRNA4* and *COMT* genotypes showed no effect of cueing on reaction times during long-delay trials. This null effect remained among infants who had the T/C – Met/Met combination of genes ($M_{RT\ Difference}$ = 0.55 ms, *SD* = 121.96 ms, *t*(5) = 0.011, *p* = 0.992). However, infants who had the Met/Met *COMT* genotype and the C/C version of the *CHRNA4* instead showed a substantial reaction time benefit for targets appearing in the non-cued location ($M_{RT\ Difference}$ = 77.43 ms, *SD* = 147.48 ms, *t*(2) = 0.909, *p* = 0.459). This pattern suggests that the sensitivity to spatial cueing that has been associated with

the *CHRNA4* C/C genotype may counteract the relative insensitivity to cueing that is evident among infants with the Met/Met *COMT* genotype.

Discussion

The results of this study demonstrated that infants' genotypes for three different genes – *COMT*, *DAT-1*, and *CHRNA4* – are related to their responses during the spatial cueing task. These relationships included separate main effects of *COMT* and *DAT-1* and effects of *CHRNA4* in combination with the dopaminergic genes. The main effects of *COMT* and *DAT-1* suggest that functioning of the dopamine neurotransmitter system influences spatial attention and orienting. However, different aspects of the dopaminergic system appear to be relevant for the facilitative and inhibitory effects elicited by spatial cues. Specifically, the effects of *DAT-1* genotype were evident only when examining facilitation effects of cueing. Furthermore, *DAT-1* genotype influenced the reaction time measure, but not the orienting measure, with the 9-repeat carriers showing stronger facilitation of reaction time to the cued location compared to the 10/10 genotype. Levels of striatal dopamine have been shown to modulate motor activity (Freed & Yamamoto, 1985), with increased levels of dopamine associated with enhanced speed of motor functions and reduced levels of dopamine associated with slowed or inhibited movement (e.g., symptoms of Parkinson's disease; Nahmias, Garnett, Firnau, & Lang, 1985). The specificity of the present effects on infants' response latencies but not on their direction of orienting suggests that the 9-repeat genotypes may be associated with an overall enhancement of motor activity.

However, the contradictory findings regarding the neurochemical implications of the different *DAT-1* genotypes make it difficult to clearly interpret the current results. Some reports have indicated that the 10/10 genotype is associated with increased dopaminergic activity (Jacobsen, et al., 2000; van de Giessen, et al., 2008; van Dyck, et al., 2005; Wonodi, et al., 2009) while others have indicated that the same genotype is associated with reduced dopaminergic activity (Heinz, et al., 2000; Mill, et al., 2002). It is possible that the effects of *DAT-1* genotype on dopamine functioning may vary across brain regions. Only a subset of these studies have specifically examined the effects of *DAT-1* genotype on striatal DAT expression, though even this subset has produced conflicting reports (Heinz, et al., 2000; Jacobsen, et al., 2000; van de Giessen, et al., 2008; van Dyck, et al., 2005). The results of the current study are consistent with the reports of reduced dopaminergic activity among individuals with the 10/10-repeat genotype, though this interpretation is based solely on behavioral results and cannot directly address dopamine activity.

While *DAT-1* genotype effects were evident only for the facilitative effects of cueing on reaction time, the effects of *COMT* genotype were limited to the inhibition of return effects elicited during the spatial cueing task. For both the orienting and reaction time measures, the Val allele was associated with stronger inhibition of return effects than the Met/Met genotype, which was associated with chance-level orienting behavior. To my knowledge, no previous studies have specifically examined the effects of *COMT* genotype on exogenous orienting within a healthy sample. The relatively strong effects of *COMT* genotype in the current results are initially surprising, given that *COMT* has been

robustly related to measures of executive attention and prefrontal functioning. Because the spatial cueing task is considered a reflexive orienting task, the possible contributions of the executive attention system to performance on this task have largely been ignored. However, the current results suggest that executive attention processes may be relevant for exogenous orienting behaviors. In particular, the Met/Met genotype is associated with higher levels of dopaminergic activity in prefrontal regions and enhanced cognitive and attention control. In the context of the spatial cueing task, it is possible that infants with this genotype have enhanced controlled or focused attention, making them less sensitive to information that appears outside the focus of their attention. As a result, the peripheral cues may be less likely to affect their orienting behaviors.

The results of this study also provide more evidence that inhibition of return effects are dissociable from the facilitative effects seen during short-delay trials. The specificity of the effects of *COMT* genotype on inhibition of return but not facilitation suggests that these effects are mediated by at least partially independent networks. As discussed earlier, disengagement and re-orienting of attention typically involve the posterior attention system (Posner & Petersen, 1990) while the anterior attention network mediates executive or controlled attention (Posner & Dehaene, 2000). The distinction between these networks has been supported by evidence that both overt and covert shifts of attention recruit parietal cortex and subcortical regions involved in oculomotor control (Posner & Dehaene, 2000; Rothbart & Posner, 2001). However, covert orienting of attention among adults is also dependent on regions in the anterior network, most notably the frontal eye fields (Moore & Fallah, 2001, 2004; Thompson, Biscoe, & Sato, 2005).

Furthermore, some evidence suggests that anterior regions may have more substantial contributions to these aspects of visual attention during early development compared to adulthood (Craft & Schatz, 1994b; M. H. Johnson, Tucker, Stiles, & Trauner, 1998), and Johnson (1990) suggested that the development of the frontal eye fields is crucial for the emergence of inhibitory pathways involved in inhibition of return. Thus, the effects of *COMT* genotype on the inhibitory effects of spatial cueing may reflect the additional involvement of frontal regions during inhibition of return.

Unlike *DAT-1* and *COMT*, the effects of *CHRNA4* genotype on infants' orienting behaviors were predominantly evident when examined in combination with the dopaminergic genes. Though the very small sample sizes largely precluded identifying significant interaction effects, the patterns of results provide intriguing preliminary evidence of a modulatory role for *CHRNA4*. For example, infants' *CHRNA4* genotypes modulated the effects of *DAT-1* genotypes on facilitation of orienting during short-delay trials. Among infants with the 10/10 genotype, those who also had the C/C genotype were most likely to orient to the cued location. In contrast, among carriers of a 9-repeat allele, the T allele was associated with stronger facilitation of orienting effects. Similarly, *CHRNA4* genotypes modulated the relationship between *COMT* genotype and inhibitory effects on infants' response times. When *COMT* was considered in isolation, infants with the Met/Met genotype showed no evidence of inhibition of return effects. However, if these infants also had the C/C genotype for *CHRNA4* they showed much stronger inhibition of return effects, suggesting that the C/C genotype may counteract the relative insensitivity to the cue seen within the overall Met/Met group.

These effects of *CHRNA4* in combination with *DAT-1* and *COMT* suggest that the cholingeric neurotransmitter system may have an overall modulatory role for the orienting attention system. One possibility is that variations in cholinergic functioning affect speed of processing, since the nAchRs are primarily responsible for rapid synaptic transmission in parietal cortex. However, the modulatory effects of *CHRNA4* varied across the two dopaminergic genes; in combination with *DAT-1,* the effects were evident for the proportion of orienting measure, whereas the interaction with *COMT* affected response times. The lack of an interaction effect with *DAT-1* on response time casts doubt on a global effect of *CHRNA4* on speed of processing during attention tasks. A second possibility is that variations in cholingeric functioning affect overall levels of arousal and alerting. Although norepinephrine has been most clearly linked to alerting attention processes, some researchers have argued that the influence of norepinephrine on alerting is at least partially mediated by modulating cholinergic functioning (Beane & Marrocco, 2004). Though the exact functional implications of the *CHRNA4* variants remain unknown, there is speculation that the $C^{1545}T$ SNP may affect the affinity of the nAchR for acetylcholine (Alkondon, et al., 2000; Greenwood, et al., 2005; Greenwood, et al., 2009; Parasuraman, et al., 2005; Rodriques-Pinguet, et al., 2003), which could have an overall priming effect for the attention system. Furthermore, cholinergic activity can increase overall sensitivity to stimuli (Sarter & Bruno, 1999; Sarter, Givens, & Bruno, 2001; Sarter, Hasselmo, Bruno, & Givens, 2005), which could be expressed as an increased likelihood of orienting, as was the case for the *CHRNA4* interaction with *DAT-*

1, or as more rapid response time, as was evident for the combinatorial effects of *CHRNA4* and *COMT*.

