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Attention and Self-regulation in Infancy and Toddlerhood

The Early Development of Executive Functions and Effortful Control

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Abstract
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Executive functions are higher-order cognitive functions underlying self-regulation of behavior. That is, executive functions make it possible to resolve internal conflicts and behave according to future goals rather than acting on sudden impulses or going on automatic. Very similarly, the temperamental construct of effortful control is defined as being able to inhibit a dominant response, instead acting on a subdominant response. In children, poor executive functions and low levels of effortful control have both been associated with several negative outcomes, such as lower academic achievements and externalizing behavior problems. Although these self-regulatory functions seem to play a very important role in child development, little is still known about them during the first years of life. Furthering the knowledge of early executive functions and effortful control would likely increase the chances of early detection of risks of poor development. The present thesis aimed to investigate individual differences in executive functions and effortful control in infancy and toddlerhood, as well as the early development of, and the relation between, these two functions. The thesis further aimed to investigate the relationship between the self-regulatory functions and activity level, and the possibility of predicting toddlerhood self-regulatory functions with sustained attention in infancy. In Study I, individual differences in 10-month-olds' rudimentary executive functions were found, and these were related to temperamental activity level. In Study II, individual differences in sustained attention in infancy were found to predict toddlerhood executive functions and effortful control. Both these self-regulatory functions improved significantly from infancy to toddlerhood although the individual stability was low. Executive functions and effortful control were related in toddlerhood but not in infancy. In Study III we replicated and extended the finding of a longitudinal relation between infant sustained attention and toddlerhood executive functions. In addition, partial support for the proposition that executive functions develop in a hierarchical fashion was found, with simple inhibition being predictive of more complex forms of working memory two years later. The results from the three studies combined contribute to a better understanding of the early development of the self-regulatory functions executive functions and effortful control.

Keywords: Executive functions, Effortful control, Sustained attention, Infancy

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To my grandmother Britta,
for encouraging and appreciating
academic work like no one else.

List of Papers

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

I Johansson, M., Forssman, L., & Bohlin, G. (2014). Individual differences in 10-month-olds' performance on the A-not-B task. *Scandinavian Journal of Psychology, 55,* 130-135.

II Johansson, M., Marciszko, C., Gredebäck, G., Nyström, P., & Bohlin, G. (2015). Sustained attention in infancy as a longitudinal predictor of self-regulatory functions. *Infant Behavior and Development, 41,* 1-11.

III Johansson, M., Marciszko, C., Brocki, K., & Bohlin, G. (2015). *Individual differences in early executive functions: A longitudinal study from 12 to 36 months.* Manuscript submitted for publication.

Contents

Introduction

As infants and young children grow older, one observable marker of maturity is their increasing ability to regulate their own behavior. With age, they get better and better at stopping sudden impulses, waiting for things they desire, calming themselves down and staying focused and attentive to tasks for longer periods of time. In adulthood, these abilities are in many respects essential to a functional everyday life: to organizing work, planning for upcoming events, handling traffic etc. As will be further described below, self-regulatory abilities are also of major importance at school. During the first few years of life, children become less dependent on the surrounding adults for support with this regulation. Whereas the young infant needs more or less constant help with regulation of behavior and emotion, the older infant and toddler already manage some aspects of these abilities on their own. The maturation of self-regulation is closely tied to the development of prefrontal areas of the brain, and, more specifically, to the higher-order cognitive processes of executive functions. The early development of executive functions and the closely related construct effortful control is the focus of the present thesis. These functions underlying self-regulation of behavior will, when discussed together, be referred to as self-regulatory functions.

Executive functions

Definition

The concept of executive functions originates from the cognition and brain damage research on adults, with early studies finding for example, that lesions to certain areas in the frontal cortex resulted in patients' problems with regulation of behavior and emotion (see Stuss & Knight, 2013 for a historic review). With increasing understanding of the importance of these higher-order cognitive processes for everyday functioning, executive functions have also become an important construct within the field of developmental psychology. Although there are several definitions and descriptions of the construct, most researchers of today would agree that executive functions encompass the components of inhibition, working memory and shifting (also referred to as switching or cognitive flexibility). Diamond (2006) defined these three components as follows: “Inhibition, that is, the ability to ignore distraction and stay focused, and to resist making one response and instead make another. Working memory, that is, the ability to hold information in mind and manipulate it. Cognitive flexibility [shifting], that is, the ability to flexibly switch perspectives, focus of attention, or response mappings.” (p.70). Cognitive flexibility or shifting is dependent upon both working memory and inhibition. Diamond further means that working memory and inhibition together enable us to meet novel challenges, adapt to changes and behave flexibly rather than “going on automatic” (Diamond, 2006). In line with this, executive functions have been described as central to goal-directed behavior and to behaving according to conscious choices and decisions: “Goal-directedness is a hallmark of theoretical models of EF [executive functions], and in this respect executive functions are central aspects of volitional, free will-based definition of self-regulation and self-control through which the autonomous individual directs thinking, feeling and will as a purposeful agent in the world” (Blair & Ursache, 2011, p. 307). In other words, executive functions help us resolve internal conflicts and behave in ways that make us reach future goals rather than acting on first impulses.

Whether and how the various executive functions are related to each other is an issue that has been under extensive discussions (see Garon, Bryson, & Smith, 2008 for a review). In adults, working memory, inhibition and shifting have been found to be systematically correlated yet distinct separate functions (Miyake et al., 2000). A quite recent study revised this picture somewhat, finding that once the common or unitary aspect of executive functions was accounted for, there was no unique variance left for a specific inhibition factor (Miyake & Friedman, 2012). The interpretation of this finding has been that inhibition may be considered a core aspect of executive functions. The picture of how executive functions are structured in childhood is less clear. Whereas some studies of school-aged children have found a similar structure to that found in adults with separable but interrelated functions (Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003), studies of younger children have mainly found support for executive functions constituting a unitary construct without separable subcomponents (Hughes, Ensor, Wilson, & Graham, 2009; Wiebe, Andrews Espy, & Charak, 2008; Wiebe, Sheffield, Mize Nelson, Clark, Chevalier, & Andrews Espy, 2011; but see Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012 for a solution with two components). However, inhibition has been suggested to constitute a core function in childhood as well, upon which later executive functions depend (Barkley, 1997; 2011).

Development in childhood

Although the structure of executive functions during childhood is not entirely clear, the development of these functions in preschool- and school-aged children has been fairly well studied (see Best & Miller, 2010; Best, Miller, & Jones, 2009; Diamond, 2013; Garon et al., 2008; Hughes, 2011 for reviews). For example, from the extensive work by Diamond and colleagues, we know that major developmental improvements in executive functioning occur between the ages of 3 and 5 years, and that some fundamental developmental steps are not taken until the age of 6 or 7 (Diamond, Carlson, & Beck, 2005; Diamond, Kirkham, & Amso, 2002; Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994; Kirkham, Cruess, & Diamond, 2003; or see Diamond, 2002; 2006 for reviews). Others have shown how the development of executive functions continues in adolescence and early adulthood (e.g., Anderson, 2002; Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Blakemore & Choudhury, 2006; Crone, 2009; Jurado & Rosselli, 2007). In these age-groups there is also quite a large number of studies showing how poor executive functions are associated with a variety of problematic outcomes, such as externalizing behavior problems (e.g., Bohlin, Eninger, Brocki, & Thorell, 2012; Granvald & Marciszko, 2015; Schoemaker, Mulder, Dekovic, & Matthys, 2013; Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005), poor social skills (e.g., Hughes, 1998; Razza & Blair, 2009; Riggs, Jahromi, Razza, Dilworth-Bart, & Müller, 2006), and lower academic achievement (e.g., Blair & Peters Razza, 2007; Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001). Deficiencies in executive functions are further related to clinical problems such as ADHD and autism (e.g., Barkley, 1997; 2011; Hill, 2004; Pennington & Ozonoff, 1996). Although there are no established causal relationships between executive functions and these negative outcomes, poor childhood executive functions are clearly indicative of risk for developmental problems.

Development in infancy and toddlerhood

Executive functions are not only of relevance in childhood, adolescence and adulthood, but also in infancy and toddlerhood. Very simple or rudimentary forms of executive functions are proposed to exist already during the first year of life. For example, using the so-called Detour reaching and A-not-B tasks, Diamond (1985; 1988; 1990; or see 2002; 2006 for reviews) has shown how the abilities of keeping a goal in mind and inhibiting a prepotent motor response emerge and improve between the ages of 8 to 12 months. Further improvements then seem to occur in the later parts of the second year of life (Diamond, Towle, & Boyer, 1994; Diamond, Churchland, Cruess, & Kirkham, 1999; Diamond, Lee, & Hayden, 2003). These results are well in line with more recent work showing that executive functions improve over infancy and toddlerhood (e.g., Bernier, Carlson, & Whipple, 2010; Bernier, Carlson, Deschenes, & Matte-Gagné, 2012; Carlson, 2005; Garon, Smith, & Bryson, 2014; Hughes & Ensor, 2007; Miller & Marcovitch, 2015; Wiebe, Lukowski, & Bauer, 2010). For example, Miller and Marcovitch (2015) found that infants passed a larger number of executive function tasks at 18 than at 14 months, and Hughes and Ensor (2007) found improvements in executive function performance over the ages 2, 3 and 4 years. As indicated by these studies, the interest in studying executive functions already in the first years of life has started to increase, but the number of studies is still quite small and many questions regarding early development remain unanswered. Especially studies taking individual differences into account and investigations of early development using a longitudinal approach are very few. These types of studies are essential to shedding light on the predictability of individual children's executive function development, and in the longer run, for identifying risks of poor development at an early stage.

The A-not-B paradigm

The A-not-B paradigm, first developed by Piaget (1954), has often been used as a measure of early executive functions. This task involves hiding an object in one of two locations (A and B) while the infant is watching. The object is first hidden at location A and after a short delay the infant is encouraged to search for it. After repeated hidings at location A, the object is hidden at location B. After the shift of hiding location, infants younger than 12 months often show a perseverative search response by continuing to search at location A (e.g., Diamond, 1990). That is, they continue to search at the location where their previous search behavior has been reinforced. Diamond et al. (e.g., Diamond, Cruttenden, & Niederman, 1994) proposed that overcoming the perseverative error and instead successfully searching at location B requires both the ability to hold a spatial location in mind over a delay period and the ability to inhibit a prepotent response – that is, rudimentary forms of working memory and inhibition. By changing aspects of the design, such as increasing the number of A trials to build up an even stronger prepotency, or extending the delay, the difficulty of the A-not-B task has been found to change, and thereby capture developmental changes in a variety of ages during infancy and toddlerhood (Diamond, 1985; 1990; Diamond, et al., 1994; Marcovitch & Zelazo, 1999; 2009). The A-not-B paradigm has sometimes been modified so that the child's response is looking rather than reaching (e.g., Bell, 2012; Bell & Adams, 1999; Cuevas & Bell, 2010), thereby avoiding the additional demands involved in motor control of reaching behavior (cf. Berger, 2004; 2010). A further development of this methodology has been the use of eye-tracking (e.g., Forssman, Bohlin, & von Hofsten, 2014; Watanabe, Forssman, Green, Bohlin, & von Hofsten, 2012). This paradigm relies on anticipatory gaze, that is, on voluntary sustained anticipatory looking until the expected event occurs (i.e., the hidden object reappears). One advantage of this methodology is that it allows for continuous measures (Forssman et al., 2014; Gredebäck, Johnson, & von Hofsten, 2010). The use of eye-tracking also eliminates the ostensive cues that sometimes have been suggested to explain performance on the A-not-B task (Csibra & Gergely, 2009; Topál, Gergely, Miklósi, Erdöhegyi, & Csibra, 2008).

Studies using the A-not-B task have often found age differences in the length of delay tolerated before committing the perseverative error (e.g., Diamond, 1985; Diamond & Goldman-Rakic, 1989), mainly interpreted as differences in the maturity of very simple forms of working memory. Apart from age-related differences, Diamond (1985) also found this aspect to differ between same-aged infants. Interestingly, Clearfield, Diedrich, Smith, and Thelen (2006) investigated individual differences in performance not only on the search trials after the shift of hiding location (the B trials), but also on the initial A trials. Using a version of the A-not-B task where the object was kept in full view of the infant at all times, they found that the commonly reported behavior of correct search responses in A trials and perseverative errors in B trials was preceded by a developmental period of erratic search behavior in both A and B trials. These results indicate that additional information about infants' cognitive development could be achieved by studying individual differences in performance over the entire task, not only in B trials. In the traditional version of the task using hidden objects, the initial A trials are considered to require keeping information in mind (i.e., a rudimentary form of working memory), and B trials are considered more demanding, requiring both keeping information in mind and using this information to inhibit the habitual search response. One approach to increasing our understanding of the early individual differences in executive functions has been to investigate how A-not-B task performance relates to aspects of infant temperament. Bell (2012) investigated how parental ratings of infant temperament were related to 8-month-olds' performance on a looking version of the A-not-B task. Contrary to what the author had expected, higher levels of activity and distress to limitations were related to better executive function performance at this early age. As regulatory aspects of temperament have mainly been suggested to relate to cognitive development in the opposite direction to what was found in Bell's (2012) study (e.g., Gerardi-Galton, 2000; Rothbart, Sheese, Rueda, & Posner, 2011a; Rueda, Posner, & Rothbart, 2005), further studies of infant temperament and early forms of executive functions are needed.

