Attention and the Early Development of Cognitive Control

Infants’ and Toddlers’ Performance on the A-not-B task

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Dissertation presented at Uppsala University to be publicly examined in Gustavianum, ,
Uppsala. Friday, February 24, 2012 at 10:15 for the degree of Doctor of Philosophy. The
examination will be conducted in Swedish.

Abstract
Forsman, L. 2012. Attention and the Early Development of Cognitive Control: Infants’
Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences 74.

In the first years of life there is a dramatic development of cognitive abilities supporting
cognitive control of behavior. This development allows the child to make future-oriented
predictions and to increasingly act in a goal-directed manner. The early development of
cognitive control is presumably closely tied to the maturation of the attention systems. Further,
attentional control processes have been suggested to be the unifying construct underlying
cognitive control in both children and adults. The general aim of the present thesis was to further
our understanding of the early development of cognitive control. This aim was approached by
examining the attention processes underlying cognitive control in infancy and toddlerhood, with
a particular focus on age-related improvements in attentional control. This thesis consists of
three studies that have used the A-not-B paradigm to investigated infants’ and toddlers’ ability
to search for a hidden object or to correctly anticipate the reappearance of a hidden object. The
A-not-B paradigm is one of few well-studied paradigms for research on the early development
of cognitive control and this paradigm involves conflict resolution and requires a flexible shift
of response set to achieve a goal.

Study I of this thesis examined individual differences in 10-month-olds’ ability to search
for a hidden object in a manual A-not-B task. We investigated the infants’ search behavior,
both in terms looking and reaching responses, the relation between individual differences in
performance on A and B trials, and also the relation between the two response modalities.

Study II used eye tracking and focused on the role of attentional demand on 10- and 12-months-
olds’ ability to anticipate the reappearance of a hidden object. This study intended to clarify
age-related improvements, particularly in relation to the ability to resist visually distracting
information that interfered with the task at hand.

Study III also employed an eye tracker to measure 18-month-olds’ predictive eye movements
in anticipation of a hidden object under conditions marked by different attention demands. This
study not only investigated the toddlers’ ability to overcome a visual distractor, but also their
ability to keep a representation in actively in mind over different delays. In addition, the 18-
month-olds’ performance was compared to that of an adult group to shed further light on the
development of attentional control in children.

In conclusion, this thesis demonstrated that important age-related improvements in cognitive
control take place by the end of the first year of life and between 12 and 18 months of age.
More specifically, with increasing age, the children were able to resolve higher levels of conflict
thereby demonstrating improvements in attentional control. In interpreting the present data, we
argue that this development is gradual, developing from variable to stable and also that the
attentional control process is best described as continuous rather dichotomous in infancy and
toddlerhood. Based on our findings, future research should be motivated to examine changes in
attentional control processes in relation to the early development of cognitive development.

Keywords: cognitive control, attention, eye tracking, children, A-not-B

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ISSN 1652-9030
ISBN 978-91-554-8253-4
urn:nbn:se:uu:diva-164299 (http://urn.kb.se/resolve?urn=nbn:se:uu:diva-164299)
List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.


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### Abbreviations

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<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
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<tr>
<td>AOI</td>
<td>Areas of interest</td>
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<tr>
<td>DFT</td>
<td>Dynamical Field Theory</td>
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<tr>
<td>EEG</td>
<td>Electroencephalogram</td>
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<tr>
<td>HCSM</td>
<td>Hierarchical Competing Systems Model</td>
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<td>PDP</td>
<td>Parallel Distributed Processing</td>
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<td>PFC</td>
<td>Prefrontal Cortex</td>
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Introduction

Throughout infancy and toddlerhood there is a dramatic development of cognitive abilities characterized by the new emergence of cognitive control. Cognitive control processes are brought into play in situations that require cognitive flexibility, when an automatic response is insufficient for acquiring an attained goal. These control processes involve being able to flexibly shift response set or focus of attention, actively hold information in mind, and the inhibition of distractions or prepotent responses in the face of new task demands. The early improvements in cognitive control allow the child to make future-oriented predictions and to increasingly act in the world in a goal-directed manner. These abilities have been suggested to emerge in their rudimentary form during the first year of life and continue to develop throughout childhood and well into adolescence (for reviews see Diamond, 2002; Jurado & Roselli, 2007; Zelazo, Carlson & Kesek, 2008).

The development of cognitive control is presumably closely tied to the maturation of the attention systems (e.g., Posner, Rothbart, Sheese & Voelker, 2011; Rueda, Posner, Rothbart & Davis-Stober, 2004; Rothbart & Posner, 2001; see Garon, Bryson & Smith, 2008 for a review). Moreover, attentional control processes have been proposed to be the unifying construction underlying cognitive control in both children (Garon, et al., 2008; Lehto, Juujärvi, Kooistra & Pulkkinen, 2003) and adults (MaCabe, Roediger, McDaniel, Balota & Hambrick, 2010; Miyake et al., 2000). Thus, an exploration of attentional control in the first years of life appears to be a promising venue for a better understanding of early changes in cognitive control. Further, cognitive processes involved in goal-directed actions tend to become more complex and difficult to interpret with increasing age. For that reason, a fruitful research agenda for understanding these processes is to take a developmental perspective and examine the early development of attentional and cognitive abilities involved in cognitive control. From a broader perspective, research on cognitive development in the first years of life has the potential to yield insight into how early attentional and cognitive abilities lead to higher mental functioning in later years.

The A-not-B paradigm is one of the few well-studied paradigms for research on the development of cognitive control in infancy and toddlers. In this paradigm, 8- to 12-month-olds tend to search successfully for an object that is repeatedly hidden in location A, and continue to search at this location despite having seen the object being hidden at a new location (B). The
repetition of the previously correct response that is no longer appropriate is called an A-not-B error or perseverative error. Consequently, flexible shift of response set is needed for successful performance and with development children improve on the task sustaining longer delays between hiding and search without perseverating (e.g., Diamond, 1985). This improvement is taken as an indication of development of cognitive control.

The general purpose of this thesis has been to explore the early development of cognitive control and particularly the role of attentional control for infants’ and toddlers’ performance on the A-not-B task. This has been done in a series of experiments. In Study I we used a manual version of the task and studied individual differences in infants’ looking and reaching performance. In Study II and Study III we employed an eye tracker and assessed infants and toddlers’ performance by measuring their gaze under conditions marked by different attention demands in a looking version of the task (Study II & III). Before proceeding with a description of the early development of attention and cognitive control, I begin by clarifying the concepts of cognitive control and attention.

Cognitive control

As humans, we do not just reflexively react to salient sensory information in our immediate environment. We can efficiently interact with other humans and objects, engage in complex behaviors involving extended goals, and predict the outcome of events and other humans’ actions. To accomplish this we need to be able to inhibit automatic and habitual responses, resist distractions to stay on task, hold information (e.g., a goal, or an occluded object) in mind, and flexibly shift responses or focus of attention. These partly dissociable abilities support cognitive control of behavior and are crucial for actions that are attention demanding, such as newly learned skills, novel situations, or when a context changes (Diamond, 2006; Miller & Cohen, 2001; Miyake et al., 2000; Lehto et al., 2003).

Many cognitive abilities, such as memory, inhibition and set shifting, supporting cognitive control (e.g., Miyake et al., 2000), emerge in their rudimentary form in the first year of life. The ability to hold representations in mind can be seen during the first 6 months of life (Johnson, 2005a; Pelphray & Reznick, 2002). Further, a basic form of the ability to inhibit a response develop during the latter half of the first year and improves significantly between 6.5 to 12 months of age (Diamond, 1990). The ability to shift response set has been suggested to involve the coordination of memory and inhibition (e.g., Diamond, 2006; Garon et al., 2008). This ability develops by the end of the first year and is commonly assessed with the A-not-B task. A detailed description of the early development of cognitive abilities as measured by this task will be given in a later section.
The early emerging cognitive abilities involved in cognitive control continue to be refined throughout childhood and have been shown to have different developmental trajectories, some not reaching adult competence until late adolescence (e.g., Diamond, 2002; Jurado & Roselli, 2007).

Tasks that require cognitive control of behavior have been associated with the functioning of the prefrontal cortex (PFC) in infants, children, and adults. The PFC has unique, but overlapping connections with virtually all sensory and motor systems, and many subcortical structures (e.g., Barbas & Pandaya, 1991; Fuster, 1989; Miller & Cohen, 2001). In general, brain regions subserving sensory and motor systems mature first, whereas the dorsolateral PFC and temporal cortices associated with cognitive control functions mature later (Gogatay et al., 2004; Sowell et al., 2004). Support for the role of the PFC in relation to tasks that require cognitive control comes from studies on adult patients with brain damage (Barcelo & Knight, 2002), functional neuroimaging studies of healthy adults (Duncan & Owen, 2000), electroencephalogram (EEG) studies of infants (Bell, 2001), and studies of rhesus monkeys (Diamond & Goldman-Rakic, 1989).

However, not all complex actions require cognitive control of behavior. With practice and experience, actions tend to become more automatic and less attention demanding (Miller & Cohen, 2001). Thus, the term cognitive control is used in this thesis to refer to processes involved in the facilitation and inhibition of behavior in situations when an individual cannot achieve a goal through immediate automatic responses. Further, as will be argued throughout this thesis, attention processes are of importance for cognitive control, as these processes appear to be involved in performance on a variety of tasks that require cognitive control (e.g., Baddley, 1986, 2002; Diamond, 2002; Eigsti et al., 2006; Garon et al., 2008; Kane & Engle, 2002; Rothbart & Posner, 2001).

Attention

Attention is one of the oldest research areas in the experimental field of psychology. William James was probably the first to suggest that attention consists of several systems. In *Principles of Psychology*, on the subject of attention, William James wrote:

> Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thoughts. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has real opposite in the confused, dazed, scatter-brained state which in French is called *distraction*, and *Zerstreutheit* in German

(James, 1891, p. 403-404)
As suggested by William James, attention has a limited capacity and involves selectivity and control of attention. His definition is equivalent to current definitions of attention as a cognitive process wherein certain stimuli, thoughts or objects are prioritized, while irrelevant or distracting ones are ignored (Carr, 2004; Klein, 2004). These attentional processes apply to attention in general, but in this thesis the focus is on visual attention and particularly the role of attentional control in tasks that requires cognitive control for successful performance (i.e., tasks based on the A-not-B paradigm).

The limited capacity of attention refers to the limited amount of information or stimuli that can be simultaneously attended to and actively maintained (Broadbent, 1958; Kahneman, 1973; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). For example, research has found that when adults have to divide their attention between a motor and verbal task their performance becomes less precise (Chen et al., 1996). Similarly, in a study on children’s performance on a visual-search task their performance decreased when they had to allocate more attentional resources to carry out a motor response (Smith, Gilchrist & Hood, 2005). Thus, this shows that performance on cognitive control tasks may decrease when the attentional demand is increased.

Selective attention is important for any task that requires cognitive control. This attention process involves selecting and restricting the amount of sensory information that should be attended to for further processing (Posner & Bois, 1971). The ability to selectively attend has been related to the orienting system. On a neural network level, this system involves two major cortical areas: the temporal parietal junction and the frontal eye fields (Posner et al., 2011). The functioning of the orienting system involves engagement of visual attention toward a specific stimulus, the disengagement of visual attention from a specific stimulus, and the shifting of attention between different stimuli (Colombo, 2001). What we as humans visually attend to and shift our attention toward can be triggered by exogenous factors, such as a salient stimulus appearing in our visual field, or be driven by endogenous factors related to internal representations, such as a task goal (Corbetta & Shulman, 2002). Shifts of gaze that are driven by exogenous factors are described as automatic, whereas gaze shifts driven by endogenous factors involve control of gaze (Colombo, 2001; Jonides, 1980; Posner & Raichle, 1994; Posner et al., 2011).