Finally, the pattern of effects seen for *CHRNA4* and *COMT* in combination further suggests that the contributions of the anterior/executive attention system should not be disregarded in studies of exogenous orienting. One interpretation is that even a basic attention task requires a balance between the flexibility provided by reflexive orienting processes and the stability provided by executive attention processes. Based on evidence that the role of dopamine activity in cognitive functioning is not straightforward (Mattay, et al., 2003), Nolan, Bilder, Lachman, and Volavka (2004) proposed that the Met allele of *COMT* would enhance performance on tasks requiring cognitive stability but would show opposite, detrimental effects during tasks requiring flexibility. The current results are consistent with this hypothesis, as the Met/Met genotype was associated with orienting responses that were more stable and less impacted by the cueing information. Since all infants in this sample successfully completed the cueing task (those who did not were excluded), it is important to refrain from claims that the Met allele is associated with "poor" orienting behavior. Stability of focused attention also contributes to effective information processing; as with other cognitive skills it is likely that the balance between controlled and flexible attention is critical for successful navigation of the world.

Chapter 6: Conclusions

The present studies represent an effort to develop a comprehensive understanding of the factors that influence early selective attention behaviors and the implications of these behaviors for infants' exploration and learning about their world. These studies have provided several new findings. Study 1 demonstrated that infants' sensitivity to salient non-social cues impacts the way that they gather information about predictable stimuli. Furthermore, preferential selective attention to one of two equally predictable items supported enhanced learning of the attended item. However, infants' responses to the cueing information were highly variable during Study 1, which meant that there was not a straightforward relationship between spatial cueing and learning. Study 2A explored this individual variability and showed that there is only modest stability in infants' selective orienting behaviors across multiple experiences with the spatial cueing task. Over time, the spatial cueing became less effective at inducing selective attention biases among the overall group of infants. In addition, infants' orienting behavior during early test sessions did not reliably predict their behavior during either subsequent test session, though their behaviors during the final two sessions were more closely related. Nonetheless, substantial stability was evident when infants were assessed for whether they maintained significant cueing effects over time, despite changes in the magnitude of these effects.

While Study 2A assessed the nature of infants' behavior during the spatial cueing task over time, Studies 2B and 2C explored some of the factors that may contribute to variations in individual infants' sensitivity to spatial cueing. Study 2B indicated that

infants who showed robust inhibition of return effects also showed a bias for rapid approach to novel toys, providing some support for Posner's (Posner & Cohen, 1984; Posner, et al., 1985) hypothesis that inhibition of return effects may reflect a bias towards novel information that is inherent to the human attention system. Finally, the results of the genotyping done in Study 2C suggested that individual differences in infants' attention responses to cueing information may reflect a balance between systems that mediate focused attention and those that support sensitivity to ongoing stimuli.

Implications

These findings have a number of implications for understanding selective attention, both among adults and in developmental contexts. These include implications related to methodology, the relationship between facilitative and inhibitory cueing effects, and the importance of considering the contributions of multiple neural systems to attention processes. First, on a methodological level, these studies have clearly demonstrated that the specific task parameters used to assess cognitive functioning can markedly affect behavioral results. As a group, infants in Study 1 did not show the expected inhibition of return effects for either the orienting or reaction time measures. This finding was surprising, as intensive pilot testing had been done to ensure that the task parameters were appropriate for this age group. However, the increased number of items on the screen during each trial likely increased competition for infants' attention, thereby introducing additional factors that influenced infants' deployment of selective attention. Though it is difficult to disentangle the many factors that may have influenced the results of Study 2A, the specific task parameters also likely contributed to the changes

in infants' behaviors seen over the course of repeated testing. In particular, the specificity of the task parameters may have been one factor that contributed to these changes, since the efficacy of spatial cueing is highly dependent on the specific delay lengths intended to elicit facilitation and inhibition of return. Again, despite pilot testing that identified optimal delay lengths for this age group, it is highly likely that the timing parameters were optimal for different infants at different times during the month of testing.

The results of Study 2B also demonstrated that multiple behavioral measures that purportedly reflect the same cognitive process may in fact tap into different components of a higher-order function. In this study, the relationship between infants' behaviors during the spatial cueing task and their responses to novelty was highly dependent on the specific measures of sensitivity to novelty. While performance on the spatial cueing task was closely related to infants' behavior during the motor approach task, opposite effects were seen with the dishabituation to novelty task and there was little relationship with parental reports of infants' everyday behaviors. Thus, measures of motor activation in response to novelty may reflect processes that are quite different from those mediating sustained attention to novelty. These findings offer a cautionary message about the care that must be taken when selecting behavioral measures to assess cognitive functioning.

There was little evidence across these studies for a relationship between facilitation and inhibition of return effects. This was somewhat surprising, given that the two effects are often conceptualized as coupled processes. Both effects are dependent on regions of the posterior attention network, particularly regions involved in the control of eye movements (Rothbart & Posner, 2001). Many researchers treat inhibition of return as

a more mature version of facilitation, primarily because the inhibitory effects develop somewhat later and recruit neural systems in addition to those that mediate the facilitative effects (M. H. Johnson, 1990). However, studies that have carefully manipulated stimulus properties and timing parameters during covert orienting tasks have shown that facilitation and inhibition of return are dissociable effects (Berlucchi, 2006; Collie, Maruff, Yucel, Danckert, & Currie, 2000; Lupianez, Ruz, Funes, & Milliken, 2007; Pratt & Hirshhorn, 2003). The data from the present studies are consistent with these reports, suggesting that facilitation and inhibition of return effects of spatial cueing are qualitatively different. Measures of facilitation and inhibition of return were not related in any of the repeated test sessions. Furthermore, the facilitation and inhibition of return effects were related to the measures of novelty in very different ways. Infants who showed facilitation effects during the cueing task were faster to approach the toys overall during the free play task, regardless of the toy category. In addition, infants who showed facilitation effects demonstrated a preference for the novel face that was consistent with the overall group performance during the dishabituation task. Finally, genetic polymorphisms of *DAT-1* were most closely related to individual differences in measures of facilitation. Infants who showed inhibition of return effects during the spatial cueing task showed markedly different effects for all of these measures. Though these infants were fast to approach toys during the free play task, this rapid approach was specific to the novel toys. During the dishabituation task, infants who showed inhibition of return effects did not show a preference for the novel face, and in fact did not discriminate between the novel and familiar faces at all. Finally, it was variations in *COMT*, rather

than *DAT-1*, which were most closely related to individual differences in measures of inhibition of return. These data thus suggest that the facilitative and inhibitory effects elicited during the spatial cueing task are not mediated by the same underlying processes, at least among 7-month-old infants.

Interestingly, there was also some evidence that the orienting and reaction time measures of spatial cueing effects were dissociable. This was most evident for the inhibition of return measures, as the orienting and reaction time measures showed different relationships with other variables. In Study 2B, infants who showed inhibition of return effects on orienting tended to respond to novelty in a manner that was similar to the overall group. During the free play task, these infants were faster to approach the novel toys; however, continuous analyses indicated that the magnitude of inhibitory effects on orienting was not related to individual infants' propensity to rapidly approach the optimal novel toy. In addition, infants who showed inhibition of return effects on orienting showed a preference for the novel face during the dishabituation task that was consistent with the preference seen among the overall group. In contrast, infants who showed inhibition of return effects on reaction time showed an approach bias during the free play task that was specific to the optimal novel toy. Furthermore, these infants did not show the novelty preference that was typical of the overall group during the dishabituation task. These results suggest that orienting and reaction time measures may not reflect the same underlying process.