A hierarchical model of development

To further the understanding of early development of executive functions, Garon et al. (2008; 2014) have proposed a theoretical framework based on previous empirical findings and the work on adults by Miyake et al. (2000). They suggest that simple forms of executive functions, such as delaying a response or holding information in mind, should precede more complex forms of working memory, inhibition and shifting. The early, simple abilities are suggested to become increasingly coordinated over development and thereby to enable the development of more complex abilities. For example, by the end of the first year infants can hold simple rules or pieces of information in mind, and are also able to resolve internal conflicts such as inhibiting prepotent reaching responses, but the coordination of these skills, which can be seen in the ability to use information held in mind to inhibit habitual motor responses, does not start to appear until sometime during the second year. The more complex abilities then continue to develop over the entire toddler and preschool period, with the most fundamental improvements not starting to take place until the third year (Garon et al., 2008; 2014). From this perspective, executive functions develop in a hierarchical fashion.

As will be further discussed below, attention processes are often proposed to be of importance for executive function development. This also applies to the hierarchical model. Garon et al. (2008; 2014) mean that attention constitutes the foundation for the development of executive functions. They specifically highlight the importance of focused or sustained attention in the development of executive functions, that is, the ability to attend to a stimulus over a period of time without being distracted. They argue that better sustained attention allows the child to be in control over what information is being processed, and should therefore promote the development of goal-directed and self-regulatory behavior. The hierarchical model thus takes the stand that attention processes are essential as precursors of the early emerging simple forms of executive functions, but also emphasizes the continued importance of attention throughout the development (Garon et al., 2008; 2014).

The hierarchical framework of executive function development is built on previous literature showing steady improvements on more and more complex tasks with age (see Garon et al., 2008 for a review). However, these findings are almost entirely based on cross-sectional comparisons of mean level of executive function performance between different age groups. For example, the delay over which infants can keep information about a hidden toy in mind, is significantly longer in 12-month-olds than in 6-month-olds (see Pelphrey & Reznik, 2003, for a review), and performance on working memory tasks requiring updating and elaboration of information kept in mind is better in 5-year-olds than 3-year-olds (e.g., Carlson, 2005; Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Garon et al. (2014) themselves have found more complex forms of executive functions to develop faster in preschool age than in late infancy and early toddlerhood, and the opposite pattern for more simple functions. To further evaluate the explanatory value of the hierarchical model, longitudinal studies of individual differences in simple and complex executive functions as well as attention are needed. This is particularly true in light of a couple of recent studies that have shown poor stability in individual infants' level of executive function performance over the first years of life (Miller & Marcovitch, 2015; Wiebe et al., 2010). However, these studies did not investigate the claim of a hierarchical development of simple executive functions predicting later, more complex ones, but rather the stability in executive function performance on the same tasks over time. To our knowledge, the only study that empirically supports the suggestion that individual differences in more complex executive functions build on early, simple ones is the work by Friedman, Miyake, Robinson, and Hewitt (2011). They succeeded in predicting adolescent performance on executive function tasks from a simple inhibition task requiring the child to withhold a reaching response, already from the age of 14 months. Although in line with the suggestions by Garon et al. (2008; 2014), the role of attention in the hierarchical development was not taken into account.

Issues of assessment

Studies of the early development of executive functions require valid and reliable measures. However, it is well known that assessing executive functions in infants and toddlers is associated with several problems. For example, executive function tasks almost inevitably put demands on other skills than the cognitive ones that they are intended to measure, such as verbal, motor and perceptual abilities. As these skills are all undergoing major developmental changes during the first years of life, task performance will reflect variance not only related to individual differences in executive functions. This idiosyncratic variance could affect the possibilities of finding longitudinal relations in task performance, the reason being that the variance reflecting executive functioning likely varies with age (e.g. Espy, Bull, Kaiser, Martin, & Banat, 2008; Wiebe et al., 2010). In addition, tasks successfully used with older children are often adapted to suit infants and toddlers. When making these adjustments there is always an impending risk that the psychometric properties of the tasks will be affected and that the tasks will not tap into the functions intended. As the number of studies on the early development of executive functions has started to increase, more tasks for very young children have become available (e.g., Garon et al., 2014; Hughes & Ensor, 2005). Although encouraging, problematic issues with assessing infant and toddler executive functions still need to be taken into account in studies of early development.

Effortful Control

Definition

Whereas the concept of executive functions originates from the literature on adult cognition, the closely related construct of effortful control was first used in the infancy and childhood temperament literature. Rothbart and colleagues (e.g., Rothbart & Bates, 2006) defined temperament as "constitutionally based individual differences in reactivity and self-regulation, in the domains of affect, activity, and attention" (p. 100). That is, individual differences in both behavioral and physiological reactions to internal and external stimuli and in how these reactions are regulated. By defining temperament as constitutionally based, they suggest that these fundamental individual differences in reactivity and regulation are mainly dependent on biological or genetic differences, but that they are also affected by experience over development. Effortful control is a temperamental trait of self-regulation, allowing children to suppress affective or "automatic" behavior and instead act more freely in, for example, situations of internal conflict (Rothbart, Ellis, Rueda, & Posner, 2003). The definition of effortful control is "the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors" (Rothbart & Bates, 2006, p. 129). Empirically, effortful control has been found to include tendencies of low intensity pleasure, perceptual sensitivity, attentional focusing and inhibitory control (e.g., Rothbart, 2011; Rothbart & Bates, 2006; Rothbart & Derryberry, 2002; Rothbart et al., 2003).

Similarities to executive functions

The definition of effortful control lies very close to that of executive functions and the similarity between effortful control and inhibition is particularly striking. Overcoming internal conflict is central in the definitions of both constructs, and it has been argued that effortful control and executive functions are not only overlapping, but rather one unitary construct reflecting the same functions (e.g., Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013; Zhou, Chen, & Main, 2012). By reviewing the literature on childhood executive functions and effortful control, Zhou et al. (2012) concluded that differentiations between the two constructs seem to be the consequence of the constructs originating from separate research traditions, rather than any "real" differences. For example, both effortful control and executive functions are linked to areas of the prefrontal cortex (Diamond & Goldman-Rakic, 1989; Lezak, Howieson, Bigler, & Tranel, 2012; Posner & Rothbart, 2009; Rothbart, Derryberry, & Posner, 1994), and it has been argued that these neural substrates are in fact the same (Allan & Lonigan, 2011). However, very few studies have actually compared individual differences in executive functions and effortful control, and to complicate the picture even further, some studies have used the terms interchangeably (see, e.g., Diamond, 2006; 2013). Importantly, whereas executive functions most often is viewed as a primarily cognitive construct, effortful control may be seen to reflect a somewhat broader self-regulatory ability, also including motivational and emotional aspects of regulation (Rothbart & Bates, 2006).

Development

In the temperament literature, effortful control is described as self-regulation at a behavior level, with different mechanisms driving this regulation at different points in early development. Rothbart (2011) means that effortful control appears around the age of 10 months, but already during the first few months of life, individual differences in basic regulatory behaviors, such as hesitating before approaching novel stimuli or expressing distress, are observed and can be assessed using temperamental scales (Gartstein & Rothbart, 2003; Rothbart, Sheese, & Posner, 2007). However, more advanced and complex regulatory skills are not sufficiently mature until several months later. Effortful control has been found to develop rapidly during childhood (Rothbart & Bates, 2006; Rothbart, Ellis, & Posner, 2011b), but similarly to what is described above regarding the knowledge base of executive function development, the number of longitudinal studies of the early development of effortful control is small. For example, questions regarding both stability and change over the first few years of life are still unanswered.

In childhood, poor effortful control is related to several negative outcomes. Valiente and colleagues (Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008) found positive correlations between effortful control and academic achievement, and low levels of effortful control have also been related to externalizing behavior (Eisenberg et al., 2005; Olson, Sameroff, Kerr, Lopez, & Wellman, 2005). These studies further suggest an overlap between effortful control and executive functions, as very similar results have been found for poor executive functions in childhood.

Assessment

Assessing effortful control in infancy and toddlerhood is generally associated with fewer problems than the assessment of early executive functions. The reasons for this are the frequently used parental rating scales with good psychometric properties developed by Rothbart et al. (e.g., the Early Childhood-, and Children's Behavior Questionnaires; Putnam, Gartstein, & Rothbart, 2006; Putnam, Rothbart, & Gartstein, 2008; Rothbart, Ahadi, Hershey, & Fisher, 2001). Using these scales, effortful control is assessed from a behavioral point of view, from which individual differences in child behavior in everyday life are investigated. For example, parents rate how often their children are able to wait for a desired item, or how often they stop a forbidden activity when told to do so. By taking this behavioral approach to self-regulatory functions, the assessment of effortful control is quite different from the assessment of executive functions. Executive functions are almost always assessed using laboratory tasks aimed at tapping into as purely cognitive functions as possible. However, Kochanska and colleagues (e.g., Kochanska, Murray, & Harlan, 2000; Murray & Kochanska, 2002) have operationalized effortful control somewhat differently than Rothbart et al., by using laboratory tasks as their major assessment tool. These tasks are very likely to tap into cognitive, emotional as well as motivational aspects of self-regulation. This could be viewed as being in line with the above-described idea of effortful control as an overlapping but broader construct than executive functions. At the same time, however, this approach further adds to the lack of clarity as regards the relationship between the two constructs. Although the degree of overlap between effortful control and executive functions is not yet clear, both constructs are defined as functions underlying regulation of behavior. Therefore, the two constructs will from here on be referred to as self-regulatory functions when discussed together.

Attention as the foundation of self-regulatory functions

Attention has repeatedly been proposed to play a major role in the development of executive functions and effortful control. As briefly mentioned above, Garon et al. (2008; 2014) argue that attention constitutes the developmental foundation of the early emerging simple executive functions, and then continues to be of importance throughout the executive function development. These thoughts are mainly based on the significant work done by Posner, Rothbart and colleagues (e.g., Posner & Rothbart, 2000; 2009; Rothbart et al., 1994; 2007; 2011a; Rueda, Posner, & Rothbart, 2011), suggesting that self-regulatory functions rely on the brain networks that are also important for attention processes. In very young infants, the so-called orienting network is of major importance, with self-regulation mostly depending on orienting from or toward external stimuli. For example, distressed 3-month-olds have been found to temporarily calm down by turning to visual stimuli provided by adults (Rueda et al., 2011). During the first years of life, the anterior attention network develops; a network important for more will-controlled or executive attention. Self-regulatory functions start to successively rely less on the orienting network and more on the anterior attention network. Rothbart et al. (2011a) suggest that by the age of 18-20 months, self-regulatory functions such as effortful control have started to come under control of the anterior attention network. In this literature, it is sometimes difficult to differentiate the underlying attentional processes from executive functions or effortful control. Blair and Ursache (2011) clarified this by defining attention as relatively fast psychophysical reactions whereas executive functions were characterized as slower and more conscious or deliberate. They wrote: "…executive attention is the attentional component of executive functions and as such is important for directing cognitive resources in situation that require the engagement of the PFC [prefrontal cortex] to resolve conflict by holding information in working memory, inhibiting automatic responses, and shifting perspective or cognitive set as needed" (Blair & Ursache, 2011, p. 307). The idea of attention being the foundation of more advanced self-regulatory functions is also in line with the suggestion made in the cognition literature on adults, that the various components of executive functions share an underlying attentional process (Baddeley, 1996; 2002; Conway & Engle, 1996; Engle, 2002).