Control of attention can be defined as the ability to actively maintain a representation or a goal when encountering distraction or conflict that interferes with the task at hand (Fan, McCandliss, Sommer, Raz & Posner, 2002; Engle, 2002; Kane & Engle, 2002; Rueda, Fan, et al., 2004). Therefore, conflict resolution is an important characteristic of attentional control. Control of attention has been related to the executive attention
system in both children and adults (Rueda, Fan, et al., 2004) and it shows a significant increase in functioning during the second year of life (Gao et al., 2009; Posner et al., 2011. On a neural level the executive attention system involves the anterior cingulate gyrus, anterior insula, basal ganglia, and parts of the prefrontal cortex (Posner & Fan, 2008). The executive attention system is believed to enhance attentional control through the guidance of internal representations, and partly by inhibiting and facilitating the orienting system (Fuentes, 2004; Rothbart & Posner, 2001; Ruff & Rothbart, 1996). A recent fMRI study (Gao, et al., 2009) has investigated connectivity of brain structures related to the executive attention network in early development. This study showed that the connectivity between these brain structures were spare during infancy, but strongly increased at 2 years of age.

In sum, attention consists of several systems and can be characterized by a limited capacity, selectivity and control. The functioning of the attention systems involves selecting certain information over other, and controlling attention. These functions are of importance for many behaviors, but particularly for behaviors or thought processes that requires cognitive control, such as goal-directed behaviors.

Development of visual attention in infancy and toddlerhood

The development of visual attention in infancy and toddlerhood is thought to take place in a social context, concurrently with neurological maturation and developmental changes in behavior (Johnson, 2001). An example of this is the infant’s ability to perceive and imitate others’ actions, which requires attention toward the actions and thereby provides a mechanism for developing new behaviors (Meltzoff, 1990). In that sense, infants actively participate in their own development. As young infants are restricted by their inability to move around on their own, visual attention is important for their exploration of the environment and for gaining knowledge about the world. In fact, one of the earliest appearing skills in infancy is the development of ocular motor control, which functions at a mature level only a few weeks after birth (Rosander & von Hofsten, 2002; von Hofsten & Rosander, 1996). Ocular motor control enables infants to direct their attention to extract visual information in the environment (Rosander & von Hofsten, 2004) and is also crucial for social communication and for establishing bonds with caregivers (Guastella, Mitchell & Dadds, 2008). From the first days of life infants visually attend to different features of their environment. For example, newborns prefer to look at face-like rather than non-face-like patterns (Morton & Johnson, 1991), moving stimuli rather than static stimuli (Volkman & Dobson, 1976), and novel rather than familiar stimuli (Slater, Morison, & Somers, 1988).

However, during the first months of life, infants’ attention can be described a slow and “sticky,” and they have difficulty in shifting their gaze
between different stimuli (Johnson, 2001). At 3 to 6 months of age, the orienting system becomes functional, and this system is involved in infants’ increasing ability to shift attention between stimuli (Johnson, Posner & Rothbart, 1991; Ruff & Rothbart, 1996). By this age infants demonstrate more gaze control and are attracted by new, interesting, objects and events, and they are able to orient their gaze quickly. They can also disengage their gaze from one stimulus and direct it to another (Hood & Atkinson, 1993), which also means that they quickly habituate, lose interest, and stop looking. Their ability to shift gaze quickly also enables them to track temporarily occluded objects. Studies using eye tracking have shown that 4-month-olds can learn to predict an object that move back and forth behind an occluder (Johnson & Shuwairi, 2009) and that this ability is significantly improved by 6 months of age (Kochukhova & Gredebäck, 2007). These findings indicate that 4- to 6-month-olds can form representations of temporarily occluded objects and use their experience of occluded events to make predictive eye movements. However, gaze shifting during the first 6 months of life is primarily reactive and strongly governed by novelty (Blaga & Colombo, 2006; Dannemiller, 2005).

Control of attention
During the latter half of the first year, infants begin to develop more endogenous control over their attention, and this development continues well into childhood (Colombo, 2001; Courage, Reynolds & Richards, 2006; Posner, Rothbart & Thomas-Thrapp, 1997; Ruff & Capozzoli, 2003). This development is thought to take place because of the child’s increasing experience and the neural maturation of the attention system (Posner et al., 1997; Posner, Rothbart, Thomas-Thrapp & Gerardi, 1998; Ruff & Rothbart, 1996). The development of attentional control is of importance for cognitive control of behaviors. For instance, research has shown that manipulation of attention on tasks that requires flexibly shift of responses has an effect on infants and young children’s performance (Berger, 2004; 2010; Kirkham, Cruess & Diamond, 2003; Thelen, Schöner, Scheier, & Smith, 2001).

Conflict resolution is central to attentional control. It has been suggested that an important transition in attentional control takes place between infancy and toddlerhood, as children become better at resolving conflict during information processing, such as handling distractions (Posner & Rothbart, 1998; Rothbart & Posner, 2001; Ruff & Rothbart, 1996). Some support for this suggestion comes from research on the antisaccade task. In this task the participants must inhibit a gaze a target that appears in the peripheral visual field and instead produce a saccade to the contralateral side. Whereas 4-month-olds are unable to produce a saccade to the contralateral side (Johnson, 2005), children around 12 to 18 months demonstrate the ability to inhibit the automatic gaze response and are able overcome conflict on this task (Scerif et al., 2005).
Further, evidence from infancy throughout the preschool years shows that, once in a focused state, children are resistant to distractors (e.g., Richards, 2004; Ruff & Capozzoli, 2003). However, compared to preschoolers, infants have difficulty maintaining their attention on a task over longer time periods (e.g., Richards, 2004). Development of visual attention in early development involves continued enhancement of the executive attention system and integration with the orienting system (e.g., Ruff & Rothbart, 1996). In relation to tasks that involve goal-directed reaching responses, such as the manual A-not-B task, another important integration is the integration between the visual system and the action systems.

Integration of the visual systems and the reaching systems

The integration of the visual attention system and the reaching system plays an important role in goal-directed behaviors as the direction of gaze often guides actions (Land, 1992; Land et al., 1999). A study by von Hofsten (1982) demonstrated that newborns have some ability to coordinate eye and hand movements, as the newborns were better at aiming pre-reaching attempts toward a slowly moving object when they were visually fixating the object compared to when they were not visually fixating the object. However, this is very far from a fully developed integration. Instead, at a certain time in development, the infant’s visual system appears to be more sophisticated and mature compared to the infant’s reaching system. This can be demonstrated by the fact that infants around 3 to 6 months of age show discrimination in the preferential looking task, but do not show preferential reaching (Atkinson, 2000). Infants tend to begin to reach for objects around the age 4 to 5 months, but their reaches are jerky and indirect, and it takes months before their reaches become smooth and controlled (Berthier, 1996; von Hofsten, 1991; Thelen, Corbetta & Spencer, 1996). Further, the development of visually guided reaching is protracted (Clearfield, Diedrich, Smith & Thelen, 2006; Thelen et al., 1996). It has been suggested that the visual and the reaching systems gradually becomes more integrated from around 6 months of age (Atkinson, 2000).

Some support for this suggestion comes from a study by van der Meer et al. (1994) that compared predictive looking with predictive reaching in infancy. Infants between 4 and 12 months of age were presented with a toy that moved behind an occluder on a horizontal plane. The infants did not start to reach for the toy until they were 5 months of age. However, at this age they only reached for the toy when it was in sight, but they anticipated the reappearance of the toy by looking at the end of the occluder ahead of time. At 8 months of age they started their reach toward the toy while it was still occluded. This finding suggests that the ability to anticipate an event with a gaze develops prior to the ability to make anticipatory reaches.
Further support for the slower maturation of the reaching system compared to the visual system comes from research on infants’ looking and reaching performance on hide-and-search tasks (e.g., the delayed-response task, the A-not-B task). In these tasks, infants search for an object that is hidden in one of several (often two) hiding locations. Several early anecdotal reports indicated that infants sometimes looked at the correct hiding location while reaching toward the incorrect hiding location (e.g., Diamond, 1985; Piaget, 1954). More systematic investigations have demonstrated that around the age of 5 to 8 months, infants’ search behavior in terms of looking is superior to that of reaching, whereas from 9 month of age no difference in performance could be found between modalities (Cuevas & Bell, 2010). However, one study (Hofstadter & Reznick, 1996) has shown that even 11-month-old infants are more advanced in their looking behavior compared to their reaching behavior when it comes to searching for hidden objects. In interpreting these findings, it has been suggested that the cognitive abilities required for finding hidden objects become integrated with the reaching system at a later age (Bell & Adams, 1999; Cuevas & Bell, 2010). Alternatively, as infants are still in the process of developing controlled reaches by the end of the first year (Thelen et al., 1996), another plausible suggestion is that a reaching response is more attention demanding than a looking response at a certain time in development.

Hide-and-search task, such as the A-not-B task, has been employed not only to examine developmental differences in response modalities (i.e., looking and reaching). Indeed, the A-not-B task has more commonly been used to examine the early development of cognitive control. The following sections will address this topic.

The early development of cognitive control: The A-not-B task

The A-not-B task is a widely used paradigm to investigate the early development of cognitive control. This is a task that requires flexible responses to achieve a goal (to find the hidden object). It was originally developed by Jean Piaget to investigate children’s stages of sensory-motor development (Piaget, 1954; for reviews see Marcovitch & Zelazo, 1999; Thelen et al., 2001; Wellman, Cross, & Bartsch, 1986). In his studies he observed that children progressively gain more knowledge of the world through their own active exploration. In the standard version of the A-not-B task, an infant watches as an experimenter hides an interesting object in one of two locations (A and B). The object is first hidden at location A and the infant is thereafter encouraged to search for the object. Whereas infants around 4 to 8 months of age often fail to search for the object, 8- to 12-
month-olds readily, or with a brief training, successfully retrieve the object from location A. Following several successful searches at location A, the infant watches as the object’s hiding location is switched to location B. Infants younger than 12 months of age typically continue to search at the previously correct location (A), despite having seen the object being hidden at the new location (B). This search error is termed an A-not-B error or perseverative error. In Piaget’s (1954) original explanation, infants younger than 8 months of age fail to search for the object because they lack an understanding of object permanence. That is, they do not understand that the object continues to exist when it is out of sight. Infants between 8 to 12 months of age have developed some understanding of object permanence, according to Piaget, but they perseverate on B trials because they believe that the act of searching is the cause of the objects existence.

Piaget’s study on the A-not-B task and the theory of infants’ development of object permanence prompted a whole research field. The considerable attention given to infants’ performance on the task is, in part, because the infants’ perseverative behavior is fascinating. But more so, because of what it can tell us about how infants develop and how they gain knowledge. Since Piaget’s first description of the task it has been repeated in numerous studies. Subsequent research on the A-not-B task has established that the perseverative behavior, as such, is a robust phenomenon that has been found in various versions (e.g., Clearfield et al., 2006; Cuevas & Bell, 2010; Diamond, Cruttenden, & Neiderman, 1994; Smith, Thelen, Titzer & McLin, 1999). For example, researchers have varied the distinctiveness of the covers (e.g., Butterworth, 1977), the number of hiding locations (e.g., Diamond et al., 1994), whether searches involve reaching or looking (e.g., Cuevas & Bell, 2010), the delay between hiding and search (Diamond, 1985), whether the object is hidden or visible (Launders, 1971), and types of motor responses (e.g., crawling or walking, see Berger, 2010). Based on findings from these various manipulations, Piaget’s original explanation has been challenged. The contemporary consensus among researchers is that Piaget’s explanation for the A-not-B error is incorrect, but researchers disagree on why the original theory is insufficient for explaining perseverative errors (see for example Marcovitch & Zelazo, 2009 and Thelen et al., 2001 target articles with commentaries). Many current theories of the perseverative error seen in the A-not-B task have focused on the role of memory and inhibition.

Theories of memory and inhibition

Several researchers have suggested that the cause of perseverative errors on the A-not-B task is related to inhibition. As infants are found to perseverate in non-hidden A-not-B tasks, where the object is in full view, it suggests that they have difficulties with inhibiting a motor response (e.g., Butterworth, 1977; Diamond et al., 1994; Diamond & Doar, 1989). For example,
Launders (1971) found that infants who made an instrumental response to find the object on A trials made more perseverative errors than those who merely observed the object disappear and reappear on A trials. Thus, instead of attributing infants’ perseverative error to an incomplete understanding of object permanence, the perseverative error might instead reflect a tendency to repeat the previously successful response.