The genetic data collected in Study 2C provided unique insight to the neural systems involved in early selective attention. In particular, the results provided more

evidence of the interdependence of neural systems supporting different attention components. The different systems implicated in alerting, selectivity/orienting, and executive attention are likely dissociable to a degree, given evidence of maintenance of function following insults to one of these systems. However, the genetic data in this study demonstrate the importance of multiple systems for even a relatively simple attention task. Based on these results, both the cholinergic and dopaminergic systems play a role in reflexive orienting. Evidence for a significant contribution of *COMT* genotype in infants' reflexive orienting was particularly striking for two reasons. First, reflexive orienting tasks, including the spatial cueing task, have predominantly been considered to involve attention processes that are mediated by a posterior (e.g., parietal cortex, pulvinar, superior colliculus) attention network. Yet the influence of *COMT* genotype is typically seen in measures of frontal and prefrontal cortex functioning, suggesting that reflexive orienting also involves attention processes that are mediated by the anterior attention network. Second, most researchers have found the earliest behavioral evidence of prefrontal cortex developments and associated executive attention skills during late infancy and preschool ages. However, the contribution of *COMT* genotype in explaining individual variation in reflexive orienting suggests that at least some aspects of frontal cortex and executive attention systems are functioning by 7 months of age.

Overall, these studies provide important contributions to our understanding of early selective attention, while also highlighting the extreme complexity of the processes mediating infants' attention behaviors. The results of these studies clearly demonstrate that even a relatively "simple" measure of reflexive orienting is in fact quite complicated.

Within the context of the spatial cueing paradigm, infants demonstrated two behavioral effects – facilitation and inhibition of return – that appear to be at least somewhat independent. Varying results across measures of orienting and reaction time suggest that different processes may mediate these two aspects of reflexive selective attention. Furthermore, the genetic data suggest that the brain systems mediating reflexive orienting are not limited to the posterior attention network but instead likely also involve executive systems in the anterior attention network. Importantly, infants show a wide range of individual differences in their reflexive orienting behaviors. Though sensitivity to novelty may contribute to understanding these differences for some infants, there is likely a much broader array of factors that influences the observed variation. Finally, the extent of these individual differences means that the functional implications of reflexive orienting for early learning will also vary across infants. Though the current work identifies sensitivity to cueing as one factor that can contribute to the organization of infants' learning, it is certainly not the only cognitive process that fulfills this role. Instead, a vast number of factors can potentially resolve competition among multiple potentially relevant stimuli, and the precise influence of these factors on infant learning will likely depend on the relevant cognitive and neural interactions, the individual infant, and his/her developmental context.

Future Directions

This complexity of such seemingly basic attention processes can be intimidating when considering future research examining developing attention systems. However, there are a number of directions that will likely yield important contributions to our

understanding of early cognitive development. First, investigations of individual differences will be crucial for studies of infant cognitive development. The vast majority of cognitive development research conducted over the past several decades has exclusively focused on group analyses, effectively ignoring those infants whose behaviors are not consistent with the overall group. It is unquestionably crucial to understand the specific cognitive skills that are generally available in infancy and early childhood, as well as the timing of development of these skills. However, research that aims to understand the functional implications of early attention skills for other aspects of development will necessarily have to contend with the extensive individual differences evident even in infancy. Increasing use of longitudinal analyses will likely represent an important methodological advance for studies seeking to understand individual differences in early cognitive development.

Methods that allow for examination of the relationship between individual differences in behavior and biology also hold promise for future studies. To my knowledge, the current study is only the second study to examine the relationship between genetic polymorphisms and specific attention behaviors in infancy. Numerous studies have tried to identify the genetic precursors to development of disordered attention behaviors (e.g., ADHD). Though these studies have identified a huge range of candidate genes, replication failures are prevalent. These mixed findings are not particularly surprising given that ADHD encompasses such a complex profile of heterogeneous behaviors. Rather than focusing on identifying genes that "cause" ADHD, identifying genes that are associated with individual differences in typical component

processes of attention may be more fruitful in identifying factors that create susceptibility to ADHD. Furthermore, examining these relationships in infancy will help bridge the gap between biology, cognition, and behavioral development.

References

Alkondon, M., Pereira, E. F. R., Eisenberg, H. M., & Albuquerque, E. X. (2000). Nicotinic receptor activation in human cerebral cortical interneurons: a mechanism for inhibition and disinhibition of neuronal networks. *The Journal of Neuroscience, 20*(1), 66-75.

Amso, D., & Johnson, S. P. (2005). Selection and inhibition in infancy: evidence from the spatial negative priming paradigm. *Cognition, 95*, B27-B36.

Amso, D., & Johnson, S. P. (2006). Learning by selection: Visual search and object perception in young infants. *Developmental Psychology, 42*(6), 1236-1245.

Aslin, R. N., & Fiser, J. (2005). Methodological challenges for understanding cognitive development in infants. *Trends in Cognitive Sciences, 9*(3), 92-98. doi: 10.1016/j.tics.2005.01.003

Atkinson, J., Hood, B. M., Braddick, O. J., & Wattam-Bell, J. (1988). Infants' control of fixation shifts with single and competing targets: Mechanisms of shifting attention. *Perception, 17*, 367-368.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development, 62*, 875-890.

Barnett, J. H., Robbins, T. W., & Muller, U. (2007). Effects of the catechol-O-methyltransferase Val-158-Met polymorphism on executive function: a meta-

analysis of the Wisconsin Card Sort Test in schizophrenia and healthy controls. *Molecular Psychiatry, 12*, 502-509. doi: 10.1038/sj.mp.4001973

Barr, C. L., Xu, C., Kroft, J., Feng, Y., Wigg, K., Zai, G., et al. (2001). Haplotype study of three polymorphisms at the dopamine transporter locus confirm linkage to attention-deficit/hyperactivity disorder. *Biological Psychiatry, 49*, 333-339.

Bates, E., & Elman, J. (1996). Learning rediscovered. *Science, 274*(5294), 1849-1850.

Beane, M., & Marrocco, R. T. (2004). Norepineprhine and acetylcholine mediation of the components of reflexive attention: implications for attention deficit disorders. *Progress in Neurobiology, 74*, 167-181. doi: 10.1016/j.pneurobio.2004.09.001

Bellgrove, M. A., Chambers, C. D., Johnson, K. A., Daibhis, A., Day, M., Hawi, Z., et al. (2007). Dopaminergic genotype biases spatial attention in healthy children. *Molecular Psychiatry, 12*, 786-792.

Bellgrove, M. A., Hawi, Z., Kirley, A., Fitzgerald, M., Gill, M., & Robertson, I. H. (2005). Association between dopamine transporter (DAT1) genotype, left-sided inattention, and an enhanced response to methylphenidate in attention-deficit hyperactivity disorder. *Neuropsychopharmacology, 30*, 2290-2297. doi: 10.1038/sj.npp.1300839

Bellgrove, M. A., & Mattingley, J. B. (2008). Molecular genetics of attention. *Annals of the New York Academy of Sciences, 1129*, 200-212. doi: 10.1196/annals.1417.013

Benson, J., B., Cherny, S. S., Haith, M. M., & Fulker, D. W. (1993). Rapid assessment of infant predictors of adult IQ: Midtwin-midparent analyses. *Developmental Psychology, 29*(3), 434-447.