As previously mentioned, Garon et al. (2008; 2014) point to the importance of sustaining focused attention over a period of time (here referred to as sustained attention) in the development of self-regulatory functions. Still, empirical studies investigating the relation between attention and these functions have mainly focused on other aspects of attention, such as processing speed. This has been done by studying infants' looking time towards various stimuli. For example, Cuevas and Bell (2014) found that 5-month-olds who spent shorter periods of time looking at a puppet (i.e., who had a higher processing speed) than a comparison group, performed better at executive function tasks in toddlerhood and early childhood. Similarly, Rose, Feldman, and Jankowski (2012) found that reaction times measured as visual latencies, in both infancy and toddlerhood predicted executive function performance at age 11 years. In this study, short visual latencies were interpreted as high processing speed and were related to better executive function performance later on. Interestingly, looking durations such as those used in the study by Cuevas and Bell (2014) were not related to later executive function performance. As these examples show, the measures interpreted as aspects of attention vary to quite a large extent between studies, making it difficult to draw any general conclusions about the relation between infant attention and later cognitive abilities. Whereas some studies compare habituation times over several seconds, others study very detailed phenomena, such as the durations between individual saccadic eye movements (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991; Bornstein & Sigman, 1986; Cuevas & Bell, 2014; Diaz & Bell, 2011; Castelhano & Henderson, 2008). Further, a recent study found that looking durations to stimuli presented on a screen were unrelated to looking durations to naturalistic scenes (Wass, 2014). In their review of infant attention development, Colombo and Cheatham (2006) pointed to another issue associated with using looking time as a measure of attention. They showed that the relationship between looking time and cognitive abilities is not linear, but rather u-shaped. At a certain stage of development, it seems that long rather than short looking times become adaptive. Colombo and Cheatham suggest that looking times reflect different aspects of attention at different ages, and that longer looking times in later infancy probably should be considered a measure of sustained attention rather than processing speed. Similar arguments have been proposed regarding the characteristics of the stimuli shown to the infants. Whereas fast processing of uncomplicated or for example static stimuli should be adaptive, longer periods of sustained attention are likely the most adaptive response to multifaceted stimuli, or stimuli requiring the infant to solve a problem (N. Kirkham, personal communication, March, 2015). An example of this is a study by Papageorgiou et al. (2014) in which infants' fixation durations were positively correlated with concurrent ratings of effortful control. In sum, although the studies using looking time measures have contributed to the idea of attention being closely related to self-regulatory functions such as executive functions and effortful control, they do not give a clear picture of this relationship. Further, with a few exceptions, such as the study by Papageorgiou et al. (2014), studies approaching the relationship between attention and self-regulatory functions by using looking time measures have largely ignored the proposition made by Garon et al. (2008; 2014) about the importance of sustained, focused attention.

Sustained attention

As previously mentioned, sustaining attention to a stimulus over a period of time without being distracted has been suggested to play a major role in the development of self-regulatory functions (Garon et al., 2008; 2014). Similarly, Colombo and Cheatham (2006) have suggested that the emergence of internally or willfully driven attention (so-called endogenous attention), of which sustained or focused attention is a part, is a step towards the development of meta-cognitive skills such as executive functioning. The ability to sustain focused attention over a period of time rapidly develops over the first few years of life (Colombo, 2001; Kannass & Oakes, 2008; Ruff & Capozzoli, 2003; Ruff & Lawson, 1990; Ruff & Rothbart, 1996), and individual differences in this ability can be seen already in early infancy (e.g., Kannass & Oakes, 2008). Sustained attention is characterized by concentrated facial expressions and body movements centering around an item of interest (Colombo & Cheatham, 2006), and free-play tasks using multiple objects are often used for assessment. The competition for attentional focus in these free-play tasks is very similar to what infants encounter in their everyday life (Kannass, Oakes, & Shaddy, 2006). When children are allowed to manipulate and play freely with several toys, a continuous increase is seen across infancy and preschool age in the time spent attending to the toys (Ruff & Rothbart, 1996).

Although sustained attention has been suggested to be an important factor in the development of self-regulatory functions, this has rarely been investigated. A few studies have found concurrent relations between sustained attention and executive functions in preschool age (e.g., Reck & Hund, 2011), but to our knowledge, only one study has investigated the longitudinal relation between infant sustained attention and toddlerhood self-regulatory functions: Kochanska et al. (2000) found that the extent of manipulating and looking at toys at the age of 9 months of age predicted levels of effortful control at 22 months. More longitudinal studies are needed to further investigate the suggested predictive relationship between sustained attention and self-regulatory functions. Answering the question of whether sustained attention constitutes a foundation for the development of effortful control and executive functions would be an important step toward understanding individual differences in these functions. As Garon and colleagues (2008) concluded: "If attention is a basic building block for the EF [executive functions] system, the implication is that attention problems at any point in development may compromise emerging EF abilities" (p. 51).

Aims of the thesis

As described in the introduction, executive functions and effortful control seem to constitute important factors in the development of self-regulation of behavior, and in the longer run, for achievements and well-being throughout life. Despite the seemingly well-established relations between poor self-regulatory functions and several negative outcomes during childhood, many questions regarding the development of these functions in infancy and toddlerhood are still unanswered. The knowledge about individual differences in executive functions and effortful control during the first few years of life is especially scarce. For example, sustained attention has been suggested to constitute a developmental foundation for self-regulatory functions and also to contribute to the continued development, but this has rarely been tested. Also, the early development of these functions has mainly been evaluated using cross-sectional data, leaving questions regarding the predictability of individual differences largely unanswered. Increasing the knowledge in this area would be an important step toward being able to detect risk development and toward the possibility of intervening at an early age. Thus, the overarching aim of the present thesis was to increase the understanding of individual differences in the development of executive functions and effortful control from infancy to toddlerhood. More specifically, Study I aimed to investigate individual differences in executive functions already at age 10 months, and whether these differences were related to sustained attention and activity level. Study II aimed to investigate the possibility of predicting individual differences in 24-month-olds' executive functions and effortful control by sustained attention at age 12 months, and to investigate the development of the two self-regulatory functions over this age span as well as their concurrent interrelations. Study III aimed to evaluate the hierarchical model of executive function development by investigating the predictability of executive functions at age 24 and 36 months, by simpler ones as well as sustained attention at age 12 months.

Empirical Studies

Method

Participants

In study I, the sample consisted of 40 10-month-old infants (*M* = 304 days, *SD* = 8 days, 23 girls) and their parents. An additional six infants were tested but excluded from the study due to fussiness (2 infants), failures in the test procedure (3 infants) or for showing a strong side bias in the A-not-B task (1 infant). All infants were born in Sweden, and the majority lived with both of their biological parents. The percentage of the parents having a university degree was 76.9 for mothers and 66.7 for fathers. All infant were born full term and developing normally.

Study II and III were based on the same sample; 66 infants (35 girls) and their parents. The families were assessed longitudinally when the infants were at age 12 months (*M* = 371 days, *SD* = 13 days), age 24 months (*M* = 747 days, *SD* = 14 days) and age 36 months (*M* = 1113 days, *SD* = 14 days). As always in longitudinal studies, there was some attrition. At the second point of data collection seven families declined to continue participating in the research project (two families had moved out of town, five reported lack of time). There was no further attrition between the second and third point of data collection. All children were born in Sweden, and all except two lived with both of their biological parents. The parents were highly educated; in 92.4 % of the families at least one parent had a university degree. All infants were born full term and developing normally.

Procedure

The recruitment process was similar for both samples. Using birth records, all families that had recently had a newborn baby and were living in the region of a Swedish university town were contacted by mail. About 30 % indicated a general interest in participating in infant research at the Uppsala Child and Baby lab. When the studies were about to start and the infants had reached the target ages, the families were contacted again, either by telephone (Study I) or mail (Study II and III). The great majority of the families agreed to participate in the particular study they were contacted about, and a date for a lab visit was scheduled. The visits lasted approximately between 30 (Study I) and 90 minutes (Study II and III) and breaks were taken regularly. When several tasks were administered, the task order was randomized. A written consent form was filled out at every visit to the lab.

In Study I, executive functions were assessed at age 10 months, and in connection with these assessments parents rated their infants' activity level and sustained attention. In Study II, sustained attention was assessed at 12 months, and in addition, executive functions and effortful control were assessed at both 12 and 24 months. In Study III, the same assessments of sustained attention as in Study II were used. Simple forms of executive functions were assessed at 12 months, and more complex forms of executive functions were assessed at 24 and 36 months.

Measures

Executive functions

A-not-B manual version

In Study I, executive functions were measured using the A-not-B task. The A-not-B apparatus was made up by two wooden frame-shaped screens (A and B) covered with pieces of blue cloth, and standing on a white chipboard. The apparatus was placed on a table, with its center right in front of the infant. Which of the two screens that was designated "A" and "B" respectively, was counterbalanced across participants. A fixed design was used, with all infants being presented with four search trials at location A (A trials) and two search trials at location B (B trials). The delay between hiding and searching was 6 s, as previous research has shown that at least a 5 s delay is necessary to elicit perseverative responses by 10 months of age (e.g., Wellman, Cross, & Bartsch, 1986). At the beginning of each trial the experimenter attracted the infant's attention to the toy and then moved the toy from the center of the display to behind one screen, saying "Now it hides here", while gazing back and forth between the toy and the infant. The experimenter then clapped her hands to break the infant's visual fixation to the hiding location. Following the delay, the experimenter pushed the A-not-B apparatus within reach of the infant and encouraged the infant to search by saying "Where is the toy?". When reaching for the toy at the correct screen the infants were allowed to manipulate the toy briefly, when being incorrect or not searching within 10 s, the experimenter pulled the apparatus back, revealed the toy and said "Here it is!". Video recordings of the test sessions were independently coded by two trained research assistants using the video editing program Square 5 MPEG streamclip 1.2. A reaching response was defined as the first response where the infant touched one of the screens after the apparatus had been pushed towards and stopped in front of the child. Looking responses were similarly defined as the first look lasting at least 100 ms toward one of the screens. The infants' reaching and looking responses during the trials were coded independently of each other. For example, infants could look at the correct location, but reach toward the incorrect location during the same trial. For each trial, the infants' reaching and looking responses were coded in the following manner: (1) ***Correct looking/reaching response***: eye movement/reaching toward the correct screen; (2) ***Incorrect looking/reaching response***: eye movement/reaching toward the incorrect screen; (3) ***No search***: a looking/reaching response was not performed toward any of the two screens within 10 s; and (4) ***Searching at both locations***: searching at both screens simultaneously by using both hands. The outcome measures were the number of each type of response in A trials and B trials. The agreement between the two coders for 15 randomly selected infants was calculated using Cohen's Kappa and found to be .86 for reaching responses and .81 for looking responses.

A-not-B eye-tracking version

In Study II, executive functions were assessed using an eye-tracking version of the A-not-B task. Each participant was presented with two sequences of movie clips shown on a Tobii TX300 eye-tracker (sampling rate 50 Hz). Each sequence consisted of six movie clips. At the beginning of each clip, an attention catching figure (a Mickey Mouse doll) was displayed at the center of the screen and then moved horizontally until disappearing behind one of two occluders (A or B). After a delay of 4 s, a sound cue (a chime) was presented for 2 s, and thereafter the target figure reappeared from behind the occluder and moved back to the center position. The movie clips were accompanied by a child-friendly instrumental melody. The first four movie clips were all identical and constituted the four A trials. The two final clips, the B trials, were mirrored and the target figure therefore disappeared behind the other possible occluder. Which one of the two occluders the target figure was hidden behind first was counterbalanced across participants. To reduce the risk of floor as well as ceiling effects when administering the same task to children of two different ages (12- and 24-month-olds), each participant was presented with two sequences of movie clips differing in level of difficulty. The A trials were identical in the two sequences, but the B trials differed in that in one of the sequences, a bouncing ball was shown in the center of the screen for 2 seconds during the delay when the target figure was hidden. The addition of a distractor has previously been shown to increase the difficulty of the A-not-B task (Watanabe et al., 2012). The order in which the two sequences were presented to the infants was counterbalanced across participants. To minimize the risk of infants losing interest in the repeatedly shown movie clips there was a longer break (approximately 1 hr) between the two sequences. To be included in the analyses, each participant needed to attend to a minimum of two A trials (out of four) and one B trial (out of two), and they needed to "pass" the A trials by having longer looking times to the correct (occluder A) than the incorrect hiding location (occluder B). At age 12 months, data from three participants were excluded due to them attending to too few trials. No infant was excluded due to performance in A trials. The outcome measures were the proportions of looking time to the two occluders during the 2 seconds between the start of the sound cue and the reappearance of the target figure, averaged over the two B trials. That is, we measured "correct" and "incorrect" anticipatory looking for the hidden target figure in the trials after the shift of hiding location. The proportions were calculated over the screen areas of occluder A, occluder B and the center area between the two occluders.

In Study III, a number of behavioral tasks were used to assess executive functions. They are all described below in the order of age of assessment.