An alternative to the response inhibition account is the suggestion that infants have difficulty keeping the object’s new location in mind following the switch of hiding location (e.g., Bjork & Cummings, 1984; Munakata, McClelland, Johnson & Siegler, 1997). Thus, the error would stem from a memory problem, rather than being a conceptual problem as Piaget proposed. In support of a memory account, Bjork & Cummings (1984) found that when infants were presented with a five-choice version of the A-not-B task they searched incorrectly, but near the correct location on B trials. However, the infants did not search perseveratively at location A. The authors argued that the infants could hold the general hiding location in mind, but did not have the ability to encode the exact spatial location. Further, research has reported that longer delays between hiding and retrieval lead to more perseveration errors (e.g., Diamond, 1985; Munakata, 1998). As longer delays require the ability to maintain an active representation over time, this also suggests that memory is involved in search behavior on the A-not-B task.

**Diamond’s theory: memory + inhibition**

In Diamond’s (e.g., Diamond, 1985; 2006, 2009; Diamond et al., 1994) influential theory, flexible shift of response set on the A-not-B task requires both active maintenance of the last hiding location in memory, and inhibition of a previously rewarded response. These cognitive abilities (memory, inhibition and set-shifting) correspond with Miyake et al.’s (2000) model of the structure of cognitive control in adults, which has also been confirmed in older children (Lehto et al., 2004). In Diamond’s account, memory and inhibition is portrayed as partly dissociable components that follow different developmental trajectories. According to Diamond, at the time in development when infants perseverate, their memory for the last hiding location is fragile and fades quickly over time. The predisposition to repeat a previously correct response, however, is more robust and lasts longer, and is also presumed to be subcortical. Given a certain delay, the pull from the previously correct response leads to a perseverative search. With development, memory and inhibitory control becomes coordinated and enable a flexible shift of response set on the A-not-B task.

Further, Diamond (e.g., Diamond, 2006; Goldman-Rakic & Diamond, 1989) has demonstrated that the neural maturation of the dorsolateral PFC is an important factor in explaining why infants overcome this error with development. The dorsolateral PFC develops rapidly by the end of the first
year of life (Koenderink, Ulying & Mrzljiak, 1994). This time period in human life also corresponds with infants’ increasing ability to overcome the perseverative error on the A-not-B task. In a study of rhesus monkeys’ and 7.5- to 12-month-old human infants’ performance on the A-not-B task, Diamond & Goldman-Rakic (1989) found evidence that performance was related to the functioning of the PFC. Rhesus monkeys with bilateral ablations to the dorsolateral PFC had the same difficulties with the task as 7.5- to 9-month-old infants. Unoperated and parietally operated rhesus monkeys and 12-month-old infants, on the other hand, succeeded in the task. Further support for the role of the frontal cortex in performance on the task comes from studies using EEG and near-infrared spectroscopy (Baird et al., 2002; Bell, 2001; Bell & Fox, 1992).

Computational theories

Diamond’s theory has contributed significantly to the theorizing on why children make the perseverative error, but three contemporary computational models have questioned some of Diamond’s assumptions and proposed alternative explanations. According to the dynamical field theory (DFT; Smith et al., 1999; Smith, 2009; Thelen et al., 2001) children’s performance on the A-not-B task can be explained by a number of interrelated factors. These factors consist of the visual sensory input, the repetition of a motor plan and reach kinematics, and specific contextual aspects. Following a switch of hiding location, the past input competes with the more recent input. Consequently, if the combined input of past searches is stronger than the more recent input, this will lead to perseverative behavior. Smith et al. (1999) has provided some evidence supporting the suggestion that children’s performance on the A-not-B task is sensitive to contextual factors. For example, they have shown that if the experimenter touches a rod that is placed closer to the A or B hiding places, this will bias the infants’ attention and reach in that direction, or if the infants’ posture is changed between the A and B trials, perseverative error decreases. Thus, according to the DFT, development of specific cognitive abilities, such as memory or inhibition, or the maturation of the PFC is not needed to explain why children overcome the perseverative error (e.g., Smith, 2009).

In contrast, two other computational A-not-B models, the hierarchical competing systems model (HCSM; e.g., Marchovitch & Zelazo, 2006, 2009) and the parallel distributed processing model (PDP; Munakata, 1998), propose that the development of cognitive control processes is of relevance for understanding children’s performance on the task at different ages. In both models, two systems are involved and the lower system is being regulated by the higher system. This proposal is to some extent parallel to Diamond’s theory. In the HCSM (e.g., Marchovitch & Zelazo, 2009, two hierarchically arranged systems, a habit system and a representational
system, compete to guide behavior. The habit system relies on previous experience and function in early infancy. The representational system excise top-down control and develops later. Thus, the reason why children perseverate, according to this model, is because they lack the ability to exercise top-down control over the habit to search at location A.

Similarly, in Munakata’s (1998) PDP model, a competition between two systems guides the child’s responses on the switch trial in the A-not-B task. Munakata’s model is a memory account and the competition is set up between latent memory traces of location A (presumably formed in posterior cortex) and active memory traces of location B (presumably formed in PFC). According to Munakata, the latent memory system is strongly associated with previous experience and long-term memory storage, and this system develops early in infancy. The active memory system, on the other hand, is associated with working memory and attention, and this system develops slowly over the course of childhood.

In sum, prominent theories of why children perseverate on the A-not-B task differ to some extent. One important distinction that can be made between Diamond’s theory and the three computational models is that the computational models propose that the perseverative error is caused by a conflict between two systems (or past and recent input). Diamond, on the other hand, presumes that two partly dissociable systems (memory and inhibition) co-act in determining performance on the A-not-B task. However, in most theories (e.g., Diamond, 2009; Marchovitch & Zelazo, 2009; Munakata, 1998) cognitive control processes are involved in successful performance on the A-not-B task. Further, the ability to solve conflict is a common theme in these theories/models for explaining the child’s development toward more flexible behavior. As attention control is critical for conflict resolution (e.g., Fan et al., 2002; Engle, 2002; Kane & Engle, 2002; Rueda, Fan, et al., 2004) exploring the role of attentional control for children’s performance on the A-not-B task could further our understanding of the early development of cognitive control.

Theories of limited attentional resources

Another perspective on perseveration comes from cognitive capacity theories (e.g., Berger, 2004, 2010; Boudreau & Bushnell 2000; Keen, Carrico, Sylvia & Berthier, 2003), which builds on the notion of attention as a limited resource (e.g., Broadbent 1958; Kahneman, 1973; Shiffrin & Schneider, 1977). Research on adults (Engle, 2002; Kane & Engle, 2002), school-aged children (Goldin-Meadow, Nusbaum, Kelly & Wagner, 2001), and infants (e.g., Boudin-Meadow, Nusbaum, Kelly & Wagner, 2001) has demonstrated that increased attentional load affects performance in a wide variety of areas. Thus, the notion of limited attentional resources suggest that perseverative behavior may be a consequence of factors related to related to
processes competing for attentional resources. Factors such as overlearning of responses, an increased delay between hiding and search, and an introduction of distracting stimuli will all challenge the limited attentional resources and therefore influence performance. For example, Boudreau and Bushnell (2000) found that 9.5- and 10.5-month-old infants’ performance on goal-directed tasks decreased when either the motor or cognitive demand of the tasks increased. These experiments suggest that more complex motor and cognitive responses place higher demand on attentional resources, leaving fewer resources for holding the goal in mind.

Similarly, in a series of experiments, Berger (2004; 2010) presented 13-month-olds’, who were newly learned walkers, with different locomotor versions of the A-not-B task. In one experiment, the infants’ performance was compared on a low-demand condition, where they had to walk across flat ground to reach the goal, with a high-demand condition, where they had to descend a staircase to reach the goal. The experiment showed that the infants only perseverated when the motor demand was high. Further, Berger also demonstrated that the infants’ perseverative behavior was best characterized as continuous rather dichotomous, as many infants often showed subtle signs of perseveration (e.g., direction shifts) on successful B trials.

A note on studying visual attention and cognitive abilities in early development

Conducting studies on infants’ and toddlers’ development of visual attention and cognitive abilities poses a challenge due to their limited linguistic and motor skills. Therefore, researchers interested in this field of research have developed a number of clever methods. In recent years, several new techniques have become available, and the study of infant attention has developed into a field of its own, as can be seen by the number of well-established findings and reviews that has been produced (Atkinson, 2000; Colombo, 2001; 2002; Hunnius, 2007; Ruff & Rothbart, 1996). I will here give a brief description of the use of looking measures and measurements of eye movements as methods of studying visual attention. However, it should be noted that many other types of techniques are being used, such as psychophysiological (e.g., heart-rate measures) and neurophysiological (e.g., EEG, near infrared spectroscopy) measures.

The earliest used and most common method to study visual attention is the observation of looking (Aslin & McMurray, 2004). Direction and duration of gaze can be coded directly by an experimenter or later from video recordings. This method of observing looking can give a good overall measure and is useful when a more precise measure (e.g., accurate
spatiotemporal measure) is not needed. Two important paradigms based on the observation of looking have been used extensively in infancy research: the habituation paradigm and the preferential looking paradigm. In the visual habituation paradigm, which is based on infants’ preference for novelty, an infant is first repeatedly exposed to one stimulus and then to a novel stimulus. If the infants look longer at the novel stimulus, this indicates that the infant can discriminate between the two stimuli (Bornstein, 1985). The other commonly used paradigm is the preferential looking paradigm. In this paradigm an infant is presented with two stimuli and longer looking time toward one of them is interpreted to mean that the infant discriminates between the two stimuli (Fantz, 1961). However, these two paradigms may have limitations when it comes to interpreting more advanced cognitive abilities in infants. For one thing, we cannot conclude with certainty that the infant looked longer at one stimulus because he or she discriminated between them, as differences in looking time can be elicited for several reasons, but also because these paradigms only taps a limited part of cognition (Haith, 1998; Hood, 2001).

It has been suggested that a better method for studying infants’ attention and cognitive abilities, at least in relation to cognitive control, is with measures that require the infant to make a prediction in advance, for example, predicting the reappearance or searching for an of an occluded object (Diamond, 1998; Meltzoff & Moore, 1998). This suggestion has guided all three studies include in this thesis. An example of how this method has been applied comes from series of early studies of infants’ anticipatory gaze (Meichler & Gratch, 1980; Nelson, 1971). Five- and 9-month-olds’ direction of gaze was recorded with a video camera as they watched a toy train going around a track and through a tunnel. The coding of the 5-month-olds’ gaze indicated that they did not anticipate the reappearance of the toy train from the tunnel by looking there ahead of time. The 9-month-olds, on the other hand, consistently predicted the reappearance of the train by moving their gaze to the end of the tunnel before the train had disappeared. This approach of measuring the infants’ predictive gaze of an occluded object’s reappearance arguably enables interpretations of infants’ attentional and cognitive abilities with greater confidence.

As previously mentioned, the observation of looking is a useful method for global measures of looking. However, with the introduction of corneal reflection eye tracking technique in the 1960s it has become possible to measure gaze with much greater accuracy. The new eye tracking systems measure the reflection of infrared light sources on the cornea relative to the center of the pupil. This technique allows for the most accurate measure of spatiotemporal properties of looking, as it measures horizontal and vertical eye positions at a relatively high sampling rate. The use of eye tracking is now a well-established method within infant studies, and it can measure location fixations, duration fixations, and shift of fixations, as well as
anticipatory eye movements (for reviews see Aslin & Murray, 2004; Gredebäck, Johnson & von Hofsten, 2010).
The aims of this thesis

The general aim of this thesis is to examine closely the attentional processes presumably underlying the development of cognitive control in infancy and toddlerhood. This aim is of relevance as research on early attentional and cognitive abilities can potentially yield insight into how these early abilities lay the ground for goal-directed behaviors in later years. This aim is also of broader interest, for several reasons. To begin with, early attention processes has been associated with later cognitive functioning, has a presumed role in the child’s development of self-regulation, and may also be involved in disorders of attention, such as Attention Deficit Hyperactivity Disorder (ADHD).

The thesis is based on three studies that have used the A-not-B paradigm to investigate infants’ and toddlers’ ability to search for a hidden object or to correctly anticipate the reappearance of a hidden object.

Study I of this thesis focused on individual differences in 10-month-olds’ ability to search for a hidden object in a manual A-not-B task. We examined the infants’ search behavior, both in terms of looking and reaching responses, the relation between individual differences in performance on A and B trials, and also the relation between the two response modalities.

Study II used eye tracking to investigate the role of attentional demand on 10- and 12-month-olds’ ability to anticipate the reappearance of a hidden object. This study intended to clarify age-related improvements, particularly in relation to the ability to resist visually distracting information that interfered with the task at hand.