Berlucchi, G. (2006). Inhibition of return: A phenomenon in search of a mechanism and a better name. *Cognitive Neuropsychology, 23*(7), 1065-1074. doi: 10.1080/02643290600588426

Bertolino, A., Blasi, G., Latorre, V., Rubino, V., Rampino, A., Sinibaldi, L., et al. (2006). Additive effects of genetic variation in dopamine regulating genes on working memory cortical activity in human brain. *The Journal of Neuroscience, 26*(15), 3918-3922. doi: 10.1523/JNEUROSCI.4975-05.2006

Blasi, G., Mattay, V. S., Bertolino, A., Elvevag, B., Callicott, J. H., Das, S., et al. (2005). Effect of catechol-O-methyltransferase val158met genotype on attentional control. *The Journal of Neuroscience, 25*(20), 5038-5045. doi: 10.1523/JNEUROSCI.0476-05.2005

Boot, W. R., McCarley, J. S., Kramer, A. F., & Peterson, M. S. (2004). Automatic and intentional memory processes in visual search. *Psychonomic Bulletin & Review, 11*(5), 854-861.

Bornstein, M. H., & Benasich, A. A. (1986). Infant habituation: Assessments of individual differences and short-term reliability at five months. *Child Development, 57*(1), 87-99.

Bornstein, M. H., & Sigman, M. D. (1986). Continuity in mental development from infancy. *Child Development, 57*, 251-274.

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*, 179-181.

Brozoski, T. J., Brown, R. M., Rosvold, H. E., & Goldman, P. S. (1979). Cognitive deficit caused by regional depletion of dopamine in prefrontal cortex of rhesus monkey. *Science, 205*(4409), 929-932.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*(6), 215-222.

Butcher, P. R., Kalverboer, A. F., & Geuze, R. H. (1999). Inhibition of return in very young infants: A longitudinal study. *Infant Behavior and Development, 22*(3), 303-319.

Butcher, P. R., Kalverboer, A. F., & Geuze, R. H. (2000). Infants' shifts of gaze from a central to a peripheral stimulus: A longitudinal study of development between 6 and 26 weeks. *Infant Behavior and Development, 23*, 3-21.

Caldu, X., Vendrell, P., Bartres-Faz, D., Clemente, I., Bargallo, N., Jurado, M. A., et al. (2007). Impact of the COMT Val-108/158 Met and DAT genotypes on prefrontal function in healthy subjects. *NeuroImage, 37*, 1437-1444. doi: 10.1016/j.neuroimage.2007.06.021

Calkins, S. D., Fox, N. A., & Marshall, T. R. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. *Child Development, 67*(2), 523-540.

Canfield, R. L., Wilken, J., Schmerl, L., & Smith, E. (1995). Age-related change and stability of individual differences in infant saccade reaction time. *Infant Behavior and Development, 18*, 351-358.

Carter, C. S., Macdonald, A. W., Botvinick, M., Ross, L. L., Stenger, V. A., Noll, D., et al. (2000). Parsing executive processes: strategic vs. evaluative functions of the anterior cingulate cortex. *Proceedings of the National Academy of Sciences, 97*(4), 1944-1948.

Chen, J., Lipska, B. K., Halim, N., Ma, Q. D., Matsumoto, M., Melhem, S., et al. (2004). Functional analysis of genetic variation in catechol-O-methyltransferase (COMT): Effects on mRNA, protein, and enzyme activity in postmortem human brain. *American Journal of Human Genetics, 75*, 807-821.

Clohessy, A. B., Posner, M. I., Rothbart, M. K., & Vecera, S. P. (1991). The development of inhibition of return in early infancy. *Journal of Cognitive Neuroscience, 3*(4), 345-350.

Collie, A., Maruff, P., Yucel, M., Danckert, J., & Currie, J. (2000). Spatiotemporal distribution of facilitation and inhibition of return arising from the reflexive orienting of covert attention. *Journal of Experimental Psychology: Human Perception and Performance, 26*(6), 1733-1745. doi: 10.1037//0096-" "' 0.1037//0096-1523.26.6.1733

Colombo, J., Mitchell, D. W., & Horowitz, F. D. (1988). Infant visual attention in the paired-comparison paradigm: Test-retest and attention-performance relations. *Child Development, 59*(5), 1198-1210.

Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987). The stability of visual habituation during the first year of life. *Child Development, 58*(2), 474-487.

Congdon, E., Lesch, K. P., & Canli, T. (2008). Analysis of DRD4 and DAT polymorphisms and behavioral inhibition in healthy adults: implications for impulsivity. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 147B*, 27-32. doi: 10.1002/ajmg.b.30557

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience, 3*(3), 292-297.

Cornish, K. M., Manly, T., Savage, R., Swanson, J. M., Morisano, D., Butler, N., et al. (2005). Association of the dopamine transporter (DAT1) 10/10-repeat genotype with ADHD symptoms and response inhibition in a general population sample. *Molecular Psychiatry, 10*, 686-698.

Cornish, K. M., Wilding, J. M., & Hollis, C. P. (2008). Visual search performance in children rates as good or poor attenders: The differential impact of DAT1 genotype, IQ, and chronological age. *Neuropsychology, 22*(2), 217-225. doi: 10.1037/0894-4105.22.2.217

Coull, J. T., Nobre, A. C., & Frith, C. D. (2001). The noradrenergic α2 agonist clonidine modulates behavioural and neuroanatomical correlates of human attentional orienting and alerting. *Cerebral Cortex, 11*, 73-84.

Courage, M. L., & Howe, M. L. (2001). Long-term retention in 3.5-month-olds: Familiarization time and individual differences in attentional style. *Journal of Experimental Child Psychology, 79*, 271-293. doi: doi:10.1006/jecp.2000.2606,

Courage, M. L., Howe, M. L., & Squires, S. E. (2004). Individual differences in 3.5-month-olds' visual attention: what do they predict at 1 year? *Infant Behavior and Development, 27*, 19-30.

Craft, S., & Schatz, J. (1994b). The effects of bifrontal stroke during childhood on visual attention: Evidence from children with sickle cell anemia. *Developmental Neuropsychology, 10*(3), 285-297.

Davidson, M. C., & Marrocco, R. T. (2000). Local infusion of scopolamine into intraparietal cortex slows covert orienting in rhesus monkeys. *Journal of Neurophysiology, 83*, 1536-1549.

Davidson, R. J. (1992). Emotion and affective style: Hemispheric substrates. *Psychological Science, 3*(1), 39-43.

Davidson, R. J., & Fox, N. A. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science, 218*(4578), 1235-1237.

Dayan, P., Kakade, S., & Montague, P. R. (2000). Learning and selective attention. *Nature Neuroscience, 3*, 1218-1223.

Depue, R. A., & Iacono, W. G. (1989). Neurobehavioral aspects of affective disorders. *Annual Review of Psychology, 40*, 457-492.

Derryberry, D., & Reed, M. A. (1994). Temperament and the self-organization of personality. *Developmental and Psychopathology, 6*, 653-676.

Diamond, A., Briand, L., Fossella, J. A., & Gehlbach, L. (2004). Genetic and neurochemical modulation of prefrontal cognitive functions in children. *American Journal of Psychiatry, 161*(1), 125-132.

Diaz-Asper, C. M., Goldberg, T. E., Kolachana, B. S., Straub, R. E., Egan, M. F., & Weinberger, D. R. (2008). Genetic variation in catechol-O-methyltransferase:

Effects on working memory in schizophrenic patients, their siblings, and healthy controls. *Biological Psychiatry, 63*, 72-79. doi: 10.1016/j.biopsych.2007.03.031

DiLalla, L. F., Thompson, L. A., Plomin, R., Phillips, K., Fagan, J. F., & Haith, M. M. (1990). Infant predictors of preschool and adult IQ: A study of infant twins and their parents. *Developmental Psychology, 26*(5), 759-769.