12 months

Hide-and-seek

This is a working memory task inspired by a similar task used by Garon et al. (2014). In the original task, used from the age of 18 months, a toy is hidden behind one of four doors. In Study III, the hide-and-seek task was administered at 12 months of age and when piloting, we found that searching for a toy beneath cups seemed to be easier and therefore more appropriate for this age group. The experimenter demonstrated for the child how a toy could be hidden under a colorful cup, and the child was then encouraged to search for the toy. After establishing that the child was able lift the cup and had understood the game, three cups in different distinct colors, standing next to each other on a tray, were put in front of the child, though out of reach. While the child was watching, a toy was hidden beneath one of the cups. The experimenter then clapped her hands to attract the child's attention and to break the gaze toward the cup with the hidden toy. The tray was then moved towards the child who was encouraged to search. The child was allowed to lift one cup at a time until the toy was found or a maximum of three times. This was repeated once, and then another two cups were added and two more trials were administered. In the last two trials, the child was allowed to search a maximum of five times. Immediately finding the toy gave 3 points in the first two trials, and 5 points in the last two. The number of points in each trial then decreased with the number of cups that had to be lifted before the toy was found (for example, finding the toy under the third cup lifted gave 1 point in the first and second trial, and 3 points in the third and fourth trial). The number of points was added to a total score (maximum 16). Because only 50 out of the 66 infants completed all four trials of the hide-and-seek task, instead of using the absolute score a proportional score was calculated for all infants completing at least three of the four trials (n = 62). The task was considered a measure of simple forms of working memory, as the only requirement was to hold the location of one toy in mind over a minimal delay.

Reverse categorization - infancy version

Reverse categorization is a response inhibition task originally developed by Carlson and colleagues (e.g., Carlson, Mandell, & Williams, 2004) and used from the age of 24 months (see the description of this task below). We developed a simplified version of this task where the child was presented with two buckets, one red and one yellow, and a set of yellow blocks. The experimenter first demonstrated how one of the yellow blocks could be put into the yellow bucket and then invited the child to sort the blocks by handing one block at a time to the child and saying "Can you put this into the bucket?" while tapping on the yellow bucket. The child was corrected if he/she put the block into the red bucket. After six successful trials building up the prepotent response, the rule was reversed and the child was instructed to put four yellow blocks into the red bucket one at a time. As in the training trials, the rule was repeated for every test trial while the experimenter tapped on the correct bucket. In these test trials the child was not corrected, and the first response was scored regardless of whether the child self-corrected an incorrect response. This version of the reverse categorization task was administered at age 12 months. At this age, only 49 of the 66 infants completed the task (17 infants either completely refused to participate or did not follow instructions and made up their own game). The score is the total number of correctly sorted blocks (maximum 4). The task was considered a measure of simple forms of inhibition as the infants only had to overcome the habitual response and instead act according to the new instructions.

Prohibition task

This inhibition task has previously been used by Friedman and colleagues (2011) from the age of 14 months. The experimenter presented the child with an attractive toy (a colorful and glittering wand) by putting it on a table within the child's reach, while making eye-contact, shaking her head in a "no-gesture" and saying "now, [child's name] you are not allowed to touch this" and then looking away. After piloting this instruction and finding that 12-month-olds had a very hard time refraining from touching the toy, we instructed the parents to say "no" once if their child started reaching for the toy. After 30 seconds, or earlier if the child has already touched the toy, the experimenter said "It's OK, you can touch it now", and encouraged the child to play with the toy. Data from one infant were excluded because the parent interfered with the procedure. The score is the latency to touching the toy, with a maximum of 30 sec. The prohibition task was considered a measure of simple inhibition, as the only requirement was to overcome the “pull” to reach for the attractive item.

24 and 36 months

Spin the pots
This is a working memory task developed by Hughes and colleagues (e.g., Hughes & Ensor, 2005). Eight small pots, all distinctly different from each other, were placed on a spinning tray. As the child was watching, raisins were hidden in six of the eight pots. A cloth was then placed over the pots and the tray was spun 180 degrees. When the cloth was removed, the child was encouraged to search for a raisin. Only one pot was allowed to be opened in each trial and regardless of whether a raisin was found, the empty pot was put back onto the tray, which was again covered and spun. This was repeated until all the raisins were found or for a maximum of 12 trials. The task was administered at ages 24 and 36 months. At age 24 months, 57 out of the 59 participating toddlers completed the task (two refused to participate). At age 36 months, all 59 toddlers completed the task. The score is the reversed error score (12 minus the number of errors made). The task was considered a measure of more complex forms of working memory as several moving spatial locations had to be held in mind, and this information had to be constantly updated.

Reverse categorization - toddlerhood version
As mentioned above, this task was originally developed by Carlson and colleagues (e.g., 2004) for assessing inhibition in toddlers. In the original task, a demonstration is provided showing children how to sort large blocks into a large bucket and small blocks into a small bucket. They are then instructed to do the sorting themselves. Thereafter, the rule is reversed and the children are instructed to sort the large blocks into the small bucket and vice versa. After piloting this version of the task, we found that many of the 24-month-olds were confused and seemed not to understand the concept of size. The blocks were therefore replaced with toy cars and horses, sorted into buckets of equal size each with a picture of a horse or a car on it. Similar adjustments to this task have been made by the developers themselves (Carlson, 2005). The task was administered at both 24 and 36 months, and all 59 toddlers completed the task at both ages. The score was calculated as the total number of correctly sorted toys after the rule was reversed, with a maximum of 12 correctly sorted toys (6 cars and 6 horses). The task was considered a measure of more complex forms of inhibition, as being correct required both overcoming the habitual response to sort horses into the “horse-bucket” and cars into the “car-bucket” and holding the reversed rule in mind and acting on it.

36 months

Beads task

The beads task is a working memory task originating from the Stanford-Binet Intelligence Scales (Thorndike, Hagen, & Sattler, 1986), but more recently used in research on executive functions by, for example, Hughes and Ensor (e.g., 2005; 2007). The child was first familiarized with a photo of an array of 12 different beads (Colors: red, blue and green. Shapes: cylinder, cube, sphere and triangle). The experimenter then turned the photo face down and presented the child with a bead for two seconds. The bead was then put out of the child's sight and the experimenter showed the photo of the 12 beads to the child while asking "which bead did I just show you?". The experimenter gave the child feedback on the first warm-up trial, then the test phase started and another nine trials were administered without giving any feedback. The child was presented with three single-bead trials (bead shown for 2 sec), three trials with two beads (beads shown for 3 sec) and three trials with three beads (beads shown for 3 sec). The number of trials and beads had been adjusted for this age group and sample, and differed somewhat from previous studies. This task was administered at 36 months. All 59 toddlers completed all nine trials. The score is the total number of correctly remembered beads (maximum 18). This task was considered a measure of more complex working memory, as information about two different features (color and shape) for each bead had to be held in mind and differentiated from distracting beads of very similar colors and shapes.

Snow/grass

This is a task developed by Carlson and Moses (2001) that taps into response inhibition. Two cards were placed in front of the child, one green and one white. The child was then asked what color the grass is, and what color the snow is and could respond by either naming the colors (green and white) or pointing to the cards. The experimenter then explained to the child that they were going to play a silly game where the child was to point to the green card when the experimenter said "snow" and to the white card when the experimenter said "grass". The instruction was then followed by two training trials where the child was corrected if he/she pointed incorrectly. The test phase consisted of 16 trials where the words "grass" and "snow" were each presented eight times in a randomized order. The child's first response was scored regardless of whether the child then corrected incorrect responses. The task was administered at age 36 months. At this time point, 52 of the 59 participating toddlers completed all 16 trials (2 toddlers refused to participate in the task and 5 completed between 6 and 15 trials). The 57 toddlers completing at least 6 trials were included in the analyses and a proportional score was calculated. The task was considered a measure of more complex forms of inhibition, as it required holding the rule in mind and inhibiting a prepotent response.

Effortful Control

In Study II, effortful control was assessed using parental ratings on the Early Childhood Behavior Questionnaire – Very Short Form, ECBQ, (Putnam, et al., 2006). The Effortful control scale consists of 12 items describing occurrence of child behavior in everyday situations such as "When engaged in play with his/her favorite toy, how often did your child play for more than 10 minutes?" and "When being gently rocked, how often did your child smile?". The items were rated on a 7-point Likert scale. The ratings had a Cronbach's alpha value of .80 at age 12 months and .59 at age 24 months.

Sustained attention

Sustained attention in free play

In Study II and III, sustained attention was assessed from video recordings of a free play situation at 12 months of age. Each infant played together with one of his/her parents in the lab for 10 minutes while the experimenter was out of the room. All children were given the same age-appropriate toys to play with: A colorful wooden shape sorter cube, a few pieces of differently colored Duplo Lego blocks, stacking cups in different patterns and colors, a wooden toy toaster with pieces of "bread" that popped up when a leaver was pushed, and a stackable nesting tower depicting Winnie the Pooh. The parents were instructed to engage in the play in the same way they would at home. The infants' levels of attention directed to play activities were scored by one of the lab researchers using the scale Play Directed Attention from the Maternal Attention and Emotion Scaffolding – Free Play Coding Manual (MAES, Dilworth-Bart, unpublished manual). In line with the manual instructions, child behavior was coded during four two-minute segments (minute 0:00-2:00, 3:00-5:00, 5:00-7:00, 8:00-10:00). No coding was done between segments. In each segment, attention was rated on a scale from 1 to 5, with 1 meaning minimal play directed attention, lack of involvement, disinterest or brief moments of attention to a range of toys, 3 meaning that the child's attention is directed to play activities about half of the time and that sustained attention is limited, and a score of 5 meaning play directed attention throughout the segment, active involvement and sustained attention to one or more activities for substantial length of time. In the manual, child behavior for scores 2 and 4 is not described in detail, but should be chosen when child behavior would be best described as falling between the anchor scores 1 and 3, or 3 and 5, respectively. In addition to the four segment scores, each infant was also given a global score. The mean of the four segment scores and the global score was found to correlate strongly ($r = .93$, $p < .001$), and therefore only the global score was used as a dependent measure for this task. Inter-rater reliability was calculated for 20 randomly chosen videos rated by a researcher not responsible for the main coding, Cohen's Kappa = .92.

Attention span

In Study I, attention span was assessed using parental ratings on items on the Attention span/persistence scale from the Colorado Childhood Temperament Inventory (CCTI; Rowe & Plomin, 1977). The CCTI has been used for temperamental ratings of young children and infants and has shown good psychometrical properties. Five items were rated on a 5-point Likert scale with higher values indicating higher levels sustained attention or attention span. The ratings were made in the lab by the mother, after the testing procedure was finished. Cronbach's alpha = .57.

Activity level

In Study I, activity level was assessed using parental ratings on items from the Activity level scale from the CCTI (Rowe & Plomin, 1977). In this study the scale consisted of four items, rated from 1 to 5, with higher values indicating higher levels of activity. The ratings were made in the lab by the mother. Cronbach's alpha = .76.

Study I

Individual differences in 10-month-olds' performance on the A-not-B task

Background and Aims

The early development of executive functions has often been studied using the classical A-not-B paradigm, first developed by Piaget (1954). Although the focus of studies using the A-not-B task most often has been on the perseverative error observed in the more cognitively demanding B trials, it has been suggested that performance on the initial A trials also is indicative of executive function development in infancy. Study I aimed to explore individual differences in early executive functions by examining how differences in search performance during A trials related to search performance during B trials. To elicit individual differences in A trial, a fixed design was used. Contrary to most previous studies, this design did not allow for training or individual adjustment depending on performance. The study further aimed to investigate the relations between executive function performance and the two temperamental dimensions activity level and sustained attention, as such regulatory aspects of temperament have been suggested to be related to early cognitive development (e.g., Gerardi-Galton, 2000; Rothbart et al., 2011b; Rueda et al., 2005). Early anecdotal reports on the A-not-B task indicated that infants who perseverated on B trials occasionally looked toward the correct hiding location, but then reached toward the incorrect hiding location (e.g., Diamond, 1985; Piaget, 1954), suggesting superior performance in the looking modality. This was investigated by comparing infants' search performance by both looking and reaching responses within the same task.

Results

Infants' number of correct responses on A trials were significantly associated with their number of incorrect responses on B trials, $r = .34$, $p = .030$. To further explore the relation between A trial and B trial performance, the group of infants was split into two based on A trial performance. Infants in the group with better A trial performance had at least two correct reaching responses or two correct looking responses out of four ($n = 25$, 14 girls). A mixed ANOVA (2 group x 2 type of response x 2 modality) was performed to evaluate erroneous responding in B trials for the two groups. A significant group x response interaction was found, $F(1, 38) = 6.24$, $p = .020$. There were no other significant effects, all Fs < 1, ps = >.33. The group with better A trial performance had more incorrect responses on B trials, $F(1,38) = 4.18$, $p = .048$, $d = 0.66$, and fewer "no search" responses, $F(1,38) = 4.08$, $p = .050$, $d = 0.65$ (see Figure 1.).