Study III also employed an eye tracker to measure 18-month-olds’ predictive eye movements in anticipation of a hidden object under conditions marked by different attention demands. This study not only investigated the toddlers’ ability to overcome a visual distractor, but also their ability to actively maintain a representation in mind over different delays. In addition we compared their performance to that of an adult group to shed further light on the development of attentional control in children.
Method

Participants
For all three studies, we used birth records to recruit infants or toddlers living in the greater area of a university town in central Sweden. Families with children of appropriate age where contacted in writing with a letter describing the study and an invitation to participate. Parents who decided to participate were contacted by telephone, and an appointment was made. The adult participants (Study II) were recruited from a university campus area.

Study I included 29 10-month-old infants \( (M = 303.90 \text{ days}, SD = 9.59 \text{ days}, 19 \text{ girls and 10 boys}) \). Study II included a total of 80 infants, 40 10-month-olds \( (M = 304.63 \text{ days}, SD = 7.08 \text{ days}, 21 \text{ girls and 19 boys}) \) and 40 12-month-olds \( (M = 359.20 \text{ days}, SD = 5.47 \text{ days}, 21 \text{ girls and 19 boys}) \). An additional 43 infants took part in the study, but were excluded due to low gestational age (> 2 weeks before expected birth date; 2 infants), because of fussiness (15 infants) or insufficient data (< 50% of the experimental session; 26 infants). In study III the participants consisted of 60 18-month-olds \( (M = 548.75 \text{ days}, SD = 8.52 \text{ days}, 34 \text{ girls and 26 boys}) \) and 36 adults \( (M = 25.10 \text{ years}, SD = 5.38 \text{ years}, 20 \text{ women and 16 men, 81% undergraduate students}) \). An additional 19 toddlers participated in the study but were excluded because of fussiness (1 toddler) or insufficient data (< 50% of the experimental session; 18 children). An additional three adults were tested but were excluded due to technical difficulties. The attrition rate for the infants and toddlers based on insufficient data was due to both technical difficulties and a strict inclusion criterion that was decided upon before the data collection. All children who participated in the three studies were healthy and born within 2 weeks of the expected date.

Stimuli and Apparatus
Study I
In Study I, we used an A-not-B apparatus that was placed on a table in front of the infant. The apparatus consisted of two occluders (A and B) made by wooden frames that measured 18.5 cm (width) x 23 cm (height) x 7 cm (depth). The distance from center to center between the A and B occluders
were 40 cm. The wooden frames were fixed to a white chipboard and measure 30 cm (width) x 70 cm (length). Blue cloths covered the wooden frames and these were attached with Velcro (see Figure 1). Several attractive toys, such as a brightly blinking or squeaky toys, were available to be used. They were all small enough to be entirely hidden behind the occluders.

![Figure 1. Picture of A-not-B apparatus used in Study I. The occluders are hiding locations A and B.](image_url)

**Study II & III**

In Study II and Study III, stimuli consisted of movie clips, interspersed by brief attention-grabbing animations. Stimuli were recorded using a digital camera (Sony DCR-SX30, Sony Corporation, Tokyo, Japan) and edited with Sony Vegas (Sony Corporation, Tokyo, Japan). The movie clips lasted between 15-23 s and were presented on a 17-inch monitor that was part of a cornea reflection eye-tracking system (Tobii T120, Tobii Technology, Sweden). The eye-tracking system records the reflection of near infrared light from the pupil and cornea of both eyes at 60 Hz. Computer algorithms calculates the position of the gaze point on the screen with an accuracy of .5°. At the 60 cm viewing distance the display subtended a 30° x 24° visual angle.

![Figure 2. Presentation of the four A trials followed by a long and short B trial.](image_url)

The presentation of the movie clips was based on the A-not-B paradigm and consisted of four A trials followed by a long and a short B trial (see Figure 2). At the beginning of each trial, an interesting object, Mickey Mouse (referred to as Mickey below, subtending a 3.3° x 5.2° visual angle) was positioned at the center of the display and then moved behind one of two occluders accompanied by an upbeat melody in major (A or B, subtending a 8.6° x 7.2° visual angle, the space between the occluders
subtended a horizontal visual angle of 8.9°. Following a delay (when no sounds were presented), a sound cue signaled that Mickey would soon reappear. Shortly thereafter, Mickey reappeared and moved to the center of the display, again accompanied by an upbeat melody. The locations (left or right) of the occluders were counterbalanced across participants. Screen images can be seen in Figure 3.

Figure 3. Schematic screen images of one trial showing: A) Mickey’s center position, B) Mickey’s disappearance, C) the delay period, and D) Mickey’s reappearance.

A trials
In the first four movies Mickey disappeared completely behind occluder A after 5.5 s, and 3.5 s later, during the delay period, a sound cue was presented. Two seconds later1 Mickey reappeared from behind occluder A and moved toward the center of the display.

B trials
The two B trials consisted of a long B trial followed by a short B trial. During the first B trial, Mickey disappeared behind occluder B after 5.5 s and the sound cue was presented 3.5 later (as in the A trials). However, the time interval between the presentation of the sound cue and Mickey’s reappearance was extended to 9 s. During the second B trial, the time intervals for Mickey’s disappearance, the presentation of the sound cue, and Mickey’s reappearance were the same as in the A trials.

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1 In Study I, the testing of the 10-month-olds preceded the testing of the 12-month-olds and Mickey reappeared 1 s after the presentation of the sound cue. A methodological change was made before the testing of the 12-month-olds took place, so that Mickey reappeared 2 s after the sound cue (this time interval, 2 s, was also used in Study III).
**Conditions**
During the B trials, the participants were assigned to a no-distractor (referred to as control condition in Study III) and a distractor condition. Study III also included a long delay condition. In the no-distractor condition (control condition), no distractor was presented (the delay period consisted of an empty time interval, see Figure 3C). In the distractor condition, a visual distractor (a bouncing ball) was presented during the delay in the center of the screen for 2 s, 0.5 s after Mickey’s disappearance. In the long delay condition (Study III), no distractor was presented, but the time delay between Mickey’s disappearance and the presentation of the sound cue was extended to 10 s (in the A trials and all other conditions this time period was 3.5 s). See Figure 4 for a schematic diagram of trials in Study II and Study III. Please note that the control condition is referred to as no-distractor condition and that the long delay condition was only included in Study III.

**A Trials. All participants.**

**First B trial. Control Condition (no distractor is presented) and Distractor Condition (distractor is presented).**

**Second B trial. Control Condition (no distractor is presented) and Distractor Condition (distractor is presented).**

**First B trial. Long Delay Condition (no distractor is presented).**

**Second B trial. Long Delay Condition (no distractor is presented).**

*Figure 4. Schematic diagram of trials and conditions in Study II and Study III.*
Procedure

In all three studies, the infants or toddlers came to the lab with their parent(s). Before the experimental procedure began the parent(s) received a verbal description of the study’s procedure and purpose and signed a consent form. The adult participants in Study III were verbally informed about the study’s procedure and signed a consent form before the study started, but were told the purpose of the study only after it had finished. All studies were approved by the ethics committee of the Research Council in the Humanities and Social Sciences and were conducted in accordance with ethical standards specified in the 1964 Declaration of Helsinki. All participants received a token worth $13 as compensation.

Study I

The testing of the 10-month-olds in Study I took place in a quiet room at the lab. All sessions were videotaped for later coding. The infants were seated in a baby chair in front of a table, facing the experimenter, and the parent was seated behind his/her child. Before the experimental session began the infant was allowed to manipulate the toy briefly and was then presented with two warm-up trials. The purpose of the warm-up trials was to ensure that the infants would reach for the toy, and all infants did so from the first warm-up trial.

During the experimental session the A-not-B apparatus was placed at the infant’s midline and outside the infant’s reach. The infant was presented with four A trials wherein the toy was hidden behind occluder A and then with two B trials wherein the toy was hidden behind occluder B. The locations of the occluders (left or right) were counterbalanced across participants. During the trials the parent held his/her child’s hands until the experimenter cued the parent to release them. At the beginning of each trial the experimenter attracted the infant’s attention by waving or squeezing the toy. She then placed the toy behind one of the two occluders while looking back and forth between the toy and the infant to ensure that the infant paid attention to the toy’s hiding location. After hiding the toy she clapped her hands to break the infant’s visual fixation toward the hiding location. Following a 4 s delay the experimenter pushed the A-not-B apparatus toward the infant and encouraged the infant to search for the toy by asking: “Where’s the toy?” This was a cue to the parent to release his/her child’s hands to allow the child to search. If the infant made a reach toward the correct hiding location (at least touching the occluder) she/he was allowed to manipulate the toy briefly. If the infant did not manually search for the toy within 10 s or reached toward the incorrect hiding location, the experimenter pulled the apparatus back and showed the correct hiding location.
Studies II & III

The testing of the infants (Study II), toddlers and adults in (Study III) took place in a quiet and dimly lit room at the lab. The infants and toddlers were placed in a car safety seat on their parent’s lap or directly on their parent’s lap in front of the monitor. The adult participants sat on a chair in front of the monitor. Before the recording began the positions of the participant and the monitor were adjusted to obtain satisfactory gaze-tracking status. Thereafter, a calibration procedure began. During calibration, five expanding-contracting checkerboard patterned spheres (provided by the courtesy of Scott Johnson) with accompanying sounds appeared, one at a time, in each corner and in the center of the screen. Any unsuccessful calibration point was recalibrated. After a successful calibration procedure the experimental session began and the participants were presented with the movie clips, which all together lasted for approximately 2.5 min.

Data Analysis

Study I examined the infants’ first direction of a look and a reach on each trial, following the experimenters’ cue to search. Direction of look and reach was coded from videotapes by the first author (Forssman, L). A trained undergraduate student conducted an inter-reliability coding, and the percentage of agreement between the two coders was 96% for looking responses and 97% for reaching responses. The infants’ looking and reaching responses were coded independently of each other and in the following manner: 1) Correct looking/reaching response: eye movement toward the correct occluder/reaching at the correct hiding location (at least touching the occluder); 2) Incorrect looking/reaching response: eye movement toward the correct occluder/reaching at the incorrect occluder (at least touching the occluder); 3) No search: a looking/reaching response was not performed at any of the occluder within 10 s following the experimenter’s cue to search; and 4) Reaching at both locations: searching at both locations by reaching with both hands towards both hiding locations at the same time (at least touching the occluders). In our main analyses we used the proportion of a type of response, that is, averaged over the four A trials and averaged over the two B trials. Reaching at both locations was a rare response and was therefore not included in our main analyses.

In the eye-tracking studies (Study II & Study III), we defined areas of interest (AOI; see Figure 5) to measure the participants’ looking time during the experiments at specific time periods. In Study II these AOIs consisted of a left, right, and center area. In Study III, only the left and right areas were included. The left and right subtended a horizontal visual angle of 11.8° and a vertical visual angle of 12.8° and covered the left and right occluder,
respectively. The left and right AOIs were somewhat larger than the occluders as the participants could anticipate the object’s reappearance by looking at the border of each occluder. The center AOI was located between the left and right AOIs and subtended a horizontal visual angle of 2.8° and a vertical visual angle of 12.8°. The center AOI was included in Study II only for the purpose of illustrating the infants’ looking time in this area continuously throughout the task.

*Figure 5.* Defined areas of interest (AOI) in Study II and Study III. In Study II, the left, center and right areas were included, whereas in Study III, only the left and right areas were included.

The eye-tracking data in Study II and III were analyzed with programs written in MATLAB (MathWorks Inc, Natick, MA) taking into account when and where a gaze was recorded from an AOI. The statistical analyses were performed in SPSS. In all three studies ANOVAs were conducted with planned *t*-test comparisons. In Study I, correlations were also performed to reveal relations between performance over trials and modalities.
Study I

The A-not-B task is a well-studied task that is often used to investigate children’s cognitive development. In the classical version of the task, a child is asked to search for a hidden object in one of two hiding locations (A and B) following a certain delay (Piaget, 1954). After several search trials at location A the object is hidden at location B. Infants who are 8- to 12-month-old tend to continue to search at A on B trials. Thus, this task elicits perseverative search behavior, that is, the repetition of a previously correct response in a context when this response is no longer adaptive (e.g., Diamond, 1985; Milner, 1963). With increasing age, children are found to search correctly on both A and B trials, which is taken as an indication of cognitive flexibility.