Duncan, J. (2006). Brain mechanisms of attention. *The Quarterly Journal of Experimental Psychology, 59*(1), 2-27. doi: 10.1080/17470210500260674

Egan, M. F., Goldberg, T. E., Kolachana, B. S., Callicott, J. H., Mazzanti, C. M., Straub, R. E., et al. (2001). Effect of COMT Val108/158 Met genotype on frontal lobe function and risk for schizophrenia. *Proceedings of the National Academy of Sciences, 98*(12), 6917-6922. doi: 10.1073/pnas. 111134598

Eisenberg, J., Mei-Tal, G., Steinberg, A., Tartakovsky, E., Zohar, A., Gritsenko, I., et al. (1999). Haplotype relative risk study of catechol-O-methyltransferase (COMT) and attention deficit hyperactivity disorder (ADHD): Association of the high-enzyme activity Val allele with ADHD impulsive-hyperactive phenotype. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 88*, 497-502.

Everitt, B. J., Morris, K. A., O'Brien, A., & Robbins, T. W. (1991). The basolateral amygdala-ventral striatal system and conditioned place preference: Further

evidence of limbic-striatal interactions underlying reward-related processes. *Neuroscience, 42*(1), 1-18.

Everitt, B. J., & Robbins, T. W. (1997). Central cholinergic systems and cognition. *Annual Review of Psychology, 48*, 649-684.

Fagan, J. F. (1984). The relationship of novelty preferences during infancy to later intelligence and later recognition memory. *Intelligence, 8*, 339-346.

Fan, J., Flombaum, J. I., McCandliss, B. D., Thomas, K. M., & Posner, M. I. (2003). Cognitive and brain consequences of conflict. *NeuroImage, 18*, 42-57. doi: 10.1006/nimg.2002.1319

Fantz, R. L. (1963). Pattern vision in newborn infants. *Science, 140*(3564), 296-297.

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition, 7*(6), 705-718.

Farroni, T., Mansfield, E. M., Lai, C., & Johnson, M. H. (2003). Infants perceiving and acting on the eyes: Tests of an evolutionary hypothesis. *Journal of Experimental Child Psychology, 85*, 199-212. doi: 10.1016/S0022-0965(03)00022-5

Fenson, L., Sapper, V., & Minner, D. G. (1974). Attention and manipulative play in the one-year-old child. *Child Development, 45*(3), 757-764.

Fernandez-Duque, D., & Johnson, M. L. (2002). Cause and effect theories of attention: The role of conceptual metaphors. *Review of General Psychology, 6*(2), 153-165.

Fiser, J., & Aslin, R. N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences, 99*, 15822-15826.

Fisher, A. (2007). Are developmental theories of learning paying attention to attention? *Cognition, Brain, Behavior, XI*(4), 635-646.

Forbes, E. E., Brown, S. M., Kimak, M., Ferrell, R. E., Manuck, S. B., & Hariri, A. R. (2009). Genetic variation in components of dopamine neurotransmission impacts ventral striatal reactivity associated with impulsivity. *Molecular Psychiatry, 14*, 60-70. doi: 10.1038/sj.mp.4002086

Fossella, J. A., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., et al. (2002). Assessing the molecular genetics of attention networks. *BMC Neuroscience, 3*, 14.

Fox, N. A., & Davidson, R. J. (1984). Hemispheric substrates of affect: A developmental model. In N. A. Fox & R. J. Davidson (Eds.), *The psychobiology of affective development* (pp. 353-381). Hillsdale, NJ: Erlbaum.

Freed, C. R., & Yamamoto, B. K. (1985). Regional brain dopamine metabolism: A marker for the speed, direction, and posture of moving animals. *Science, 229*(4708), 62-65.

Fuke, S., Suo, S., Takahashi, N., Koike, H., Sasagawa, N., & Ishiura, S. (2001). The VNTR polymorphism of the human dopamine transporter (DAT1) gene affects gene expression. *The Pharmacogenomics Journal, 1*, 152-156.

Gartstein, M. A., & Rothbart, M. K. (2003). Studying infant temperament via the revised infant behavior questionnaire. *Infant Behavior and Development, 26*, 64-86.

Gasparini, M., Fabrizio, E., Bonifati, V., & Meco, G. (1997). Cognitive improvement during Tolcapone treatment in Parkinson's disease. *Journal of Neural Transmission, 104*, 887-894.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39*, 1-41.

Gogos, J. A., Morgan, M., Luine, V., Santha, M., Ogawa, S., Pfaff, D. W., et al. (1998). Catechol-O-methyltransferase-deficient mice exhibit sexually dimorphic changes in catecholamine levels and behavior. *Proceedings of the National Academy of Sciences, 95*(17), 9991-9996.

Gray, J. A. (1987). *The psychology of fear and stress*. New York: McGraw-Hill.

Gray, J. A. (1991). Neural systems, emotion, and personality. In J. Madden (Ed.), *Neurobiology of Learning, Emotion, and Affect* (pp. 273-306). New York: Raven Press.

Greenwood, P. M., Fossella, J. A., & Parasuraman, R. (2005). Specificity of the effect of a nicotinic receptor polymorphism on individual differences in visuospatial attention. *Journal of Cognitive Neuroscience, 17*(10), 1611-1620.

Greenwood, P. M., Lin, M.-K., Sundararajan, R., Fryxell, K. J., & Parasuraman, R. (2009). Synergistic effects of genetic variation in nicotini and muscarinic receptors on visual attention but not working memory. *Proceedings of the National Academy of Sciences, 106*(9), 3633-3638. doi: 0.1073pnas.0807891106

Haith, M. M., & McCarty, M. E. (1990). Stability of visual expectations at 3.0 months of age. *Developmental Psychology, 26*(1), 68-74.

Handy, T. C., Jha, A. P., & Mangun, G. R. (1999). Promoting novelty in vision: Inhibition of return modulates perceptual-level processing. *Psychological Science, 10*(2), 157-161.

Harman, C., Posner, M. I., Rothbart, M. K., & Thomas-Thrapp, L. (1994). Development of orienting to locations and objects in human infants. *Canadian Journal of Experimental Psychology, 48*(2), 301-318.

Heinz, A., Goldman, D., Jones, D. W., Palmour, R., Hommer, D., Gorey, J. G., et al. (2000). Genotype influences *in vivo* dopamine transporter availability in human striatum. *Neuropsychopharmacology, 22*(2), 133-139.

Holmboe, K., Fearon, R. M. P., Csibra, G., Tucker, L. A., & Johnson, M. H. (2008). Freeze-frame: A new infant inhibition task and its relation to frontal cortex tasks

during infancy and early childhood. *Journal of Experimental Child Psychology, 100*, 89-114. doi: 10.1016/j.jecp.2007.09.004

Holmboe, K., Nemoda, Z., Fearon, R. M. P., Csibra, G., Sasvari-Szekely, M., & Johnson, M. H. (2010). Polymorphisms in dopamine system genes are associated with individual differences in attention in infancy. *Developmental Psychology, 46*(2), 404-416. doi: 10.1037/a0018180

Hood, B. M. (1993). Inhibition of return produced by covert shifts of visual attention in 6-month-old infants. *Infant Behavior & Development, 16*, 245-254.

Hood, B. M. (1995). Shifts of visual attention in the human infant: A neuroscientific approach. *Advances in Infancy Research, 10*, 163-216.

Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science, 9*(2), 131-134.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 53-112). Orlando, FL: Academic Press.

Hunnius, S. (2007). The early development of visual attention and its implications for social and cognitive development. *Progress in Brain Research, 164*, 187-209. doi: 10.1016/S0079-6123(07)64010-2

Ivanoff, J., & Klein, R. M. (2001). The presence of a nonresponding effector increases inhibition of return. *Psychonomic Bulletin & Review, 8*(2), 307-314.

Iversen, S. D. (1984). Behavioural effects of manipulation of basal ganglia neurotransmitters. *Ciba Foundation Symposium, 107*, 183-200.

Izard, C. E. (1977). *Human emotions*. New York: Plenum.

Jacobsen, L. K., Staley, J. K., Zoghbi, S. S., Seibyl, J. P., Kosten, T. R., Innis, R. B., et al. (2000). Prediction of dopamine transporter binding availability by genotype: a preliminary report. *American Journal of Psychiatry, 157*, 1700-1703.