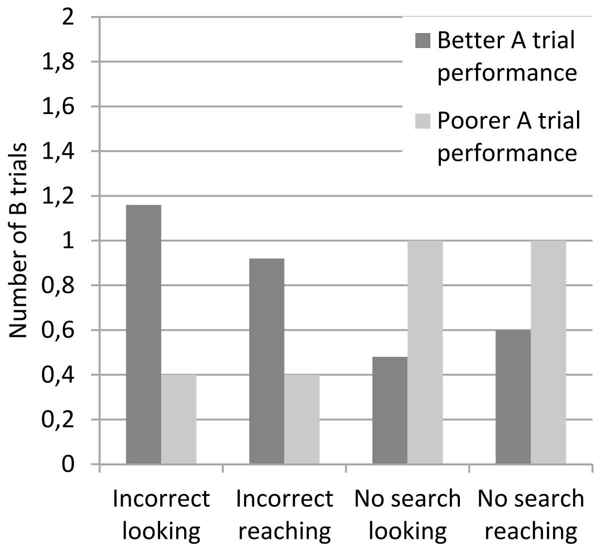

Figure 1. The group of infants with better performance on A trials had more incorrect and fewer no searching responses on B trials, than the group with poorer A trial performance.

The group with better A trial performance was found to have a lower activity level than the group with poorer A trial performance, $t(38) = 1.88$, $p = .034$, $d = 0.61$. There was no group difference with regards to attention span, $t(38) = 0.29$, $p = .77$, $d = 0.09$.

Looking and reaching responses were found to be consistently correlated for all types of responses, and over both A and B trials (correlation coefficients ranging from .54 for correct responses in B trials to .73 for incorrect responses in both A trials and B trials. All *p*s < .001) However, a repeated measures ANOVA (3 response x 2 modality) comparing performance between modalities on A trials showed a significant main effect of response, $F(2,78) = 3.96$, $p = .023$, which was modified by a significant interaction between modality and response, $F(2,78) = 5.50$, $p = .006$. Follow-up analyses showed that correct searching responses were more common for looking than for reaching, $t = 2.26$, $p = .029$, $d = 0.31$, and 'no search' responses were more common for reaching than for looking, $t = 2.77$, $p = .008$, $d = 0.84$. A similar analysis for B trials found no significant effects, all *F*s < 2.0, *p*s > 0.25.

Conclusions

This study demonstrated that with a fixed design of the A-not-B task, not allowing for training or individual adjustment, 10-month-olds show a wide variation in search behaviors and therefore a variation in performance on the task. There were individual differences in performance on A trials and these differences were shown to reflect differences in B trial performance. Infants who were more competent in their search behavior on A trials made more incorrect, perseverative searches on B trials than infants who performed more poorly on A trials. The fact that better A trial performance was followed by perseveration specifically, and not a general tendency to make more errors, is in line with the proposition by Clearfield et al. (2006); that stable correct search behavior during A trials followed by perseverative search behavior on B trials could be seen as representing a developmental step on the path toward more flexible behavior. Thus, we suggest that the infants in the group of better A trial performance had reached a developmental phase in which the ability to hold an object's location in mind over a brief delay was in place, but the requirements of B trials to use working memory in combination with inhibitory control were still too demanding (cf. Garon et al., 2008). In addition, the individual differences in rudimentary forms of executive functions were found to be related to temperamental activity level, but not to sustained attention. To some extent, the results also support the idea of modality differences in the A-not-B task, with looking performance suggested to be less cognitively demanding than manual reaching performance. Looking and reaching responses were not always in line; something noticed but not further investigated already by Piaget (1954).

Study II

Sustained attention in infancy as a longitudinal predictor of self-regulatory functions

Background and Aims

The development of self-regulatory functions has been suggested to rely on more basic or lower-level cognitive functions, such as attention (e.g., Posner & Rothbart, 2000; 2009; Rothbart et al., 1994; 2007; 2011a; Rueda et al., 2011; Garon et al., 2008). The main aim of the study was to investigate whether sustained attention at age 12 months could predict individual differences in self-regulatory functions at age 24 months. This was based on the idea that sustained attention underpins the development of the self-regulatory functions that begin to come under the control of the anterior attention network at the end of the second year of life (Rothbart et al., 2011a). Thus, we hypothesized that higher levels of sustained attention in free play at age 12 months would predict better executive functions and higher levels of effortful control at age 24 months. Concerning the concurrent relation between sustained attention and self-regulatory functions at 12 months, we posed no hypothesis, the reason being that early aspects of executive functions and effortful control should be less mature and less reflective of the anterior attention network than at 24 months.

As a means to gain further understanding of the mechanisms behind the above described developmental prediction, we also investigated the development of the two self-regulatory functions (i.e., A-not-B performance and ratings of effortful control) between age 12 and 24 months. We expected developmental improvement of these functions due to the development of the anterior attention network (Posner & Rothbart, 2000; Rothbart et al., 2011a). Based on the idea that the self-regulatory functions may not be under control of the same neural mechanisms at 12 and 24 months, we left the question open of individual stability in these functions over time. A second aim was to elucidate the relation between rudimentary aspects of executive functions (A-not-B performance) and effortful control as rated by parents, during a period of fundamental and rapid development. In line with the idea of executive functions and effortful control being largely overlapping constructs, sharing for example a reliance on the anterior attention network, and also in line with findings on older children and adults (Bridgett et al., 2013; Zhou et al., 2012), we expected the two self-regulatory measures to be concurrently related at least by the age of 24 months.

Results

To evaluate the infants' performance on the A-not-B task, we analyzed the proportion of looking time at occluder B ("correct looking") during the B trials of the task, using a 2 x 2 repeated measures ANOVA, with age (12 and 24 months) and level of difficulty (B trials with or without distractor) as factors. There were main effects of both age, $F(1, 45) = 7.99$, $p = .007$, partial $\eta^2 = .15$, and level of difficulty, $F(1, 45) = 18.91$, $p < .001$, partial $\eta^2 = .30$, but no significant interaction, $F(1, 45) = 2.25$, $p = .141$, partial $\eta^2 = .05$. As illustrated in Figure 2, the proportion of looking time at occluder B was larger in B trials without the distractor than in B trials with the distractor, and larger when the infants were 24 months of age as compared to 12 months. Possible differences in the proportion of looking time at occluder A ("incorrect looking") across age and level of difficulty were analyzed using a similar 2 x 2 repeated measures ANOVA. A main effect of age was found, $F(1, 45) = 15.01$, $p < .001$, partial $\eta^2 = .25$. All other Fs ≤ 0.74, ps $\geq .394$, partial η^2s $\leq .02$. The proportion of looking time at occluder A was smaller at age 24 months than at age 12 months (Figure 2.).

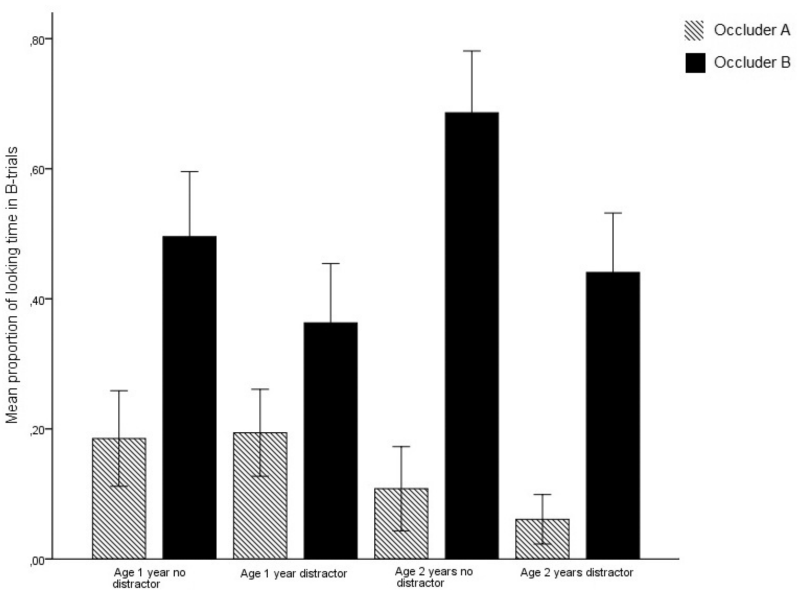

Figure 2. Mean proportions of looking time at occluder A and occluder B in the A-not-B task, over the two types of B trials (no distractor and with distractor) and age (12 and 24 months).

Due to the lack of interaction between age and condition, meaning that there were similar age effects in B trials with and without the distractor, the two conditions were aggregated in all further analyses. The Pearson correlation between the aggregated measure of "correct looking" at 12 and 24 months was $r = .21$, $p = .113$, and between "incorrect looking" at 12 and 24 months $r = .18$, $p = .188$. Infants' level of effortful control increased significantly with age, $t(57) = 5.49$, $p < .001$. The Pearson correlation between effortful control at 12 and 24 months was $r = .29$, $p = .027$.

Sustained attention at age 12 months significantly predicted the executive function measures "correct looking" ($r = .36$, $p < .001$ (one-tailed)) and "incorrect looking" ($r = -.26$, $p = .022$ (one-tailed)) on the A-not-B task, as well as the level of effortful control ($r = .25$, $p = .029$ (one-tailed)) at age 24 months. There were no significant correlations between sustained attention in free play and any of the measures of self-regulatory functions at age 12 months (all *r*s ≤ .14, *p*s ≥ .133). At 24 months, effortful control and "correct looking" in the A-not-B task correlated significantly, $r = .25$, $p = .030$ (one-tailed). There was no significant relation between effortful control and "incorrect looking" at 24 months, $r = -.09$, $p = .265$ (one-tailed). Neither were there any relations between effortful control and performance on the A-not-B task at age 12 months (effortful control and "correct looking", $r = -.03$, $p = .396$ (one-tailed); effortful control and "incorrect looking", $r = -.03$, $p = .395$ (one-tailed)).

Conclusions

In study II, we found support for the proposition that attention in infancy predicts self-regulatory functions in toddlerhood, by showing a longitudinal prediction of individual differences in 24-month-olds' executive functions and effortful control as a function of sustained attention at 12 months. The fact that we did not find any concurrent relations between sustained attention and the self-regulatory functions strengthens the proposition that the relations are truly longitudinal, rather than a mere product of concurrent relations in infancy being carried forward in time. Further, the analyses revealed overall improvements in both measures of self-regulatory functions from 12 to 24 months. This improvement could be interpreted to reflect the maturation of the anterior attention network (Rothbart et al., 2011a). The executive function performance, and to some degree also the ratings of effortful control, showed weak individual stability over time. This further supports the notion of a shift in the processes underlying self-regulatory performance during this developmental period. We also found that the two self-regulatory functions executive functions and effortful control were related already in toddlerhood, supporting the existence of a common underlying core of these constructs.

Study III

Individual differences in early executive functions:
A longitudinal study from 12 to 36 Months

Background and Aims

Garon et al. (2008; 2014) suggested that simple forms of executive functions, for example delaying a response or holding information in mind, should precede more complex forms of working memory, inhibition and shifting. They proposed that executive functions develop in a hierarchical fashion, with the early, simple abilities getting more and more coordinated over development and thereby enabling more complex abilities. They also emphasize the importance of attention in the development of executive functions, proposing that attention is an essential precursor of the early emerging simple forms of executive functions, but also continues to be of importance over development. However, one unanswered question concerns *in what way* attention contributes to the executive function development, once the earliest forms of simple functions have emerged. The hierarchical model is almost entirely based on group level comparisons or cross-sectional data. Longitudinal studies taking an individual differences perspective are needed to further evaluate the explanatory value of this model to early executive function development. Using a longitudinal individual differences design, Study III aimed to investigate the theoretical claim that simpler forms of executive functions should underlie the development of more complex ones in later development, and further, to increase the understanding of the predictive role of attention in this development. We investigated this by studying simpler forms of executive functions as well as sustained attention at age 12 months as longitudinal predictors of more complex executive functions at ages 24 and 36 months. In line with the theoretical suggestions, we expected better performance on the simpler executive function tasks and higher levels of sustained attention at age 12 months to be associated with better performance on the executive function tasks at ages 24 and 36 months. Further, we studied whether or not the contribution of sustained attention at 12 months to later complex executive functions would go via the concurrent simple executive functions, by examining independent contributions of sustained attention and simple executive functions at 12 months to executive functions at 24 and 36 months.

Results

Pearson correlations between the measures of simple executive functions and sustained attention at 12 months, and the measures of executive functions at age 24 and 36 month were conducted, see Table 1. One of the simpler executive function measures at 12 months was significantly correlated with toddlerhood executive function performance: better performance on the prohibition task at 12 months was associated with better performance on both spin the pots and beads task at 36 months. None of the simpler infancy measures predicted executive function performance at age 24 months. Higher levels of sustained attention at age 12 months was longitudinally related to better performance on both spin the pots and beads task at 36 months. Sustained attention did not predict performance on any of the executive function tasks at 24 months.