Several studies on the A-not-B task have shown individual differences in same-age infants’ ability to overcome the perseverative error (e.g., Diamond, 1985; Pushina, Orekova & Stroganova, 2005), but individual differences in infants’ initial search behavior on A trials have not been a primary interest. Instead, possible differences in performance on A trials have often been leveled out as part of the administration of the A-not-B task, either by training the infants to search at location A, or by administering various numbers of A trials until the infants’ performance has been defined as successful according to some criteria over repeated trials (Smith et al., 1999). Arguably, differences in performance on A trials in same-age infants may reflect individual differences in competence or maturity.

From a developmental perspective it has been argued that on the path toward flexible search behavior, infants first develop a stable search pattern on A trials and consequently perseverate on B trials, before they, with increasing maturity, become truly flexible (Clearfield et al., 2006). Further, the experimental research on the A-not-B task have shown that the amount of prior searches at location A may be of relevance for bringing about the perseverative error seen in the A-not-B task (Marchovitch & Zelazo, 1999; 2009; but see Wellman et al., 1986). It has been suggested that more prior searches at A makes a flexible switch of search behavior more difficult on B trials and increases the likelihood of perseverative behavior (e.g., Marchovitch & Zelazo, 2009). It is also possible that individual differences in performance on the A trials may be of relevance for performance on the B trials, but previous research has not investigated this suggestion.
The developmental research on the A-not-B task and has also been interested in the role of response modalities (i.e., looking and reaching responses) for infants’ search performance. Initial interest in comparing infants’ performance on looking and reaching versions of the task stem from anecdotal reports that infants sometimes looked toward the correct hiding location, but reached perseveratively on B trials (Diamond, 1985; Piaget, 1954). Research that has compared infants’ performance on looking and reaching versions of the task indicates that at a certain time in development a reaching response may be more demanding and/or more vulnerable to perseveration than a looking response (e.g., Cuevas & Bell, 2010; Hofstadter & Reznick, 1996). For example, in Cuevas & Bell’s (2010) study of infants between 5 and 10 months of age, the infants’ looking performance were superior to their reaching performance on the task before 9 months of age. However, comparisons of infants’ looking and reaching responses on separate tasks do not inform us on possible differences in modalities within the task or to what extent the response modalities are coupled.

Study I examined 10-month-olds’ looking and reaching responses on a manual A-not-B task. This is an age group that tends to perseverate on the A-not-B task, at least with a 6 s delay (Diamond, 1985). In the current study, the infants were not trained to search at location A, and they were not required to search successfully on A trials before the switch to B trials. The aims of the study were to: 1) investigate how individual differences in search performance on A trials relate to search performance on B trials; 2) to examine possible differences in performance between response modalities and explore the extent looking and reaching are coupled, trial by trial, within the same task.

First, we expected individual differences in performance on A trials and also that the infants would display different types of search errors such as incorrect searches, not searching at all and searching at both locations. It was hypothesized that the infants who searched more at the correct location on A trials, compared to infants who searched more variably on A trials, would display more incorrect searches on B trials (Clearfield et al. 2006; Marchovitch & Zelazo, 2009). Second, an exploratory issue was to study how looking and reaching responses are coupled, trial by trial, to evaluate differences in performance between modalities, as reaching responses could be more demanding and more vulnerable to perseveration.

Design

In a within-subjects design, the infants were presented with four A trials followed by two B trials. The location of the A and B occluders was counterbalanced across participants. At the beginning of each trial the experimenter drew the infants’ attention toward the object of interest (an
attractive toy). Thereafter, the object was hidden behind one of two occluders (A or B). Following a 6 s delay, the infants were cued to search for the object and their first direction of look (correct, incorrect or no-search) and reach (correct, incorrect, no-search or reaching at both locations) was coded for each trial. In our main analyses we used the infants’ averaged (proportion of each type of response in the A and B trials, respectively) looking (i.e., correct, incorrect and no-search) and reaching (i.e., correct, incorrect and no-search) responses. As reaching toward both locations was a rare response, this response was not included in our main analyses.

Correlations were conducted between proportions of types of looking and reaching responses between the A and B trials to clarify relations in response patterns. An ANOVA was performed to examine the infants’ type of responses in the two response modalities before and after the switch of hiding location.

Results

Our results demonstrated variability and individual differences in infants’ search responses during the A trials, see Table 1. The proportion of infants who searched correctly on all four A trials was 34% for looking and 17% for reaching responses. Thus, many infants also searched incorrectly at location B and/or did not perform a search response. However, none of the infants searched at the incorrect location on all four A trials.

Table 1. Descriptive Data of Number of Infants Performing a Type of Looking and Reaching Response in each Trial. Mean values and standard deviations represent the proportion of a response.

<table>
<thead>
<tr>
<th></th>
<th>1st A trial</th>
<th>2nd A trial</th>
<th>3rd A trial</th>
<th>4th A trial</th>
<th>A trials M</th>
<th>A trials SD</th>
<th>1st B trial</th>
<th>2nd B trial</th>
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<td>4</td>
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<td><strong>Reaching Responses</strong></td>
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<td>Correct</td>
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<td>16</td>
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<td>Incorrect</td>
<td>4</td>
<td>2</td>
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<td>No-search</td>
<td>9</td>
<td>10</td>
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<td>8</td>
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<td>Both locations</td>
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Correlation analyses between type of search responses during A and B trials showed associations between performance in A trials and B trials, see Table 2. Correct looking/reaching responses on A trials were positively correlated with incorrect looking/reaching on B trials, and negatively
correlated to no-search looking and reaching responses on B trials. For reaching, incorrect responses on A trials was unrelated to reaching responses on B trials, whereas incorrect looking responses on A trials were positively correlated with correct looking responses on B trials. No-search looking and reaching responses on A trials were positively correlated with no-search looking and reaching responses on B trials. These correlations indicate that infants who made more correct looking and reaching responses on the A trials, made more incorrect, but fewer no-search responses on B trials.

An ANOVA was conducted on type of response in the two response modalities on A and B trials. The ANOVA showed a significant interaction between type of trial (A vs. B) and type of response (Correct vs. Incorrect vs. No-search), $F(1,28) = 15.64, p = .000$. To clarify the interaction, correct, incorrect, and no-search responses were compared between A and B trials. The result from the $t$-tests showed that the infants’ responses were significantly more correct during A trials, $t(28) = 5.22, p = .000$, significantly more incorrect during B trials, $t(28) = 3.13, p = .004$, and no-search responses were more common during B trials compared to A trials, $t(29) = 2.42, p = .022$. These results indicate that performance in the two response modalities was equivalent and that the infants’ displayed the typical perseverative search behavior on B trials.

Table 2. Pearson Correlations between Correct, Incorrect and No-Search Looking and Reaching Responses during the A and B Trials.

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<tr>
<td>1. Correct Looking A trials</td>
<td>-57**</td>
<td>-78***</td>
<td>-28</td>
<td>.66***</td>
<td>-.54**</td>
<td>.60***</td>
<td>-.21</td>
<td>-.51**</td>
<td>-.08</td>
<td>.37*</td>
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<td>-.25</td>
<td>.51***</td>
<td>-.03</td>
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<td>3. No-search Looking A trials</td>
<td>-.16</td>
<td>-.57**</td>
<td>.77***</td>
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<td>-.14</td>
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<td>4. Correct Looking B trials</td>
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<td>-.19</td>
<td>.03</td>
<td>-.28</td>
<td>-.09</td>
<td>.52**</td>
<td>-.21</td>
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<td>5. Incorrect Looking B trials</td>
<td>-.76***</td>
<td>-.89**</td>
<td>-.92</td>
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<td>6. No-search Looking B trials</td>
<td>-.58**</td>
<td>-.19</td>
<td>.62***</td>
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<td>7. Correct Reaching A trials</td>
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<td>8. Incorrect Reaching A trials</td>
<td>-.24</td>
<td>-.62***</td>
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<td>9. No-search Reaching A trials</td>
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<td>12. No-search Reaching B trials</td>
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Note. * $p < .05$, ** $p < .01$, *** $p < .00$

Finally, the correlations between looking and reaching responses (see Table 2) indicate that the infants’ direction of a looking and reaching response tended to be coupled over the A and B trials. Descriptive data show that over the four A trials and two B trials, the infants’ looking and reaching responses were coupled on average 70% of the time. Non-coupling of
looking and reaching responses constituted several combinations of behaviors (e.g., looked correctly – no-reach, reached correctly – looked incorrectly, looked correctly – reached incorrectly) and did not reflect a specific behavioral pattern.

Discussion

This study showed that, on the group level, the infants demonstrated the perseverative search error, but also individual differences in search behavior. Infants’ performance on A trials was related to their performance on the B trials. Infants who made more correct searches on A trials perseverated on B trials, whereas infants who made few correct searches on A trials made more no-search responses and few incorrect responses on B trials. One third of the infants made correct looking responses and one fourth of the infants made correct reaching responses on all four A trials. Thus, many infants showed variable response patterns on A trials, searching not only at the correct location, but also at the incorrect location and/or also made no-search responses. This shows that for many of the infants, searching for the hidden object was a difficult task, even on A trials, which may indicate that their memory for the hidden object declined over the delay (Diamond, 1985). Both incorrect and no-search responses on A trials could reflect limits in memory.

The fact that the good A trial performers made more perseverative errors than poor performers suggest that perseverative search errors could be due to some other aspects than poor memory per se. In line with Clearfield et al.’s (2006) idea of a gradual development of cognitive abilities underlying performance on the A-not-B task, we interpret these results as with increasing maturity infants develop a stable and correct search pattern on A trials, but they still lack the ability to flexibly shift search response following the switch of hiding location. Further, according to Diamond’s notion (e.g, 1985, 2006, 2009) this could mean that the good A trial performers have reached a developmental stage where they have a fairly good ability to hold a hidden object in mind over a 6 s delay. However, on the switch trial their performance is still poor, as it requires both holding the object in mind and inhibiting repeating a previously correct response. Obviously, a longitudinal design would be necessary to test these suggested developmental effects.

The results from this study also showed that there was no difference in performance between the two response modalities. This result is parallel to Cuevas & Bell’s (2010) study that found that infants’ performance on looking and reaching versions of the A-not-B task was equivalent by 9 and 10 months of age. An important distinction between their study and our study is that we measured looking and reaching responses within the same task. By doing this we were able to explore the coupling of looking and
reaching responses within the same task. We found that the infants’ looking and reaching responses were in the same direction on most trials. This could reflect an integration of infants’ visual attention and reaching systems that gradually develop over the first year (e.g., Atkinson, 2000). Interestingly, our results show that on the occasions when the infants’ looking and reaching responses were not coupled, this did not seem to reflect a specific pattern of response behavior, but instead several combinations of response behaviors.

Finally, in line with Berger (2004, 2010) we suggest that the relatively poor performance of the infants, on a group level, could arise because the current A-not-B task requires an integration of several abilities or processes that may tap the infants’ limited cognitive resources. Arguably, in comparisons with many other A-not-B studies (e.g., Clearfield et al., 2006) our task was more difficult as we did not train the infants to search at location A, we used a delay (6 s) that seems to be difficult for 10-month-olds, and we also introduced a distractor (i.e., the hand-clapping that followed the hiding of the object). The introduction of a distractor has been used in other A-not-B studies (e.g., Cuevas & Bell, 2010; Diamond, 1985) and its purpose is to prevent the infant from visually fixating the object’s hiding location. A possible effect of a visual distractor on infants’ performance on the A-not-B task could be tested with an experimental design. This will be further investigated in Study II and Study III. Further, most previous studies have used a dichotomous measure of infants’ performance as either correct or incorrect (e.g., Cuevas & Bell, 2010; Diamond, 1985; Hofstadter & Reznick, 1996; but see Berger, 2004, 2010), but our findings indicates that the perseverative error may be better characterized as a gradual rather than a dichotomous phenomenon. This suggestion is explored in Study II and Study III where we use eye tracking, as this enables a more continuous measure of infants’ performance during the A-not-B task.
Study II

Study II investigated the role of attention demand on 10- and 12-month-olds’ performance on a looking version of an A-not-B task. This study was motivated by the need for a better understanding of the attentional processes presumably underlying the early development of cognitive control (e.g., Garon et al., 2008). The end of the first year has been suggested to be a period in development when attentional control emerges (e.g., Rothbart & Posner, 2001; Ruff & Rothbart, 1996). Attentional control is especially important in the face of distractions or conflict that interfere with the task at hand (Engle, 2002; Kane & Engle, 2002; Rothbart & Posner, 2001) and of relevance in tasks that assess cognitive control, such as the A-not-B task.