James, W. (1890). *The principles of psychology* (Vol. 1). New York, NY: Henry Holt and Co.

Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience, 2*(2), 81-95.

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition, 40*, 1-19.

Johnson, M. H., & Tucker, L. A. (1996). The development and temporal dynamics of spatial orienting in infants. *Journal of Experimental Child Psychology, 63*, 171-188.

Johnson, M. H., Tucker, L. A., Stiles, J., & Trauner, D. (1998). Visual attention in infants with perimatal brain damage: Evidence of the importance of anterior lesions. *Developmental Science, 1*(1), 53-58.

Johnson, S. P., Slemmer, J. A., & Amso, D. (2004). Where infants look determines how they see: Eye movements and object perception performance in 3-month-olds. *Infancy, 6*(2), 185-201.

Kang, A. M., Palmatier, M. A., & Kidd, K. K. (1999). Global variation of a 40-bp VNTR in the 3'-untranslated region of the dopamine transporter gene (SLC6A3). *Biological Psychiatry, 46*, 151-160.

Kanwisher, N., & Wojciulik, E. (2000). Visual attention: Insights from brain imaging. *Nature Reviews Neuroscience, 1*, 91-100.

Kerns, J. G., Cohen, J. D., Macdonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303*(5660), 1023-1026.

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: evidence for a domain general learning mechanism. *Cognition, 83*, B35-B42.

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, location, location: Development of spatiotemporal sequence learning in infancy. *Child Development, 78*(5), 1559-1571.

Klein, R. M. (1988). Inhibitory tagging system facilitates visual search. *Nature, 334*(4), 430-431.

Klein, R. M. (2000). Inhibition of return. *TRENDS in Cognitive Sciences, 4*(4), 138-147.

Langton, S. R. H., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences, 4*(2), 50-59.

Lewkowicz, D. J., & Berent, I. (2009). Sequence learning in 4-month-old infants: Do infants represent ordinal information? *Child Development, 80*(6), 1811-1823.

Loo, S. K., Specter, E., Smolen, A., Hopfer, C., Teale, P. D., & Reite, M. L. (2003). Functional effects of the DAT1 polymorphism on EEG measures in ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry, 42*(8), 986-993. doi: 10.1097/01.CHI.0000046890.27264.88

Lupianez, J., Klein, R. M., & Bartolomeo, P. (2006). Inhibition of return: Twenty years after. *Cognitive Neuropsychology, 23*(7), 1003-1014. doi: 10.1080/02643290600588095

Lupianez, J., Ruz, M., Funes, M. J., & Milliken, B. (2007). The manifestation of attentional capture: facilitation or IOR depending on task demands. *Psychological Research, 71*, 77-91. doi: 10.1007/s00426-005-0037-z

Macinnes, J. W., & Klein, R. M. (2003). Inhibition of return biases orienting during the search of complex scenes. *Scientific World Journal, 3*, 75-86.

Mannisto, P. T., & Kaakkola, S. (1999). Catechol-O-methyltransferase (COMT): Biochemistry, molecular biology, pharmacology, and clinical efficacy of the new selective COMT inhibitors. *Pharmacological Reviews, 51*(4), 593-628.

Maruff, P., Hay, D., Malone, V., & Currie, J. (1995). Asymmetries in the covert orienting of visual spatial attention in schizophrenia. *Neuropsychologia, 33*(10), 1205-1223.

Matsuzawa, M. (2001). Development of saccade target selection in infants. *Perceptual and Motor Skills, 93*, 115-123.

Mattay, V. S., Goldberg, T. E., Fera, F., Hariri, A. R., Tessitore, A., Egan, M. F., et al. (2003). Catechol-O-methyltransferase val158-met genotype and individual variation in the brain response to amphetamine. *Proceedings of the National Academy of Sciences, 100*(10), 6186-6191. doi: .1073/pnas.0931309100

McCall, R. B., & Carriger, M. S. (1993). A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child Development, 64*(1), 57-79.

McCarley, J. S., Wang, R. F., Kramer, A. F., Irwin, D. E., & Peterson, M. S. (2003). How much memory does oculomotor search have? *Psychological Science, 14*(5), 422-426.

McConnell, B. A., & Bryson, S. E. (2005). Visual attention and temperament: Developmental data from the first 6 months of life. *Infant Behavior and Development, 28*, 537-544. doi: 10.1016/j.infbeh.2005.09.002

McCulloch, J., Savaki, H. E., McCulloch, M. C., Jehle, J., & Sokokoff, L. (1982). The distribution of alterations in energy metabolism in the rat brain produced by apomorphine. *Brain Research, 243*, 67-80.

Mentis, M. J., Sunderland, T., Lai, J., Connolly, C., Krasuski, J., Levine, B., et al. (2001). Muscarinic versus nicotinic modulation of a visual task: A PET study using drug probes. *Neuropsychopharmacology, 25*(4), 555-564.

Mesulam, M.-M. (1981). A cortical network for directed attention and unilateral neglect. *Annals of Neurology, 10*, 309-325.

Meyer-Lindenberg, A., Nichols, T., Callicott, J. H., Ding, J., Kolachana, B. S., Buckholtz, J., et al. (2006). Impact of complex genetic variation in *COMT* on human brain function. *Molecular Psychiatry, 11*, 867-877. doi: 10.1038/sj.mp.4001860

Mier, D., Kirsch, P., & Meyer-Lindenberg, A. (2009). Neural substrates of pleiotropic action of genetic variation in *COMT*: a meta-analysis. *Molecular Psychiatry*, 1-10. doi: 10.1038/mp.2009.36

Mill, J., Asherson, P., Browes, C., D'Souza, U., & Craig, I. (2002). Expression of the dopamine transporter gene is regulated by the 3' UTR VNTR: evidence from brain and lymphocytes using quantitative RT-PCR. *American Journal of Human Genetics, 114*, 975-979. doi: 10.1002/ajmg.10948

Miller, G. M., & Madras, B. K. (2002). Polymorphisms in the 3'-untranslated region of human and monkey dopamine transporter genes affect reporter gene expression. *Molecular Psychiatry, 7*, 44-55. doi: 10.1038/sj/mp/4000921

Moore, T., & Fallah, M. (2001). Control of eye movements and spatial attention. *Proceedings of the National Academy of Sciences, 98*, 1273-1276.

Moore, T., & Fallah, M. (2004). Microstimulation of the frontal eye field and its effect on covert spatial attention. *Journal of Neurophysiology, 91*, 152-162.

Nahmias, C., Garnett, E. S., Firnau, G., & Lang, A. (1985). Striatal dopamine distribution in parkinsonian patients during life. *Journal of the Neurological Sciences, 69*, 223-230.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220-246. doi: 10.1037//0033-2909.126.2.220

Nolan, K. A., Bilder, R. M., Lachman, H. M., & Volavka, J. (2004). Catechol-O-methyltransferase Val158Met polymorphism in schizophrenia: differential effects of Val and Met alleles on cognitive stability and flexibility. *American Journal of Psychiatry, 161*, 359-361.

Panksepp, J. (1982). Toward a general psychobiological theory of emotions. *Behavioral and Brain Sciences, 5*, 407-467.

Panksepp, J. (1986). The anatomy of emotions. In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory, Research, and Experience: Vol. 3. Biological foundations of emotions* (pp. 91-124). San Diego, CA: Academic Press.

Parasuraman, R., & Espeseth, T. (2007). Genetic and neuroimaging studies of cholinergic-neurotrophic modulation of visual attention. *Progress in Natural Science, 17*, 7-18.

Parasuraman, R., Greenwood, P. M., Haxby, J. V., & Grady, C. L. (1992). Visuospatial attention in the dementia of the alzheimer type. *Brain, 115*(3), 711-733.