Table 1. *Pearson correlations between the executive function and sustained attention predictor variables in infancy, and the measures of executive functions in toddlerhood (N = 42-59).*

	24 months		**36 months**			
	Spin the Pots	Reverse Cat.	Spin the Pots	Beads task	Reverse Cat.	Snow/ Grass
12 months						
Hide-and-seek	-.13	-.07	.12	.16	-.08	-.44[b]
Reverse Cat.	-.10	.14	.18	.10	.02	.08
Prohibition task	.11	-.12	.33**[a]	.38**[a]	.00	.07
Sustained attention	-.07	.08	.25*[a]	.25*[a]	-.04	.05

** = p < .010, * = p < .050, [a] = one tailed test, [b] = As the hypotheses were directional and this correlation goes in the opposite direction from what was predicted, we are not allowed to interpret this correlation.

To evaluate whether sustained attention and simple executive functions independently contributed to the variance in the more complex toddlerhood measures of executive functions, multiple linear regressions were conducted. The outcome variables in these regression analyses were the two toddlerhood executive function measures with which more than one of the infancy predictor variables were bivariatly correlated (spin the pots and beads task at age 36 months). The predictor variables were sustained attention and performance on the prohibition task, as these were concurrently correlated, $r = .26$, $p = .034$. Analyzing the independent contribution to the explained variance in performance on spin the pots at age 36 months, performance on the prohibition task showed an independent contribution, $ß = .29$, $p = .032$, but sustained attention did not, $ß = .15$, $p = .271$; $R^2 = .128$. When performance on the beads task was the dependent variable a very similar result was found: performance on the prohibition task independently contributed to the explained variance, $\beta = .33$, $p = .013$, but sustained attention did not, $\beta = .17$, $p = .176$; $R^2 = .169$.

Conclusions

In line with our expectations based on the hierarchical model (Garon et al., 2008; 2014), better performance on the prohibition task was longitudinally related to better performance on both measures of working memory at age 36 months. This result gives at least partial support to the idea of simpler executive functions, such as in this case simply withholding a response, constituting a basis for the development of more complex functions. It has been suggested that inhibitory control constitutes a central aspect of executive functions. For example, Miyake and Friedman (2012) have suggested that inhibition is the common core of executive functions, and Barkley (1997) proposed that inhibition constitutes a core upon which later executive functions depends. Our finding that performance on the prohibition task in infancy was a good predictor of later executive functions further supports the notion of inhibition having an essential role in the foundation of executive function development. Further, we found that better sustained attention in a free play session was associated with better performance on the tasks tapping into working memory at age 36 months. The novelty of this finding was that sustained attention did not contribute to the more complex toddlerhood executive functions beyond concurrent simple inhibition. In combination with the result showing that our measure of simple inhibition did contribute beyond sustained attention, the results could be interpreted as sustained attention being an integrated part of simple inhibition at 12 months of age, and consequently that the importance of sustained attention at this age to later executive function development goes via simple executive functions.

General Discussion

Key findings

The present thesis aimed to increase the understanding of individual differences in rudimentary forms of executive functions and effortful control already in infancy. It further aimed to investigate the possibility of predicting individual differences in toddlerhood self-regulatory functions with sustained attention and simple or rudimentary forms of executive functions in infancy. In addition, developmental improvements in executive functions and effortful control from infancy to toddlerhood were investigated, as well as the relation between these two self-regulatory functions.

In Study I, individual differences in 10-month-olds' executive functions were found. We suggest that the infants showing more correct performance on the initial A trials, but simultaneously perseverating more on the B trials of the classic A-not-B task had reached a developmental phase in which the ability to hold an object's location in mind over a brief delay was in place, but the ability to use working memory in combination with inhibitory control as required by B trials had yet to develop (cf. Garon et al., 2008). That is, a more advanced step in the development than was the case of the infants showing a more erratic performance in both A and B trials. Further, infant executive function performance was related to differences in activity level as rated by their parents. Infants performing better on A trials had a lower activity level. However, ratings of infant sustained attention were not related to executive function performance. There were a few differences in performance with regard to response modality in the A-not-B task, indicating that responding correctly by looking may be less cognitively demanding than doing so by reaching. On a general level, however, the two modalities were positively correlated.

In Study II, we found that individual differences in infant sustained attention predicted toddlerhood executive functions and effortful control. This was in line with the suggestion that attention constitutes a foundation for the development of self-regulatory functions (Garon, 2008; 2014; Posner & Rothbart, 2000; 2009; Rothbart et al., 1994; 2007; 2011a; Rueda et al., 2011). Sustained attention was not concurrently correlated with the self-regulatory measures, possibly reflecting that, in infancy, the self-regulatory functions are considered to be more immature and less reliant on the anterior attention network than in toddlerhood (Rothbart et al., 2011a). Further, it was found that both executive functions, as measured with an eye-tracking version of the A-not-B task, and effortful control, measured with parental ratings, significantly improved from infancy to toddlerhood. However, the stability over time was weak, with only ratings of effortful control being significantly correlated between 12 and 24 months. The two self-regulatory constructs of executive functions and effortful control were positively correlated in toddlerhood, but not in infancy.

In Study III, at least partial support for the hierarchical model of executive function development was found. Individual differences in performance on one of the simpler infant executive function measures predicted performance on tasks reflecting more complex functions in toddlerhood. Better performance on a simple inhibition task requiring the infants to withhold a reaching response was related to better performance on two working memory tasks two years later. The predictive relation between infant sustained attention and toddlerhood executive functions found in Study II was again found in Study III. Sustained attention was positively related to performance on the same two working memory tasks that were predicted by infant simple inhibition. One of the novel contributions of Study III is the finding that sustained attention did not contribute to the more complex toddlerhood executive functions above and beyond concurrent simple inhibition. In combination with the result showing that the measure of simple inhibition did contribute above and beyond sustained attention, the results could potentially be interpreted as indicating that sustained attention is an integrated part of simple inhibition in infancy, meaning that at this age, sustained attention contributes to later executive function development via this simple executive function.

Longitudinal development of self-regulatory functions

Apart from the individual differences found in Study I, indicating steps of executive function maturation in the first year of life, the two longitudinal studies (II and III) further revealed overall improvements with development. In Study II the participants performed significantly better at the executive function task and received higher ratings of effortful control at 24, than at 12 months of age. Performance on the A-not-B task showed that infants spent more time looking at the correct hiding location and less time looking at the incorrect hiding location at the older age, reflecting improvements in holding the correct hiding location in mind over a delay and simultaneously inhibiting the prepotent search response (cf. Diamond et al., 1994). The improvements in effortful control were in line with what studies on other age groups have shown (see Rothbart & Bates, 2006; Rothbart et al., 2011b, for reviews) and means that the parents found their children to be better at for example waiting for things they desired and stopping forbidden activities when told to do so, at age 24 months than at 12 months. In Study III, significant improvements were found in the two executive function tasks used at both 24 and 36 months of age; the spin the pots task and the reverse categorization task, reflecting improvements in working memory and inhibition. The fact that the 24- and 36-month-old toddlers could be assessed with more advanced and complex executive function tasks than the 12 month-old infants is, in one sense, also a sign of improvement in these functions. Over all, the results of both longitudinal studies point to significant development of executive functions and effortful control over the first years of life; a development that likely reflects the maturation of prefrontal areas of the brain such as the anterior attention network (e.g., Rothbart et al., 2011a). These results are all in line with expectations, and with results from previous studies investigating executive function performance on group level (see Garon et al., 2008, for a review). However, although it is of importance to understand how self-regulatory functions develop on a general level during infancy and toddlerhood, the main focus of the present thesis was to further the knowledge of the development of individual differences in these functions. General improvements found on group level may not necessarily reflect a stable development in all or even most individuals. To understand and be able to predict the development of self-regulatory functions on an individual level is an important step toward detecting and understanding risk development.

(Lack of) stability

The few previous studies taking an individual differences approach to development have indicated a very limited individual stability in early executive functions over time (Miller & Marcovitch, 2015; Wiebe et al., 2010). A similar pattern was found in the two longitudinal studies included in this thesis (II and III). In Study II, A-not-B performance revealed no stability in executive functions between the ages 12 and 24 months, and in Study III, performance on the reverse categorization and spin the pots tasks were not stable between the ages 24 and 36 months. Indeed, the only measure of self-regulatory functions that did show stability over time was the effortful control ratings. The lack of stability could be understood both by major developmental changes occurring around the second year of life, and methodological issues with, for example, measures tapping into other developing mechanisms than self-regulatory ones at these ages.

The rapid development of the prefrontal areas of the brain that takes place during the first years of life has been suggested to result in a shift of processes underlying self-regulatory performance (Posner & Rothbart, 2000; 2009;

Rothbart et al., 1994; 2011a). Around the age of 20 months self-regulatory functions, such as executive functions, start to rely on the so-called anterior attention network rather than on the earlier more basic or lower level mechanisms (Rothbart et al., 2011a). This major developmental change could possibly explain why there was no significant relation between executive function performance at 12 and 24 months. Further, as this change is gradual, individual differences in executive functions at 24 months may still be affected, complicating observation of systematic covariation with tasks at other ages, such as between 24 and 36 months. The lack of stability may, however, also be due to idiosyncratic variance in other functions undergoing major developmental changes in the early years (Espy et al., 2008; Wiebe et al., 2010). As briefly mentioned in the introduction, many other abilities, such as perceptual, verbal or motor abilities, are necessary for executive function task performance. As these abilities also undergo major development at this age, performance on executive function tasks may be particularly affected by this "task impurity" early on in life. The consequence of this would be that an individual's performance on a specific task may reflect executive functions to a varying degree over development (Wiebe et al., 2010). So, why is it that the ratings of effortful control were significantly related between the ages of 12 and 24 months? The answer probably lies in how effortful control was assessed, rather than any "real" differences in stability between executive functions and effortful control. As will be further discussed below, effortful control was measured using parental ratings of self-regulatory behaviors in everyday life. This type of behavior may show stability regardless of what attention networks or brain structures underlie the cognitive abilities eliciting the behaviors. Stability in effortful control over time is also in line with the theoretical framework of temperament, from which the construct originates. Temperamental traits are suggested to generally show relative stability over time (e.g., Rothbart, 2011). In addition, the use of parental ratings for assessment of effortful control may have exaggerated the stability, as parents may have an established picture or expectation of how their children behave (cf. Kagan & Fox, 2006; Saudino, 2003).

From simple to complex executive functions

In accordance with the hierarchical model of executive function development (Garon et al., 2008; 2014), simple or rudimentary forms of executive functions should become increasingly coordinated over development and thereby enable more complex forms to appear during toddlerhood. This suggestion may seem rather self-evident as most complex abilities build on earlier, simpler ones (cf. motor development or language learning), but as previous studies have indicated a weak stability in early executive functions, the hierarchical development empirically shown on group level may not necessarily reflect a development of individual differences. The applicability of this model therefore needed to be evaluated with longitudinal data on individual differences. If the hierarchical model can be considered to explain executive function development, individual differences in early simple functions should predict later, more complex ones. Simple forms of executive functions are defined as holding small amounts of information in mind, such as the location of a hidden object, over brief periods of time, and inhibiting responses such as delaying reaching for an object. The more complex functions, which start to develop during toddlerhood, are defined as updating or elaborating on information held in mind, or inhibiting a response based on information held in mind (Garon et al., 2008; 2014). The results of Study III provided partial support for the idea that simple executive functions constitute a basis for the development of more complex ones, in that the ability to simply inhibit a reaching response was predictive of later working memory.

Contrary to expectations, worse performance on the hide-and-seek task, assumed to tap into rudimentary forms of working memory, was associated with better performance on a toddlerhood inhibition task (the reverse categorization task). However, as our hypotheses were directional and one-tailed tests were used, this finding cannot be further interpreted. Working memory tasks similar to the hide-and-seek task have been used with infants and toddlers (e.g., Garon et al., 2014; Bernier et al., 2010), but to our knowledge, not as early as at 12 months. During assessments, we observed that the more active and less reserved infants tended to perform relatively well on the hide-and-seek task. This may indicate that, at this early age, performance on this task is favored by quick or impulsive search behavior. Finding valid and reliable measures for early assessment of rudimentary forms of working memory is an important task for future research. Methodological issues may also explain the fact that there were generally few longitudinal correlations supporting the hierarchical model of executive function development. Similarly to the findings of weak stability in executive function performance, longitudinal relations between simple and complex functions may be affected by task performance not solely reflecting variance related to individual differences in executive functions (e.g., Espy et al., 2008; Wiebe et al., 2010). This issue, as well as the issue of major developmental changes in the structures underlying self-regulatory functions proposed by Posner et al. (e.g., Rothbart et al., 2011a), is not discussed by Garon et al. (2008; 2014). Rather, in the hierarchical framework individual stability over time seems to be taken for granted. The findings from Study II, in addition to the small number of longitudinal relations found in Study III, may indicate otherwise. This issue will be further discussed below in relation to the findings of sustained attention being predictive of self-regulatory development.