In this study we used a looking version of the A-not-B task and used an eye tracker to measure the infants’ gaze. This methodological approach is arguably more sensitive to the role of shifting of visual attention compared to the manual versions of the A-not-B task, with the latter requiring much more motor involvement. Further, eye tracking also allows for a more continuous measure of the infants’ performance as it enables a quantitatively measure of gaze to both hiding locations. The use of a quantitative measure is in contrast to most previous studies on the A-not-B task, where the infants’ performance has been described as either correct or incorrect (but see Berger, 2004; 2010).

In the recent theoretical debate on why children perseverate on the A-not-B task (see for example, Marcovitch & Zelazo, 2009, target article with commentaries) the core issue concerns the role of mental representations and inhibitory control for infants’ successful performance on the task. From another perspective, Berger (2004, 2010; see also Boudreau & Bushnell, 2000) has suggested that the perseverative error on the A-not-B task could be a result of taxing of infants’ limited attentional resources, rather than being specifically related to either difficulties in memory or inhibition. Arguably both memory and inhibitory processes are involved in infants’ performance on the A-not-B task, and both processes are dependent on attentional resources. The theory of limited attentional resources (e.g., Kahneman, 1973) implies that perseverative behavior may be caused by factors related to task difficulties that can involve increased cognitive and/or motor demands. As the A-not-B task is a complex task for infants, increasing the task demand could produce the perseverative error.
The aim of Study II was to examine age-related improvements in attentional control in 10- and 12-month-olds in an A-not-B task marked by different attentional demands. We tracked the infants’ gaze to measure their ability to correctly anticipate the reappearance of a hidden object by looking at the correct location ahead of time. Attentional demand was manipulated through the presentation of a visual distractor to half of the infants in each age group during the B trials.

We predicted that the infants in both age groups would correctly anticipate the object’s reappearance during the A trials as even younger infants have been found to anticipate occluded objects in eye-tracking studies (Gredebäck & von Hofsten, 2007). On B trials, we hypothesized that the 12-month-olds would have developed more attentional resources than the 10-month-olds as attentional control is suggested to develop by the end of the first year (e.g., Rothbart & Posner, 2001). Therefore, the younger infants would show more perseverative looking and less anticipatory looking, that is, looking more at A and less at B than the older infants. We also expected that the distractor would lead to more perseverative looking (i.e., looking at A) and less correct looking (i.e., looking at B) in both 10- and 12-month-olds in line with the notion of taxing limited attentional resources (e.g., Berger, 2004, 2010). The question of whether the 12-month-olds would be better at dealing with the distractor was an explorative issue. On the first B trial, the time period between the presentation of the sound cue and the object’s reappearance was extended to 9 s to allow for exploration of the infants’ anticipatory looking over a longer time period (i.e., in contrast to being a brief response).

**Design**

All infants were presented with six movie clips representing four A trials followed two B trials and their gaze was measured continuously throughout the task, but our research questions concerned their ability to anticipate the reappearance of an object (a Mickey Mouse figure). The A trials were the same for all participants and during these trials the object first disappeared behind occluder A. Following a delay, a sound cue was presented and shortly after the object reappeared from occluder A. During the B trials the object switched hiding location (occluder B) and we used a between-subject design in that half of the infants in each age group were assigned to a either a distractor or a no-distractor condition. In the **distractor condition** a ball that moved up and down was presented in the center of the display for 2 s during the delay period when the object was hiding. In the **no-distractor condition** there was no distractor presented as in the A trials.

We analyzed the infants’ mean looking time at occluder A and B during 1 s following the presentation of the sound cue in anticipation of the object’s
reappearance during the A and B trials. An analysis of the infants anticipatory looking at occluder A and B was also conducted for the extended time period in the first B trial. To test our hypotheses, we used mixed repeated measures analysis of variances (ANOVAs) and planned t-tests.

Results

Raw data for the 12-month-olds’ mean looking time in the left, right and center AOIs during the A trials, the first B trial and the second B trial is presented in Figure 6. Their general looking pattern was similar to that of the 10-month-olds, but relevant effects of age and condition are presented below.

Figure 6. Raw data for 12-month-olds’ looking in each area of interest (A, B, and C) during the A trials and B trials in the no-distractor and distractor conditions.
For the A trials, the infants directed their gaze toward the center of the display at the stimulus onset, and then transferred their gaze to the A occluder behind which Mickey disappeared. During the delay, mean looking time to the A occluder decreased and the infants demonstrated gaze shifts (by also looking at the B and C area). The figures also show that the infants looked at occluder A following the sound cue and transferred their gaze to the center of the display when Mickey during the post-reappearance period.

For the B trials, the infants in the distractor condition had more looking time at the center of the display when the visual distractor was presented. However, the data also show gaze shifts during the time preceding the cue signal, that is, the infants did not just fixate their gaze on one particular area. The infants looking to the AOIs decreased during the 9 s that followed the sound cue in the long B trial. Decreased looking means that infants looked somewhere else at the screen or outside the screen.

An ANOVA was conducted to clarify whether the infants correctly anticipated the object’s reappearance during the A trials and to establish the equivalence of performance in the different groups (assigned conditions on B trials and age). The results showed a significant main effect of area, $M_A = .30 \text{ s}, M_B = .08 \text{ s}; F(1, 38) = 44.40, p = .000$, all other $F$’s < 2.09, and $p$’s > .15. These results demonstrate that the infants in both age groups correctly anticipated the object’s reappearance during the A trials by looking primarily at the correct occluder.

To examine the effect of the visual distractor on the 10- and 12-month-old infants’ anticipatory looking during the B trials an ANOVA was carried out. The results showed a significant interaction between area and condition, $F(1, 76) = 4.93, p = .029$. Planned comparisons, to test our hypothesis of an effect of distraction, revealed that the infants in the distractor condition looked more at the incorrect occluder (A) than the infants in the no-distractor condition, $M_{\text{no distractor}} = .11 \text{ s}, M_{\text{distractor}} = .22 \text{ s}, t(78) = 2.08, p = .041$, but there was no significant difference between conditions in looking at the correct occluder (B), $M_{\text{no distractor}} = .21 \text{ s}, M_{\text{distractor}} = .15 \text{ s}, t(78) = 1.21, p = .231$ (see Figure 7).
Figure 7. The 10- and 12-month-olds’ mean looking time (s) and standard error during 1 s following the sound cue during the B trials. The white and black bars indicate the A and B areas (occluders), respectively.

The ANOVA of anticipatory looking during the B trials also showed a borderline significant interaction between area and age group, $F(1, 76) = 3.83, p = .054$. Planned comparisons, to test our hypothesis of an age effect, were performed and revealed that the 10-month-olds had longer anticipatory looking time at the incorrect occluder (A) than the 12-month-olds, $M_{10\text{ months}} = .24 \text{ s}, M_{12\text{ months}} = .09 \text{ s}, t(78) = 2.99, p = .004$, but there was no significant difference between age groups in anticipatory looking time at occluder B, $M_{10\text{ months}} = .18 \text{ s}, M_{12\text{ months}} = .18 \text{ s}, t(78) = .20, p = .984$ (see Figure 7). These analyses demonstrate that the distractor induced more perseverative looking and also that the younger age group displayed more perseverative looking than the older age group. There was no significant difference in correct anticipatory looking as an effect of distraction or age.

We also examined anticipatory looking over the extended time period in the first B trial to clarify the infants’ attentional strategies over a longer time period (9 s divided into three time intervals: 0-3 s, 3-6 s, and 6-9 s). See Figure 8 for an illustration of mean looking time during the first time interval (0-3 s) in the two age groups and conditions.
The ANOVA of anticipatory looking during the extended time period in the first B trial revealed a significant interaction between time interval and age group, $F(1, 76) = 7.83, p = .007$, and a borderline significant interaction between time interval, condition, area, and age group, $F(1, 76) = 3.61, p = .061$. To understand these interactions follow-up analyses were performed related to our hypotheses. An ANOVA for each time interval with condition, age group, and area as independent variables showed that this interaction was not significant in any of the three time intervals, $F$’s < 1.84, and $p$’s > .17. Planned comparisons of looking time at occluder A and occluder B during the three time intervals between conditions showed non-significant effects for all intervals, $t$’s < .179, $p$’s > .079. Planned comparisons of the effect of age showed that the 10-month-olds were found to have longer looking time at occluder A in the first (0-3 s), $M_{10 \text{ months}} = .92$ s, $M_{12 \text{ months}} = .35$ s, $t(78) = 3.72, p = .000$, and middle (3-6 s), $M_{10 \text{ months}} = .68$ s, $M_{12 \text{ months}} = .38$ s, $t(78) = 2.07, p = .042$, time interval, all other $t$’s < .74, and $p$’s >.46. These results indicate that the older infants did not manage the distractor better than the younger infants. However, the 12-month-olds showed less perseverative looking than did the 10-month-olds during the first 6 s of the extended time period. Further, distraction or age did not have a significant effect on looking at the B occluder.
Discussion

This study demonstrated that the infants in both age groups correctly anticipated the object’s reappearance during the A trials by looking at the correct occluder ahead of time, indicating that they remembered the object’s hiding location. Further, the absence of an age effect indicates that there is no age-related difference between 10- and 12-month-olds’ ability to remember and correctly anticipate the reappearance of an occluded object over a relatively brief time delay (3.5 s).

In support of our hypothesis of an age effect during the B trials, the 10-month-olds displayed more perseverative looking than the 12-month-olds. This may reflect the development of attentional control by the end of the first year (Colombo, 2001; Ruff & Rothbart, 1996). The age effect lasted over 6 s during the extended period in the first B trial. This suggests a protracted direction of attention, rather than a quick response to the sound cue. Surprisingly, an age effect was not found for correct anticipatory looking, indicating that partly separate mechanisms could be involved in perseverative and correct anticipatory looking. This could mean that the ability to inhibit a gaze response develops between 10 and 12 months of age, whereas the ability to hold the object’s new hiding location in mind (over a brief delay) shows little development in this age period. This suggestion is parallel to Diamond’s (e.g., 2009) notion that both memory and inhibition are jointly involved in performance on the A-not-B task.

The result also support the hypothesis that increased attention demand, induced by the visual distractor, would led to more perseverative looking in both age groups. This demonstrates that the visual distraction taxed the infants’ ability to selectively attend to the correct hiding location and to control their anticipatory looking. This finding is in line with the perspective that the taxing of limited attentional resources is an important factor underlying the perseverative behavior found in the A-not-B task (Berger, 2004, 2010; Boudreau & Bushnell, 2000). However, the effect of the distractor was only found for perseverative looking and not correct anticipatory looking, suggesting that only inhibition of a previously correct gaze response was affected. Interestingly, the 12-month-olds were not found to be better at handling the distractor than the younger infants, which could mean that their attentional resources are still insufficient to overcome the distraction. This indicates that examining the effect of distraction and the taxing of limited attentional resources on performance on the A-not-B task in older children would be helpful for understanding the development of attentional control. Thus, this issue is further explored in Study III.
Study III

Attentional control has been defined as the ability to keep a representation or goal actively in mind in the face of conflict (e.g., Kane & Engle, 2002; Rueda, Fan, et al., 2004). The switch of hiding location from A to B in the A-not-B task involves such a conflict. Further, the notion of attention as a limited resource (e.g., Berger, 2010; Kahneman, 1973; Posner & Snyder, 1975) suggests that introducing factors that tax attentional resources can lead to a decrease in performance. In the current study we were specifically interested in investigating whether distraction and/or increased time delay effects anticipatory looking on an A-not-B task. An 18-month-old age group was chosen, as it has been suggest that an important development takes place with regard to the ability to overcome distracting information between 18 to 24 months of age (Clohessy, Posner & Rothbart, 2001; Rothbart & Posner, 2001; see Garon et al., 2008 for a review). Additionally, as control of attention is not close to fully developed by 18 months of age (Rueda, Fan et al., 2004; Rueda, Posner, Rothbart & Davis-Stober, 2004) we compared the 18-month-olds’ anticipatory looking to that of adults to further our understanding of the development of attentional control.