Parasuraman, R., Greenwood, P. M., Kumar, R., & Fossella, J. A. (2005). Beyond heritability: Neurotransmitter genes differentially modulate visuospatial attention and working memory. *Psychological Science, 16*(3), 200-207.

Parasuraman, R., Greenwood, P. M., & Sunderland, T. (2002). The apolipoprotein E gene, attention, and brain function. *Neuropsychology, 16*(2), 254-274.

Pearce, J. M., & Hall, G. (1980). A model for pavlovian learning: Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review, 87*(6), 532-552.

Poirier, J., Delisle, M.-C., Quirion, R., Aubert, I., Farlow, M., Lahiri, D., et al. (1995). Apolipoprotein E4 allele as a predictor of cholinergic deficits and treatment outcome in Alzheimer disease. *Proceedings of the National Academy of Sciences, 92*, 12260-12264.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review, 78*(5), 391-408.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bouwhuis (Eds.), *Attention and Performance* (Vol. X, pp. 531-556). Hillsdale, NJ: Erlbaum Lawrence Associates.

Posner, M. I., & Dehaene, S. (2000). Attentional networks. In M. S. Gazzaniga (Ed.), *Cognitive Neuroscience: A Reader* (pp. 156-164). Malden, MA: Blackwell Publishers.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology, 2*(3), 211-228.

Posner, M. I., & Raichle, M. E. (1994). *Images of Mind*. New York: Scientific American Library.

Posner, M. I., Rothbart, M. K., & Thomas-Thrapp, L. (1997). Functions of orienting in early infancy. In P. J. Lang, R. F. Simons & M. T. Balaban (Eds.), *Attention and*

Orienting: Sensory and Motivational Processes (pp. 327-346). Mahwah, NJ: Lawrence Erlbaum Associates.

Posner, M. I., Rothbart, M. K., Thomas-Thrapp, L., & Geradi, G. (1998). Development of orienting to locations and objects. In R. D. Wright (Ed.), *Visual Attention* (pp. 269-288). New York: Oxford University Press.

Pratt, J., & Hirshhorn, M. (2003). Examining the time course of facilitation and inhibition with simultaneous onset and offset cues. *Psychological Research, 67*, 261-265. doi: 10.1007/s00426-003-0130-0

Putnam, S. P., & Stifter, C. A. (2002). Development of approach and inhibition in the first year: parallel findings from motor behavior, temperament ratings and directional cardiac response. *Developmental Science, 5*(4), 441-451.

Reid, V., & Striano, T. (2005). Adult gaze influences infant attention and object processing: implications for cognitive neuroscience. *European Journal of Neuroscience, 21*, 1763-1766.

Reid, V., Striano, T., Kaufman, J., & Johnson, M. H. (2004). Eye gaze cueing facilitates neural processing of objects in 4-month-old infants. *NeuroReport, 15*, 2553-2555.

Reinvang, I., Lundervold, A. J., Rootwelt, H., Wehling, E., & Espeseth, T. (2009). Individual variation in a cholinergic receptor gene modulates attention. *Neuroscience Letters, 453*, 131-134. doi: 10.1016/j.neulet.2009.02.029

Richards, J. E. (2001). Attention in young infants: A developmental psychophysiological perspective. In C. A. Nelson & M. Luciana (Eds.), *Handbook of Developmental Cognitive Neuroscience* (pp. 321-338). Cambridge, MA: The MIT Press.

Richards, J. E. (2003). The development of visual attention and the brain. In M. de Haan & M. H. Johnson (Eds.), *The Cognitive Neuroscience of Development* (pp. 73-98). Hove and New York: Psychology Press.

Ritz, E. G., Woodruff, A. B., & Fagen, J. W. (1984). Short- and long-term stability of habituation rate and looking time in four-month-old infants. *The Journal of Genetic Psychology, 144*, 285-286.

Robbins, T. W., Cador, M., Taylor, J. R., & Everitt, B. J. (1989). Limbic-striatal interactions in reward-related processes. *Neuroscience and Biobehavioral Reviews, 13*(2/3), 155-162.

Rodriques-Pinguet, N., Jia, L., Li, M., Figl, A., Klaassen, A., Truong, A., et al. (2003). Five ADNFLE mutations reduce the Ca2+ dependence of the mammalian α4β2 acetylcholine response. *The Journal of Physiology, 550*(1), 11-26. doi: 10.1113/jphysiol.2003.036681

Roesch, M. R., Calu, D. J., Esber, G. R., & Schoenbaum, G. (2010). Neural correlates of variations in even processing during learning in basolateral amygdala. *The Journal of Neuroscience, 30*(7), 2464-2471. doi: 10.1523/JNEUROSCI.5781-09.2010

Rose, S. A., & Feldman, J. F. (1987). Infant visual attention: Stability of individual differences from 6 to 8 months. *Developmental Psychology, 23*(4), 490-498.

Rothbart, M. K. (1981). Measurement of temperament in infancy. *Child Development, 52*, 569-578.

Rothbart, M. K. (1986). Longitudinal observation of infant temeprament. *Developmental Psychology, 22*(3), 356-365.

Rothbart, M. K. (1988). Temperament and the development of inhibited approach. *Child Development, 59*(5), 1241-1250.

Rothbart, M. K. (2007). Temperament, development, and personality. *Current Direction in Psychological Science, 16*, 207-212. doi: 10.1111/j.1467-8721.2007.00505.x

Rothbart, M. K., Ahadi, S. A., & Hershey, K. L. (1994). Temperament and social behavior in childhood. *Merrill-Palmer Quarterly, 40*, 21-29.

Rothbart, M. K., & Derryberry, D. (1981). Development of individual differences in temperament. In M. E. Lamb & A. L. Brown (Eds.), *Advances in Developmental Psychology* (Vol. 1, pp. 37-86). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rothbart, M. K., Derryberry, D., & Hershey, K. (1993). Stability of temperament in childhood: Laboratory infant assessment to parent report at seven years. In V. J. Molfese & D. L. Molfese (Eds.), *Temperament and Personality Development Across the Life Span* (pp. 85-119). Mahwah, NJ: Lawrence Erlbaum Associates.

Rothbart, M. K., Derryberry, D., & Hershey, K. (2000). Stability of temperament in childhood: Laboratory infant assessment to parent report at seven years. In V. J. Molfese & D. L. Molfese (Eds.), *Temperament and Personality Development Across the Life Span* (pp. 85-119). Mahwah, NJ: Lawrence Erlbaum Associates.

Rothbart, M. K., Derryberry, D., & Posner, M. I. (1994). A psychobiological approach to the development of temperament. In J. E. Bates & T. D. Wachs (Eds.), *Temperament: Individual differences at the interface of biology and behavior* (pp. 83-116). Washington, DC: American Psychological Association.

Rothbart, M. K., & Mauro, J. A. (1990). Questionnaire approaches to the study of infant temperament. In J. Colombo & J. W. Fagen (Eds.), *Individual differences in infancy: Reliability, stability, prediction* (pp. 411-429). Hillsdale, NJ: Erlbaum.

Rothbart, M. K., & Posner, M. I. (2001). Mechanism and variation in the development of attentional networks. In C. A. Nelson & M. Luciana (Eds.), *Handbook of Developmental Cognitive Neuroscience*. Cambridge, MA: MIT Press.

Rovee-Collier, C., Earley, L., & Stafford, S. (1989). Ontogeny of early event memory: III. Attentional determinants of retrieval at 2 and 3 months. *Infant Behavior and Development, 12*, 147-161.

Rovee-Collier, C., & Giles, A. (2010). Why a neuromaturational model of memory fails: Exuberant learning in early infancy. *Behavioural Processes, 83*, 197-206.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences, 102*(41), 14931-14936. doi: /10.1073/pnas.0506897102

Ruff, H. A., & Rothbart, M. K. (1996). *Attention in early development: Themes and variations*. New York: Oxford University Press.

Ruff, H. A., & Turkewitz, G. (1979). Changing role of stimulus intensity as a determinant of infants' attention. *Perceptual and Motor Skills, 48*, 815-826.