In sum, Study III provided partial support for the proposition by Garon et al. (2008; 2014) that early executive functions develop in a hierarchical fashion.

We found that a simple form of inhibition in infancy predicted more complex forms of working memory in toddlerhood. The hierarchical model should be further studied using different, and perhaps also a larger number of, executive function tasks. It would also be of interest to investigate whether simple forms of inhibition, seemingly a central aspect of early executive functions, would be predictive of executive function performance even later on in development.

Inhibition as a central aspect of executive functions

As discussed above, simple forms of inhibition assessed using a prohibition task requiring the infants to withhold a reaching response toward an attractive item, was predictive of working memory performance two years later.
Interestingly, this is the exact same prohibition task that was used in the study by Friedman et al. (2011) in which performance from the age of 14 months was predictive of executive functioning many years later. This suggests that this particular task taps into very central aspects of inhibition, or of early, simple executive functions in general. As mentioned in the introduction, it has indeed been suggested that inhibitory control constitutes a central aspect of executive functions. For example, Miyake and Friedman (2012) concluded that the shared variance between several important executive functions is constituted by inhibition, suggesting that this is the common core of executive functions. Furthermore, Barkley (1997) proposed that inhibition constitutes a core that “sets the stage” (p. 72) for other executive functions. The finding that performance on the prohibition task in infancy was a good predictor of later executive functions further supports the notion that inhibition plays an essential role in the foundation of executive function development. The task is also similar to the delay of gratification paradigm, in which young children are told to wait for desired items such as gifts or sweets (Kochanska et al., 2000; Kochanska, Murray, Jacques, Koening, & Vandegeest, 1996), or in which slightly older children are promised a larger reward if they can refrain from taking a smaller one (Mischel, Shoda, & Rodriguez, 1989; or see Carlson, 2005 for a review of all these delay of gratification tasks). Findings from this paradigm have shown tendencies toward not being able to wait for a desired reward to be predictive of poorer childhood outcomes related to regulatory, social and cognitive abilities (e.g., Kochanska et al., 1996; 2000; Mischel et al., 1998).

Interestingly, there was no longitudinal relation between the second measure of inhibition in infancy, performance on the reverse categorization task, and any of the toddlerhood measures, although performance on this task was correlated at trend level with performance on the prohibition task. Whereas performing well on the prohibition task required only withholding a reaching response, the reverse categorization task required both withholding the habitual response that was learned in the training trials and redirecting the motor response according to the new sorting rule. The task also included interference, as the yellow blocks were supposed to be sorted into a red, not another yellow, bucket in the test trials. In addition, the reverse categorization task may also have tapped into rudimentary forms of working memory although the design aimed to reduce these demands by continuously repeating the sorting rule and making the rule very simple by only having one type of blocks to sort instead of the original two. That is, the task may be considered to measure more complex forms of inhibition than intended. This further suggests that the particular type of inhibition targeted by the prohibition task, namely to simply withhold a response, is very central in infancy. As will be further discussed below, performance on this task alone was concurrently related to sustained attention, even further suggesting a central role of simple forms of inhibition in early executive functions.

Sustained attention and self-regulatory functions

The relationship between sustained attention and the self-regulatory functions was investigated in all three studies included in the present thesis. In Study I, sustained attention was assessed using parental ratings, and a possible relation to concurrent executive functions was hypothesized based on the previous theoretical propositions that regulatory aspects of temperament would be related to higher cognitive functions (e.g., Gerardi-Galton, 2000; Rothbart et al., 2011b; Rueda et al., 2005). In Study II and III the measure of sustained attention was derived from a multiple-toy, free-play task in the lab. In these two longitudinal studies, sustained attention was hypothesized to be predictive of later self-regulatory functions according to the theoretical ideas of Posner, Rothbart and colleagues (e.g., Posner & Rothbart, 2000; 2009; Rothbart et al., 1994; 2007; 2011a; Rueda et al., 2011) and Garon et al. (2008; 2014). In the hierarchical model of executive function development by Garon et al., it has been proposed that sustained attention constitutes a foundation for early executive functions, and that it continues to be of importance to executive function development from infancy to toddlerhood. In both Study II and III, support was found for a predictive relation between sustained attention and executive functions and effortful control later on. These longitudinal relations could be interpreted in line with what was suggested by Garon et al. (2008), namely that the ability to maintain a state of focused attention allows the child to have control over what information is being processed, which would promote goal-directed behavior. Longitudinal data on the relation between sustained attention and self-regulatory functions, such as these, are generally scarce in the literature, one exception being the empirical study by Kochanska et al. (2000), which showed that focused attention to a small set of toy blocks at 9 months predicted effortful control at 22 months. The results of our studies are consistent with the work done by Kochanska et al. However, we argue that in comparison to their study, we used a more complex and more ecologically valid play situation to assess sustained attention, and further, that our results are strengthened by the use of a variety of outcome measures in toddlerhood; behavior ratings of effortful control, as well as both eye-tracking and playful lab tasks for assessment of the narrower cognitive aspects of executive functions. In addition, by investigating independent contributions to the more complex forms of executive functions in toddlerhood, Study III furthered the understanding of the continued role of sustained attention in the development of executive functions. The results suggest that, in the development from simple to more complex forms of executive functions, sustained attention does not contribute above and beyond the simple functions, but the role of sustained attention rather seems to go via simple inhibition. Future studies should investigate whether the contribution of sustained attention in executive function development is indeed mediated by simple executive functions.

Interestingly, neither in Study I nor in Study II was sustained attention concurrently related to self-regulatory functions. The relationship between sustained attention and executive functions and effortful control was only seen longitudinally. Indeed, in Study II, we argue that the lack of concurrent relations between sustained attention and the two self-regulatory functions strengthens the suggestion that the relations are truly longitudinal and not just a concurrent relation in infancy that is carried forward in time. As described above, it has been suggested that self-regulatory functions do not start to come under the control of the brain network responsible for more advanced forms of attention until around the age of 18-20 months (Rothbart et al., 2011a). From this perspective, the findings that sustained attention did not relate to concurrent executive functions or effortful control at 10 and 12 months of age, but to later self-regulatory functions at 24 months, could be interpreted as indicating that self-regulatory functions in infancy rely on more basic forms of attention. Somewhat contradictory to this reasoning is the finding from Study III, showing that sustained attention was concurrently related to performance on a measure of simple inhibition at age 12 months of age. Importantly, this measure was also the one that was longitudinally related to the more complex forms of working memory in toddlerhood. So, why was infant sustained attention concurrently related to performance on a task requiring simply withholding a reaching response? The interpretation discussed above concerning the development of the anterior attention network would indirectly imply that this form of inhibition would rely on this network as early as the age of 12 months. However, it seems quite unlikely that this particular function would come under the control of the anterior attention network at an earlier stage than would other executive functions. When discussing these issues, it should be noted that sustained attention is not to be equated with the type of attention referred to by Posner et al. (e.g., Posner & Rothbart, 2000; 2007) as executive attention, which is only regulated by the anterior attention network. Sustaining focused attention over a period of time very likely involves more basic forms of attention processes as well (see e.g., Colombo, 2001). An indication of this would be that sustained attention is considered possible to assess long before the age, suggested by Posner et al., when the anterior attention network has matured. It may be that sustained attention taps into attention processes particularly important for inhibition. Diamond's (2006) definition of inhibition was: "Inhibition, that is, the ability to ignore distraction and stay focused, and to resist making one response and instead make another" (p. 70). In view of this definition, it is interesting to note that abilities such as ignoring distraction and staying focused are indeed also key aspects of sustained attention. This suggests a close relationship between sustained attention and inhibition, a relationship that could likely be manifested as soon as this rudimentary form of executive function has developed and regardless of what attentional brain network the self-regulatory functions rely on at that moment. This close relationship may also be the reason why simple inhibition was predictive of more complex forms of executive functions in toddlerhood.

To sum up, sustained attention seems to constitute an important foundation for the development of self-regulatory functions such as executive functions and effortful control. Although sustained attention generally was not concurrently related to these functions in infancy, there was a significant relationship between simple forms of inhibition and sustained attention. This relationship further supports the idea of attention being of importance to the simple executive functions that predict more complex, later ones. It also supports the idea that simple inhibition is a fundamental core of executive functions.

Overlap between executive functions and effortful control

In Study II, we assessed both executive functions and effortful control to get a broader perspective on early self-regulatory functions and to further the understanding of how the two constructs are related to each other. Previous studies have pointed to the similarities between executive functions and effortful control, even suggesting a unitary model (e.g., Bridgett et al., 2013; Zhou et al., 2012). These ideas are mainly based on results from studies comparing the two constructs in later childhood and in adults. Our results did show a relation between the two constructs already at the age of 24 months, with effortful control relating to the executive function measure of “correct looking” in the A-not-B task. The measures of executive functions and effortful control were not, however, related at 12 months. This could be a consequence of the above-mentioned idiosyncratic variance due to the rapid developmental changes that occurr during the first years of life. However, it could also be a consequence of the constructs executive functions and effortful control being less similar in infants than in older children (see Zhou et al., 2012, for a review). As stated in the introduction, effortful control is often seen as a broader construct than the cognitive construct of executive functions, and it has been suggested that, in infancy, effortful control is primarily exerted in relation to emotion rather than cognition (Posner, Rothbart, Sheese, & Voelker, 2012). Further studies comparing these two self-regulatory functions in infancy are needed. However, the finding discussed above, that sustained attention predicted both later executive functions and effortful control, points to the existence of a common underlying core of these self-regulatory functions. Thus, the finding also supports the unitary view proposed by for example Zhou et al. (2012).

Another aspect of the comparison between executive functions and effortful control should also be acknowledged. As mentioned in the introduction, effortful control is defined as “the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors” (Rothbart & Bates, 2006, p. 129), that is, it is defined in terms of cognitive processes. This definition, being very similar to that of executive functions, is the main reason why these two constructs are believed to overlap or reflect the same abilities. However, effortful control is most often measured indirectly using parental ratings of self-regulation at a behavior level. Although these ratings have been considered valid and reliable measures of effortful control, they could perhaps also be viewed as a measure of the behaviors regulated by cognitive abilities and not as reflections of the cognitive abilities per se. If so, rather than as a relation between two cognitive constructs, the relationship found between ratings of effortful control and measures of executive functions in Study II could be interpreted as the assumed relationship between behavior and its underlying cognitive processes, as presented in the initial section of this thesis. The overlap between the concepts of executive functions and effortful control needs to be further studied; preferably adopting a broader approach and including different types of laboratory measures as well as behavior observations and ratings (cf. Kochanska et al., 2000). However, the investigation of the relation between executive functions and effortful control in Study II still contributes important information about these concepts at ages which they have not been studied at before.

Individual differences in A-not-B performance

Findings elicited by the fixed design

The A-not-B paradigm was used to assess individual differences in executive functions in both Study I and II. Whereas many previous studies have only considered individual differences in B trial performance, Study I aimed to investigate a broader spectrum of individual differences in rudimentary forms of executive functions by assessing performance on both A and B trials. When the focus has been on perseveration in B trials, A trials have often been considered a training phase, the only purpose of which has been to build up a habitual search response to location A. Using this approach, previous studies have often allowed for individual adjustments of A trials, such as varying the number of trials depending on child performance (e.g., Bell, 2012; Bell & Adams, 1999). To elicit a wider variation of search behaviors in both A and B trials, we used a fixed design instead, where all infants were presented with four A trials and two B trials. Apart from searching correctly and incorrectly in both A and B trials, infants were quite frequently found to not search at all. Although these "no search" responses could represent a lack of motivation, observations of the infants' behavior on these occasions rather suggested that they may reflect limitations in the ability to hold a hidden object in mind. The infants seemed confused, and it was often observed that when they did not search for the object at any of the two hiding locations they tried to search at several other places, such as underneath the table or the baby-chair they were sitting in, or turned toward their parent and/or looked at the experiment leader. These observations strengthen the suggestion that absent search responses were due to memory impairments rather than lack of motivation.