Study III was based on the same task and stimuli as used in Study II, but besides including a control (no-distractor) and distractor condition, we also included a long delay condition. The aim of Study III was to examine possible effects of attention demand on the control of anticipatory looking in 18-month-olds by tracking their gaze in a looking version of the A-not-B task. It was predicted that the 18-month-olds would correctly anticipate the hidden object’s reappearance on A trials, as 10- and 12-month-olds were found to do so in Study II. On B trials, we predicted that a visual distractor would lead to more perseverative looking (i.e., looking more at location A), compared to a condition without a distractor. However, the absence of this effect would suggest a developmental improvement in dealing with distraction, given that the children in both conditions looked more at the correct than the incorrect hiding location. It was hypothesized that a longer time delay, compared to a shorter time delay, would lead to less correct anticipation, but whether this effect would be seen as looking more at location A and/or B was left an open question. These predicted effects were also examined over an extended time period in the first B trial. Finally, the 18-month-olds’ performance was also compared to that of an adult group to
further our understanding of the development of attentional control in children.

Design

The participants were presented with the same four A trials, but during the B trials we used a between-subjects design and the participants, in both age groups (18-month-olds and adults), were assigned to three different conditions marked by different attentional demands. These conditions consisted of a **control condition**, a **distractor condition** and a **long delay condition**.

We analyzed the 18-month-olds’ mean looking time at occluder A and B during 2 s following the presentation of the sound cue in anticipation of the object’s reappearance during the A and B trials. An analysis of the 18-month-olds’ anticipatory looking at occluder A and B was also conducted for the extended time period (9 s divided into three time intervals) in the first B trial. To compare 18-month-olds’ performance to that of adults the same analysis, as describe above, was conducted, but we only report age effects and age interactions from these analyses. To test our hypotheses, we used mixed repeated measures analysis of variances (ANOVAs) and planned t-tests.

Results

Analysis of anticipatory looking the A trials (averaged over the four A trials) showed that the 18-month-olds correctly anticipated the objects reappearance by looking more at occluder A than B, \( M_A = .88 \) s, \( M_B = .24 \) s, \( F(1, 57) = 76.18, p = .000 \).

Analysis of the 18-month-olds’ looking time during the B trials (averaged over the two B trials) with regard to effects of condition, showed a borderline significant interaction between area and condition, \( F(2, 57) = 3.15, p = .050 \). Planned comparisons of looking time at occluder A and occluder B between conditions were conducted to test effects related to our hypotheses. The children in the long delay condition showed less correct anticipatory looking at the correct occluder (B) compared to the children in the control condition, \( t(38) = 2.99, p = .005 \), but there was no significant difference between the groups in looking at the incorrect occluder (A), \( t(38) = .59, p = .559 \). There were also no differences between the children in the distractor condition compared to the control condition in looking at occluder A or B, \( t’s < .72 \) and \( p’s > .47 \), see Figure 9.
Figure 9. 18-month-olds’ mean looking time (s) and standard error during the 2 s interval after the sound cue in the B trials. The white and black bars indicate the A area and the B area (occluders), respectively.

An analysis of the 18-month-olds’ looking time during the extended time period (9 s divided into 3 time intervals: 0-3 s, 3-6 s and 6-9 s) in the first B trial was conducted to explore anticipatory looking over a longer time period. See Figure 10 for an illustration of the 18-month-olds mean looking time at occluder A and B during this extended time period.

Figure 10. 18-month-olds’ mean looking time (s) and standard error during the 9 s interval (divided in three time intervals) after the sound cue during the extended period in the first B trial. The bars indicate the A areas (occluder) and the B areas (occluder) during the early time interval (0-3 s), middle time interval (3-6 s) and late time interval (6-9 s).
The analysis of anticipatory looking during the extended time period revealed a borderline significant interaction between area and condition, $F(2, 57) = 2.81, p = .069$. This effect was followed up by planned comparisons of looking time at occluder A and occluder B between conditions to test effects related to our hypotheses. The children in the long delay condition showed less correct anticipatory looking, $t(38) = 2.88, p = .007$, over the extended time period compared to the children in the control condition, but there was no difference in looking at the incorrect occluder (A), $t(38) = .43, p = .672$. There were no significant differences in anticipatory looking time at occluder A or occluder B between the children in the distractor and control conditions, $t$’s $< 1.13, p$’s $> .26$.

In comparison with the 18-month-olds, the adults were found to have higher overall total looking time during the A and B trials, $F$s $= 30.28 – 67.21, ps < .000$. However, during the A trials there was no significant difference between the age groups with regard to looking at the incorrect occluder (B), $t(94) = 1.72, p = .089$. Figure 11 illustrates the adults’ mean anticipatory looking time (during 2 s) at occluder A and B in the three conditions during the two B trials.

![Figure 11. Adults’ mean looking time (s) and standard error during the 2 s interval after the sound cue in the B trials. The white and black bars indicate the A area and the B area (occluders), respectively.](image)

**Discussion**

This study showed that the 18-month-olds, in both the control and distractor condition, correctly anticipated the hidden objects reappearance following the switch of hiding location, in contrast to our prediction. This direction of
gaze was also seen during the extended time period (9 s) in the first B trials, showing that their anticipatory looking was not just a brief response. The switch of the object’s hiding location from A to B on B trials produces a conflict between previous and current information. Moreover, the presentation of the visual distractor increases the need for attentional control. Our results demonstrates that by 18 months of age children can flexibly shift their attention and resist distraction that interferes with the task at hand. This is in contrast to our findings in Study II, where the distractor led to more perseverative looking in 10- and 12-month-olds. Thus, this finding indicate that an important development of attentional control takes place between 12 and 18 months of age, which is somewhat earlier than proposed by the research literature (e.g., Posner & Rothbart, 1998; Rothbart & Posner, 2001). Clearly, longitudinal data from this age period would better describe this development.

As hypothesized, the increased attention demand induced by the long delay led to worse performance in the 18-month-olds, suggesting that a 10 s delay is challenging in this age group. This suggestion is in line with the notion of attention as a limited resource (e.g., Berger, 2004, 2010). Notably, the children in the long delay condition showed less correct, but not more incorrect anticipatory looking compared to the children in the control condition. This may indicate that the longer delay challenged the 18-month-olds ability to keep the object’s correct hiding location mind over the delay.

Overall, the 18-month-olds and the adults showed similar anticipatory looking patterns, the exception being the effect of long delay on the 18-month-olds. The main difference between the age groups seem to be the adults’ superior ability to stay on task and maintain their focus of attention.
General Discussion

The general aim of this thesis was to look closely at the attention processes underlying the early development of cognitive control in infancy and toddlerhood. This thesis rests upon two theoretical assumptions. First, attention processes are involved in cognitive abilities supporting cognitive control. Second, the early development of cognitive control is closely tied to improvements in attentional control. The three studies included in this thesis were based on the A-not-B paradigm, as this is a paradigm that involves conflict resolution and requires a flexible shift of response set for successful performance. I begin by summarizing the rationales and the main findings from each study.

Description of rationales and main findings

In Study I, we started out by using a new approach to investigate 10-month-olds’ performance on a manual version of the A-not-B task. This approach involved allowing for different types of search responses, besides correct search responses on A and B trials. We examined individual differences in 10-month-olds’ looking and reaching responses, and the relation between performance on A and B trials. The first study revealed the expected perseverative error, on a group level, but also individual differences. The infants’ performance on A trials was related to performance on B trials. Infants who made more correct searches on A trials were found to search more incorrectly (i.e., perseveratively) on the B trials. In contrast, infants who made few correct searches on A trials made less incorrect search responses and more no-search responses on B trials. Thus, non-correct search responses on B trials were not only perseverative errors. It was suggested that factors related to the difficulty of the task (e.g., the distractor/hand-clapping during the delay) increased the attentional demand of the task and consequently affected performance.

In Study II we examined the role of increased attentional demand in the control of anticipatory looking in 10- and 12-month-olds during a looking version of the A-not-B task. The method of tracking the infants’ gaze during the A-not-B task was argued to be more sensitive to the role of attentional processes compared to the manual version of the task, as it substantially reduces motor involvement. Attention demand was manipulated by
presenting half of the infants in each age group with a visual distractor during B trials. The study demonstrated that the 10-month-olds showed more perseverative looking than the 12-month-olds and that the increased attention demand induced more perseverative looking. Thus, the result from this study is in line with the perspective that the taxing of limited attentional resources leads to a decrease in performance. An unexpected result was that we found no effect of age or distractor on correct anticipatory looking. As the 12-month-olds were not found to be better at handling the distraction than the 10-month-olds this indicates that their attentional resources were still insufficient to overcome the distraction.

Therefore, in Study III we examined the effect of distraction on 18-month-olds’ anticipatory looking on the same task. This study also included a long delay condition and the 18-month-olds’ performance was compared to that of adults. The third study demonstrated that the 18-month-olds were able to correctly anticipate the reappearance of the hidden object, despite being distracted. Further, the longer delay had an effect on correct anticipatory looking, but it did not lead to more incorrect looking. In general, the main difference between 18-month-olds and the adults was that the adults showed more correct anticipatory looking and a superior ability to maintain focus on the task. In the sections that follow, I will address key aspects of this thesis in relation to current research within the field.

The development of attentional control

As previously noted, rudimentary forms of important attention processes that enable control of attention are present at birth or begin to develop in early infancy (e.g., Colombo, 2001; Rosander & von Hofsten, 2002). However, it has been suggested that the ability to control attention becomes more evident by the end of the first year of life and also that an important development takes place regarding attentional control between 18 and 24 months of age (e.g., Rothbart & Posner, 2001; Ruff & Rothbart, 1996). The results from Study II and III revealed age-related improvements in attentional control at these time points in development. Findings related to the development of attentional control will be discussed below.

As seen during the A trials, Study II demonstrated that 10- and 12-month-olds can correctly anticipate the reappearance of an occluded object following a 3.5 s delay. Arguably, this is a relatively advanced ability, as it involves keeping the hidden object’s correct hiding location in mind over the delay and forming an expectation of where the object will reappear to correctly anticipate the object’s reappearance. The absence of a trial effect showed that the infants expected rather than learned where the object would reappear. These findings suggest that infants of this age can use an internal representation to guide their anticipatory gaze following a delay. These
results could be related to previous research that has shown that the ability to hold representations in mind begin to develop already during the first 6 months of life (Jonhson, 2005; Pelphray & Reznick, 2002) and improves significantly over the first year (Diamond & Doar, 1989).

Examination of anticipatory looking on B trials revealed several interesting age-related results. The 10-month-olds showed more perseverative looking (i.e., looked more toward the incorrect occluder A) in anticipation of the object than the 12-month-olds (Study II). This indicates an age-related improvement in attention control among the older infants. An inspection of Figure 7 (p. 44) suggests that only the 12-month-olds in the no-distractor condition displayed more correct anticipatory looking than perseverative anticipatory looking. These findings confirm the suggestion that a development of attentional control can be seen by the end of the first year involving flexible shift of attention (e.g., Ruff & Rothbart, 1996).

An interesting finding in Study II was that the 12-month-olds were not found to be better at handling the visual distractor than the 10-month-olds. We suggest that the increased level of conflict (i.e., the increase in attentional demand) made it more difficult for the infants to control anticipatory looking. In fact, the ability to correctly anticipate the objects’ reappearance, despite the introduction of the visual distractor, was only seen in the 18-month-olds (Study III). This shows that an important improvement takes place with regard to attention control between 12 and 18 months of age, which is somewhat earlier than suggested by existing theories (e.g., Rothbart & Posner, 2001; Ruff & Rothbart, 1996). However, the increased attentional demand induced by the longer delay (10 s) was found to be difficult for the toddlers, as indicated by less correct anticipatory looking during this condition. We suggested that the increased delay made it more difficult for the toddlers to keep an active representation of the object’s correct hiding location in mind.