Saffran, J. R. (2003). Statistical language learning: Mechanisms and constraints. *Current Direction in Psychological Science, 12*(4), 110-114.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*(1926-1928).

Saffran, J. R., Newport, E. L., Aslin, R. N., Tunick, R. A., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the corner of your ear. *Psychological Science, 8*(2), 101-105.

Sarter, M., & Bruno, J. P. (1999). Cortical cholinergic inputs mediating arousal, attentional processing and dreaming: Differential afferent regulation of the basal forebrain by telencephalic and brainstem afferents. *Neuroscience, 95*(4), 933-952.

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Research Reviews, 35*, 146-160.

Sarter, M., Hasselmo, M. E., Bruno, J. P., & Givens, B. (2005). Unraveling the attentional functions of cortical cholinergic inputs: interactions between signal-driven and cognitive modulation of signal detection. *Brain Research Reviews, 48*, 98-111. doi: 10.1016/j.brainresrev.2004.08.006

Schneirla, T. C. (1959). An evolutionary and developmental theory of biphasic processes underlying approach and withdrawal. In M. R. Jones (Ed.), *Nebraska Symposium on Motivation* (pp. 1-42). Lincoln: University of Nebraska Press.

Schultz, W., & Dickinson, A. (2000). Neuronal coding of prediction errors. *Annual Review of Neuroscience, 23*, 473-500.

Seamans, J. K., & Yang, C. R. (2004). The principal features and mechanisms of dopamine modulation in the prefrontal cortex. *Progress in Neurobiology, 74*, 1-57. doi: 10.1016/j.pneurobio.2004.05.006

Sesack, S. R., Hawrylak, V. A., Matus, C., Guido, M. A., & Levey, A. I. (1998). Dopamine axon varicosities in the prelimbic division of the rat prefrontal cortex exhibit sparse immunoreactivity for the dopamine transporter. *The Journal of Neuroscience, 18*(7), 2697-2708.

Sheese, B. E., Rothbart, M. K., Posner, M. I., White, L. K., & Fraundorf, S. H. (2008). Executive attention and self-regulation in infancy. *Infant Behavior & Development, 31*, 501-510.

Shirtcliff, E. A., & Marrocco, R. T. (2003). Salivary cotitine levels in human tobacco smokers predict the attentional validity effect size during smoking abstinence. *Psychopharmacology, 166*, 11-18. doi: 10.1007/s00213-002-1293-x

Stanwood, G. D., Washington, R. A., Shumsky, J. S., & Levitt, P. (2001). Prenatal cocaine exposure produces consistent developmental alterations in dopamine-rich regions of the cerebral cortex. *Neuroscience, 106*(1), 5-14.

Stefanis, N. C., van Os, J., Avramopoulos, D., Smyrnis, N., Evdokimidis, I., & Stefanis, C. N. (2005). Effect of COMT Val158Met polymorphism on the continuous performance test, identical pairs version: tuning rather than improving perfromance. *American Journal of Psychiatry, 162*, 1752-1754.

Theuring, C., Gredeback, G., & Hauf, P. (2007). Object processing during a joint gaze following task. *European Journal of Developmental Psychology, 4*(1), 65-79.

Thompson, K. G., Biscoe, K. L., & Sato, T. R. (2005). Neuronal basis of covert spatial attention in the frontal eye field. *The Journal of Neuroscience, 25*(41), 9479-9487. doi: 10.1523/JNEUROSCI.0741-05.2005

Tottenham, N. (1998). MacBrain Face Stimulus Set. *John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development*. Chicago, IL.

Tucker, D. M., & Williamson, P. A. (1984). Asymmetric neural control systems in human self-regulation. *Psychological Review, 91*(2), 185-215.

Tunbridge, E. M., Bannerman, D. M., Sharp, T., & Harrison, P. J. (2004). Catechol-O-methyltransferase inhibition improves set-shifting performance and elevates stimulated dopamine release in the rat prefrontal cortex. *The Journal of Neuroscience, 24*(23), 5331-5335. doi: 10.1523/JNEUROSCI.1124-04.2004

Valenza, E., Simion, F., Cassia, V. M., & Umilta, C. (1996). Face preference at birth. *Journal of Experimental Psychology: Human Perception and Performance, 22*(4), 892-903.

Valenza, E., Simion, F., & Umilta, C. (1994). Inhibition of return in newborn infants. *Infant Behavior & Development, 17*, 293-302.

van de Giessen, E. M., de Win, M., M.L., Tanck, M. W. T., van den Brink, W., Baas, F., & Booij, J. (2008). Striatal dopamine transporter availability associated with polymorphisms in the dopamine transporter gene SLC6A3. *Journal of Nuclear Medicine, 50*, 45-52. doi: 10.2967/jnumed.108.053652

van Dyck, C. H., Malison, R. T., Jacobsen, L. K., Seibyl, J. P., Staley, J. K., Laruelle, M., et al. (2005). Increased dopamine transporter availability associated with the 9-repeat allele of the SLC6A3 gene. *Journal of Nuclear Medicine, 46*, 745-751.

Vandenbergh, D. J., Persico, A. M., Hawkins, A. L., Griffin, C. A., Li, X., Jabs, E. W., et al. (1992). Human dopamine transporter gene (DAT1) maps to chromosome 5p15.3 and displays a VNTR. *Genomics, 14*, 1104-1106.

Vandenbergh, D. J., Thompson, M. D., Cook, E. H., Bendahhou, E., Nguyen, T., Krasowski, M. D., et al. (2000). Human dopamine transporter gene: coding region conservation among normal, Tourette's disorder, alcohol dependence and attention-deficit hyperactivity disorder populations. *Molecular Psychiatry, 5*(3), 283-292.

VanNess, S. H., Owens, M. J., & Kilts, C. D. (2005). The variable number of tandem repeats element in DAT1 regulates *in vitro* dopamine transporter density. *BMC Genetics, 6*(55). doi: 10.1186/1471-2156-6-55

von der Malsburg, C. (1995). Binding in models of perception and brain function. *Current Opinion in Neurobiology, 5*, 520-526.

Watanabe, M., Kodama, T., & Hikosaka, K. (1997). Increase of extracellular dopamine in primate prefrontal cortex during a working memory task. *Journal of Neurophysiology, 78*, 2795-2798.

Weinshilboum, R. M., Otterness, D. M., & Szumlanski, C. L. (1999). Methylation pharmacogenetics: Catechol-O-methyltransferase, thiopurine methyltransferase, and histamine-N-methyltransferase. *Annual Review of Pharmacology and Toxicology, 39*, 19-52.

Winterer, G., Musso, F., Konrad, A., Vucurevic, G., Stoeter, P., Sander, T., et al. (2007). Association of attentional network function with exon 5 variations of the CHRNA4 gene. *Human Molecular Genetics, 16*(18), 2165-2174. doi: 10.1093/hmg/ddm168

Witte, E. A., Davidson, M. C., & Marrocco, R. T. (1997). Effects of altering brain cholinergic activity on covert orienting of attention: comparison of monkey and human performance. *Psychopharmacology, 132*, 324-334.

Wonodi, I., Hong, L. E., Stine, O. C., Mitchell, B. D., Elliott, A., Roberts, R. C., et al. (2009). Dopamine transporter polymorphism modulates oculomotor function and DAT1 mRNA expression in schizophrenia. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 150B*, 282-289. doi: 10.1002/ajmg.b.30811

Woodward, A. L. (2000). Constraining the problem space in early word learning. In R. M. Golinkoff et al. (Ed.), *Becoming a word learner: A debate on lexical acquisition* (pp. 81-114). New York, NY: Oxford University Press.

Wright, R. D., & Richard, C. M. (1998). Inhibition-of-Return is not reflexive. In R. D. Wright (Ed.), *Visual Attention* (pp. 330-347). New York: Oxford University Press.