An additional finding of relevance for understanding the development of attentional control is the comparison between the 18-month-olds and the adults in Study III. Overall, the anticipatory looking pattern during the A and B trials over conditions was similar in the two age groups, the exception being the long delay condition where the 18-month-olds showed non-preferential looking. However, the adults had longer looking times throughout the task compared to the 18-month-olds, which was most notable for correct anticipatory looking. This was interpreted to reflect the adults’ superior ability to maintain their attention on task and also shows, as expected, that attentional control is far from fully developed by 18 months of age. In fact, studies on the attentional network task (e.g., Rueda, Fan, et al., 2004) has demonstrated that it is not until seven years of age that children perform equivalent to adults on the executive control part of the task, which measures the ability to solve conflict.
Our data on age-related improvements in attentional control between 10 and 12 months, and between 12 and 18 months have contributed to our knowledge of the early development of attentional control. Future work should use longitudinal designs to confirm these cross-sectional findings. Further, what exactly underlies these behavioral changes is less clear. Many researchers have suggested that the neural maturation of the attention systems plays an important role in children’s increasing ability to manifest control of attention (e.g., Colombo, 2001; Garon et al., 2008; Ruff & Capuzzoli, 2003; Ruff & Rothbart, 1996), but more evidential data is needed. However, a recent study has shown some promising results that address this issue. Gao and colleagues (2009) examined brain connectivity in brain structures related to the orienting attention network and executive attention network in children from 2 weeks to 2 years of age by using resting states fMRI. This study demonstrated that brain structures related to the orienting attention network showed strong connectivity in neonates. Further, executive attention network were found to be present in early infancy, but that brain connectivity between these areas were spare during infancy and strongly increased at 2 years of age.

Why do children perseverate? Some explanations

As described in the introduction, the ability to selectively attend to relevant aspects and disengage from irrelevant aspects, when task demands change, requires attentional control (e.g., Garon et al., 2008). Thus, attentional control is necessary for any task that requires conflict resolution, such as the A-not-B task. Ever since Piaget (1954) shared his reports on infants’ performance on the A-not-B task, the reason why children perseverative has been debated. The studies included in this thesis by no means intended to solve this debate. Rather, the studies were based on the A-not-B paradigm because infants’ and toddlers’ performance on this task can inform us about the early development of attentional and cognitive control. However, some novel explanations for understanding the perseverative error will be suggested in this section.

In Study I, our investigation of the 10-month-olds’ performance, on a group level, demonstrated the expected perseverative error across modalities (i.e., looking and reaching), but examination of individual difference data revealed variation in search performance. Infants who made more correct searches on the A trials searched more at the incorrect on B trials (i.e., perseverated), compared to infants who searched less at the correct location on A trials. This implies individual differences in competence or maturity and also that perseveration can be seen as a developmental step in infants’ cognitive development. This interpretation is parallel to the suggestion put forward by Clearfield et al., (2006) that the path toward flexible behavior
(e.g., searching correctly on both A and B trials) involves a development from too much variability in behavior to too much stability. Further, it is possible that the individual differences in competence, seen in Study I, could be explained by other cognitive or behavioral measures that were not included in the study. For example, a study by Sheese et al. (2008) has shown that infants who performed well on an anticipatory looking task that assessed control of attention also showed more signs of self-regulation. Therefore, to better understand individual differences in performance among same-aged infants, future work should examine whether these differences relate to differences in other cognitive or behavioral measures, such as differences in temperament (e.g., activity level).

In Study I, we argued that one reason why the infants performed relatively poorly on this task was because the task was difficult for the infants’ level of maturity. The use of a visual distractor (i.e., hand-clapping during the delay) was pointed out as one of several (e.g., no training to search at A, the length of the delay) potential factors contributing to the difficulty of the task. This suggestion was supported in Study II, where a visual distractor led to more perseverative anticipatory looking in both 10- and 12-month-olds.

In fact, both Study II and Study III demonstrated that the taxing of limited attentional resources could explain a decrease in performance among the infants and toddlers. This is consistent with the theoretical view claiming that attention is dependent on a limited attentional resource (Berger, 2004, 2010; Boudreau & Bushnell, 2000; Kane & Engle, 2002). Perseverative behavior or a decrease in performance in relation to increased attentional demands is not limited to the A-not-B task or just present in infancy and toddlerhood. Studies on infants (e.g., Boudreau & Bushnell, 2000), school-aged children (e.g., Goldin-Meadow et al., 2001), and adults (e.g., Engle, 2002) using a wide variety of tasks have demonstrated a decrease in performance in relation to increased attentional demand. Consequently, the notion of the taxing of limited attentional resources as a factor underlying perseverative behavior can explain perseverative behavior in various contexts and age groups.

Developmental perspectives on cognitive control

An important issue, from a developmental perspective, is whether attentional control process and associated cognitive skills (e.g., memory and inhibition) should be described as consisting of partly separate components (e.g., Diamond, 2006) or be seen as a unitary construct (e.g., Munakata, 2001). In this section, this issue will be addresses based on findings from Study II and III. Existing theories (e.g., Rothbart & Posner, 2001) of attentional control suggest that to control attention require the guidance of internal
representations. In relation to performance on the A-not-B task on the B trials, this involves holding the correct hiding location (B) in mind. Control of attention also requires inhibiting a gazing response toward irrelevant stimuli, that is, the incorrect hiding location (A). An interesting finding in Study II and III was that the effects of the distractor (Study II) and the effect of the long delay (Study III), lead to more perseverative (but not less correct) and less correct (but not less incorrect) anticipatory looking, respectively. An interpretation of these results is that an effect of distraction makes inhibition of a gaze response more difficult and leads to perseverative looking, whereas an effect of a long delay makes it difficult to actively maintain a representation over time and therefore leads to less correct anticipatory looking. In general, this interpretation is parallel with the view of memory and inhibitory processes as partly dissociable components (Diamond, 2006; Miyake et al., 2000; Lehto et al., 2003), which is supported by research that has shown that memory and inhibition follows different developmental trajectories (e.g., Diamond, 2002, 2006). However, in line with other researchers, who propose an integrative view of cognitive control (Banich, 2009; Garon et al., 2008; MaCabe et al., 2010; Miyake et al., 2001), we argue that attention processes is critical for both memory and inhibitory processes.

New perspectives on the perseverative error

In studies on the A-not-B task the outcome measure of children’s performance is typically dichotomously scored as either correct or perseverative on B trials (but see Berger, 2004; 2010). However, the dichotomous characterization of the perseverative error appears to be a methodological question. In most previous studies on the manual A-not-B task, infants are either trained to search at location A, or the switch to B trials does not take place before the infant has made several consecutive searches at location A (Smith et al., 1999). The three studies included in this thesis have used novel approaches to address this well-studied phenomenon. Consequently, we have been able to provide new perspectives on children’s perseverative search behavior as seen in the A-not-B paradigm. Taken together, this thesis has revealed, from a developmental perspective, that the perseverative error is better described as a gradual rather than a dichotomous phenomenon.

In study I, we found that when infants are not restrained on the A-not-B task they make different types of search errors on both A and B trials. In Study II and Study III, we used a quantitative measure of infants’ and toddlers’ anticipatory gaze and assessed anticipatory gaze toward both occluders (A and B). In both studies (II & III) we found various amount of looking toward both occluders, indicating that the children’s performance
could be seen as a gradual. A similar observation has been done by Berger (2010) who assessed infants’ performance on a locomotor version of the A-not-B task and noted subtle signs of perseveration, such as longer latencies, hesitations, and directional shifts. The classical notion of the perseverative error (as seen in the A-not-B task) is that this is something the children either do or do not on B trials. Our data suggest that this interpretation does not fully capture children’s actual behavior as children may demonstrate other types of errors in varying degrees. One implication of this suggestion is that research on children’s development can gain from using more sensitive measures of children’s performance rather than dichotomous outcome measures.

**A broader perspective and future directions**

The protracted development of the human brain allows for experience-dependent learning and plasticity (e.g., Goldberg, 2002). Further, the act of attending has been found to mediate the child’s experience (e.g., Belsky, Pasco Fearon, Bell, 2007; NICHD Early Child Care Research Network, 2003) and also to have an effect on brain activity (e.g., Niebur et al., 2002; Reynolds & Chelazzi, 2004). This suggests that early attention processes may be of relevance for later cognitive and social-emotional development. In fact, several studies have shown that early attention processes are related to children’s self-regulatory and emotion regulatory abilities and also to preschoolers’ socio-cognitive understanding (e.g., Posner & Rothbart, 2000; Pollack & Tolley-Schell, 2004; Rueda, Posner & Rothbart, 2005; Yamaguchi, Kuhlmeier, Karen Wynn, & vanMarle, 2009). For example, being able to visually disengage from distressful stimuli seems to mediate emotion processing (Pollack, Cicchetti, Hornung & Reed, 2000). Further, early attention processes are moderately related to aspects of later cognitive functioning in preschool (Fagan & McGrath, 1981), childhood (Bornstein & Sigman, 1986), and adolescence (Sigman, Cohen & Beckwith, 1997). This in turn suggests that early attention problems may have implication for understanding disorders of attention, such as autism spectrum disorder and ADHD, which are often characterized by cognitive/attentional deficits. Thus, understanding the early development of attention processes appears to be an important venue that could, in part, explain later associations with cognitive, behavioral, and socio-emotional functioning.

The broader perspective of the importance of understanding early attention process, as described in the research reviewed above, indicates the direction for future research. As suggested by Colombo (2001), single-age point measurements of early attention and cognitive abilities may not be the optimal research strategy for understanding how these early abilities lay the ground for cognitive abilities and other important functions in later years.
Instead, a more advantageous approach may be to study change across periods of rapid development and also by implementing repeated measurement, especially with regard to longitudinal effects. Thus, a potential limitation of the current thesis is the lack of longitudinal data that allow for a more precise description of developmental change. However, at the planning stage of this thesis, the age groups that we chose to study were guided by the idea that the end of the first year and 18 months of age are important periods in terms of development of attentional control. Some of the findings based on this thesis have also been informative for the planning of future work. We are currently at the starting point of a longitudinal study beginning in late infancy and planned to continue into late toddlerhood with a focus on assessing the relation between attention abilities, cognitive control, and behavioral measures. The hope is that this project will shed further light on the relation between early development of cognitive control and its relevance for later functioning.

Concluding remarks

This thesis has demonstrated that important age-related improvements in control of anticipatory looking take place between 10 and 12 months of age, and between 12 and 18 month of age. More specifically, with increasing age, the children were able to resolve higher levels of conflict thereby demonstrating improvements in attentional control. It has been argued that this development is gradual, developing from variable to stable and also that the attentional control process is best described as continuous rather than dichotomous in infancy and toddlerhood. Our findings should motivate future research to examine changes in early cognitive development in relation to attentional control processes.
Acknowledgements

“Every journey conceal another journey within its line…” (J. Winterson)

Talking about journeys and research, this thesis is an important step in a longer journey that I hope will continue for many years. With any luck, it will involve conducting research the way Kate Bush dance. Starting from the beginning, I wish to thank my professors Alan Marwine, Joan Mulligan, and Vangie Blust at Green Mountain College for their enthusiasm and for inspiring me to peruse a research career in the first place. “It were as well to be educated in the shadow of a Mountain as in more classical shade.”

In making this thesis possible, I first and foremost express gratitude to my supervisor, Gunilla Bohlin, for her mentorship and for sharing her great knowledge of theories and methods. She has provided support and criticism (sometimes depressing) through every step of my research – and for that I am grateful. One of her best research advices is “follow your interest.” (I did).

I warmly thank Claes von Hofsten, Dorota Green, Hama Watanabe and Maria Johansson for fruitful collaborations on the work included in this thesis. A special thanks to Claes for his valuable advice and friendly help, it has been a privilege working with him. I am thankful for the comments and recommendations from Gustaf Gredebäck and Mats Fredriksson that helped me enhance my thesis. I also wish to thank Lilianne Eninger, my co-supervisor, and Carin Tillman for collaborations on my early research involving ADHD. Many thanks to my colleagues and friends in the developmental psychology research group and the Babylab research group for interesting scientific discussions and for good times.

Lastly, I would like to thank my family for all their support: my father for always being encouraging and for being a working-class hero (at least in spirit), my brother Magnus, for being the best little brother, and Sofia for love and all that really matters. This thesis is dedicated to the memory of my mother, Helen, who passed away much too soon. I miss you and you are in my heart always.

Stockholm, January 2012

For financial support, I am indebted to the Sven Jerring Foundation and the Helge Ax:son Johnson Foundation.
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