As intended, the fixed design further elicited individual differences in performance on A trials, reflecting the 10-month-olds' varying abilities to hold the existence and location of a hidden object in mind over a short delay, that is, differences in the maturity of rudimentary forms of working memory. For many infants the accuracy of their memory may have declined over the delay (cf. Diamond, 1985; Pelphrey et al., 2004). As previously discussed, better A trial performance was followed by perseveration specifically, not a general tendency to make more errors. Although seen from a somewhat different theoretical perspective than that of Clearfield et al. (2006), the results were interpreted to be in line with their idea that the search pattern on A trials stabilizes with increasing maturity but still does not allow for flexibility in response to the switch of location. Stable, correct search behavior during A trials and perseverative search behavior on B trials could thus be seen as representing a developmental step on the path toward more flexible behavior due to executive function development. When comparing our results with those of Clearfield et al. (2006) a few differences between the studies should be acknowledged. The seemingly poorer performance of our 10-month-olds on A trials compared to their 7- to 8-month-olds could likely be explained by their use of non-hidden objects and a shorter delay. Both these aspects should affect the working memory load of the task. Also the hand clapping following the hiding of the object in our version of the task could have increased the difficulty. Although the use of this type of "distractor" is common in A-not-B studies to prevent the infant from visually fixating the object's hiding location (e.g., Bell & Adams, 1999; Cuevas & Bell, 2010; Diamond, 1985), it is also likely to increase the cognitive demand of the task.

Differences in performance in Study I and II

The design of the eye-tracking A-not-B task used in Study II was in one sense very similar to the fixed design of the manual version used in Study I, with four A trials and two B trials presented to all infants, and with the target figure hiding behind occluders similar to the wooden screens. Still, the performance on the eye-tracking A-not-B task was found to be quite different from the performance on the manual version. In Study II, infants generally had longer looking durations to the correct than to the incorrect hiding location in B trials, both at 12 and 24 months. This was interpreted as infants actually "passing" the B trials, not committing the perseverative error. Together with the finding that all infants looked more to the correct than the incorrect hiding location in A trials in at least 50 percent of the trials (which was set as an inclusion criterion) the results from the eye-tracking version of the A-not-B task indicate considerably better performance than on the manual version administered in Study I. As the manual version was used on 10-month-olds, and the eye-tracking version was first used at 12 months, the difference in performance could at least partly be explained by maturation of executive functions over these two months. Indeed, Diamond (1985) found performance on the A-not-B task to significantly improve over time periods as short as a few weeks, and the time around 12 months of age has been suggested as a breaking point with regard to committing the perseverative error (e.g., Diamond, 1990). However, the differences in performance are probably also largely due to methodological differences between studies. In the eye-tracking version, the only response required was looking. As briefly mentioned above, looking may be less cognitively demanding than reaching in early ages, and may therefore have taxed the supposedly limited cognitive resources to a lesser extent, consequently allowing for better performance on executive function tasks (cf. Berger, 2004; 2010). In Study I, we found very small effects of modality; on a general level, looking and reaching responses were positively correlated over all types of responses and trials. However, differences between reaching and looking behavior were mainly assessed to investigate the observations made by Diamond (1985) and Piaget (1954) that infants sometimes looked to the correct hiding location but reached incorrectly, and were therefore assessed simultaneously. Thus, the difference in A-not-B performance between the manual and eye-tracking versions could still be explained by response modality differences. Responding by looking when not required to reach at all could be less cognitively demanding and therefore elicit more correct behavior. The findings from the modality comparisons of Study I support both the sporadic occurrence of deviances between motor and visual behavior, indicating that the two response modalities are differently demanding, and the proposition that infants' performance on looking and reaching versions of the A-not-B task become rather equivalent by 9 or 10 months of age (Bell & Adams, 1999; Cuevas & Bell, 2010). However, it should be noted that our manual version of the A-not-B task was probably more difficult than the ones used by Bell and colleagues. For example, reaching behind the screens seemed to be quite complicated for the 10-month-olds. This is a difficulty in the design that most likely leads to different performances on the manual versus eye-tracking tasks. Consequently, the degree to which motor demands differentiates performance on reaching and looking versions of the A-not-B task is not only a question of maturity at a certain age. It is also highly dependent on the design of the particular task.

Another methodological difference between the two versions of the A-not-B tasks was the use of first response as a dependent measure of executive function performance in Study I, and the total amount of looking time over a two-second period used in Study II. Looking durations are frequently used as measures for assessing preference (e.g., Gredebäck et al., 2010; Holmqvist et al., 2011) but the question arises as to whether infants' first looks toward the hiding locations somehow would reveal a different response pattern. Future studies should investigate the relation between looking durations and direction of first look in the A-not-B task. Although on group level, the infants did not perseverate on the A-not-B task in Study II, performance was still found to improve between age 12 and 24 months. The amount of time that looks were directed toward the correct hiding locations increased with age. This was interpreted as indicating a development of the working memory and inhibition required by B trials. This result points to the advantage of using a continuous measure of performance, such as looking duration, that enables detection of fine-grained improvements in executive functions that likely would not be detected otherwise.

In sum, these studies point to the usefulness of the A-not-B paradigm in investigating individual differences in early, rudimentary forms of executive functions. By making small adjustments to the design, the difficulty of the task can clearly be varied and thereby tap into working memory and inhibition at several ages during infancy and toddlerhood.

Limitations

The studies included in the present thesis have some limitations that need to be addressed. In Study II, the Cronbach's alpha value of the effortful control rating at age 24 months was relatively low. This value was not due to one or a few specific items, but rather a tendency for the entire scale to be less cohesive than at 12 months. The specific scale used has previously been found to be reliable for children up to 3 years of age (Putnam et al., 2006). Future studies should continue to evaluate this measure during toddlerhood. However, as the ratings of effortful control at 24 months were significantly correlated with the 12 months ratings for which the reliability was good, we believe that the scale still captured the construct of effortful control at the later age. A similar issue is to be found in Study I, where consistency between the items of the attention span/persistence scale used to assess sustained attention was rather low. The low internal consistency could possibly be one explanation for the lack of a concurrent relation between sustained attention and executive functions at 10 months of age. However, as previously discussed, the observations of sustained attention in free play used in Study II and III were also very rarely related to concurrent executive functions in infancy.

Another limitation is the small variation in parental education level found in both samples on which these studies were based. The parents were highly educated and thereby the samples do not reflect the general population in that respect. The high education level is most likely due to participants being recruited in a university town and also to the recruitment procedure itself. It is likely that the approximately 30 % of families who replied to the initial letter sent to their home, thereby indicating their interest in participating in infant research, have a higher education level and therefore are more familiar with, and more positive toward, research. Because the skewed samples may raise questions about the generalizability of the results, replication of our results using more diverse and perhaps also larger samples is needed before more firm conclusions can be drawn. However, we did generally find good variation in both the independent and dependent measures throughout the three studies. This means that the samples still represent infants and toddlers with varying levels of sustained attention, activity level and self-regulatory functions, thus reducing the concerns regarding generalizability.

A more general issue in this research field that sometimes seems to limit the advances in understanding the early development of self-regulatory functions, is that various terms and theoretical constructs are used without sufficient knowledge of their overlap or interrelations. Two such constructs discussed in the present thesis are executive functions and effortful control, but additional issues are briefly touched upon. For example, sustained attention is an often-used and well-defined construct within the field of developmental psychology, but its relation to the forms of attention or attentional brain networks referred to by Posner et al. (e.g., Posner & Rothbart, 2007; 2009; or see Posner, 2012, for a review) has, to our knowledge, never been clearly stated. Attempts have been made to put various self-regulatory constructs into a unified framework (e.g., Diamond, 2013), but there are still no truly unified terms or definitions in use by most or all researchers. Resolving this issue may seem to be of merely theoretical significance, but establishing empirically how constructs such as sustained attention, executive attention (cf. Posner, 2012) and endogenous attention (cf. Colombo, 2001) are related would make integration of various research traditions possible. This integration would likely improve the understanding of infant and toddler self-regulatory abilities. In Study II, we found support for an overlap between the theoretically differentiated constructs of executive functions and effortful control. However, future studies are needed to continue to address these issues.

Remaining questions and future directions

As continuously mentioned throughout the discussion, several additional studies are needed to fully answer the questions of individual differences in the early development of self-regulatory functions. Whereas the present thesis has contributed with some pieces of the puzzle, many questions remain and new ones have arisen along with the new findings. To further improve our knowledge of the early development of executive functions and effortful control, future studies should investigate the possibility of predicting individual differences over longer periods of time. At ages four or five years, the development of these functions has taken major steps (e.g., Best & Miller, 2010; Carlson, 2005), and it would be interesting to know whether sustained attention and simple inhibition at age 12 months are still good predictors. Also, at those ages the number of validated and established measures of executive functions is much larger than at 12, 24, and even 36 months of age, and larger test batteries could therefore be used to further strengthen the conclusions of Study II and III.

Another approach to the issues investigated in the present thesis would be to assess sustained attention at more than one time point, perhaps starting even earlier than at 12 months. This would enable more explicit testing of the direction of the relations, as well as the investigation of the continued role of attention during infancy and toddlerhood development. In Study I, it was also found that aspects of infant characteristics other than their ability to sustain attention seem to be related to early executive functions. This should be further investigated by looking into the possibility of longitudinal predictions by infant temperament.

The proposition of Study I, that individual differences in performance on the A-not-B task reflect stages of executive function development, with infants perseverating on B trials being more mature than infants showing an erratic performance, should be tested using a longitudinal design. Continuously evaluating A-not-B performance as in Study I at ages even before 10 months would allow us to draw conclusions about actual steps in development.

Another issue that needs further investigation is the quite consistent finding in Study III, that the infant measures of sustained attention and inhibition predicted performance on tasks tapping into toddlerhood working memory but not inhibition. Diamond (2013) has proposed that both the ability to stay focused and to inhibit internal and external distractions are prerequisites for working memory, in that they help "…to keep our mental workspace from becoming too cluttered…" (p. 144). This could be one explanation for the relations of infant sustained attention and inhibition to toddler working memory, but it does not answer the question of why there were no longitudinal relations with the toddler inhibition measures. Perhaps the answer is to be found in methodological issues similar to those previously discussed. Another possible explanation could be that the working memory tasks used in this study tap into broader aspects of toddler executive functioning than the inhibition tasks do, and therefore were more easily predicted. This issue needs to be addressed either by trying to replicate the findings of Study III, or by conducting a more detailed study of the mechanisms underlying these relations. The latter could possibly be done by an experimental approach.

As discussed above, the samples on which the present thesis is based consist of children of highly educated parents, and could likely be considered low-risk samples. Although establishing a knowledge base of executive function development on such low-risk samples is an important start, future studies should examine the early development of attention, executive functions and effortful control in groups more prone to developmental risks. The relationship between poor self-regulatory functions and lower levels of socioeconomic status (SES) is quite well known (e.g., Evans & Rosenbaum, 2008; Hackman & Farah, 2009; Hughes & Ensor, 2005; Li-Grining, 2007; Lipina, Martelli, Vuelta, & Colombo, 2005; Mezzacappa, 2004; Noble, Norman, & Farah, 2005). Replicating, for example, the finding of the predictive role of sustained attention in executive function development in a low SES sample would be an important step toward early intervention. The clinical implications of the current results will be further discussed below.

Clinical implications

As mentioned in the introduction, poor self-regulatory abilities have been linked to several negative outcomes during childhood and adolescence, such as externalizing behavioral problems (e.g., Bohlin et al., 2012; Granvald & Marciszko, 2015; Schoemaker et al., 2013; Willcutt et al., 2009), poorer academic achievement (e.g., Blair & Peters Razza, 2007; Bull et al., 2008; Bull & Scerif, 2001), and poorer social abilities (Hughes, 1998; Razza & Blair, 2009; Riggs et al., 2006). These negative outcomes are factors that themselves constitute risks for further negative outcomes such as problematic peer relations and low emotional well-being (e.g., Blachman & Hinshaw, 2002; Diamantopoulou, Henricsson, & Rydell, 2005; Moffitt et al., 2011). Being able to detect risks for poor development of executive functions and effortful control at a very early stage in life could likely mean better chances of intervening in this seemingly negative spiral. Several studies have shown that external factors, such as parenting behavior, school interventions and training programs have a positive effect on executive function development (e.g., Bibok, Capendale, & Müller, 2009; Diamond & Lee, 2011; Dilworth-Bart, Poehlmann, Hilgendorf, Miller, & Lambert, 2010; Dilworth-Bart, Poehlmann, Miller, & Hilgendorf, 2011; Hughes & Ensor, 2009; Rueda, Rothbart, McCandliss, & Posner, 2005; Wass, 2015). Furthermore, the results presented in the present thesis show that sustained attention assessed using an ecologically valid play session seems to be a good predictor of individual differences in executive functions and effortful control later on. This opens up the possibilities of quite easily detecting risks at a very early age. In addition, studies have shown that aspects of sustained attention can be improved through training. For example, Wass, Porayska-Pomsta and Johnson (2011) found that even very short periods of training could significantly improve 11-month-olds' attention. Although we do not know whether the relationship between sustained attention and later self-regulatory functions is a causal one, Garon et al. (2008) quite clearly state that if attention constitutes the foundation of executive function development, attention problems would be very likely to compromise the emerging executive functions. This would probably also work the other way around, with improvements in attention enhancing the executive function development. Future studies should use an experimental design to test whether training of sustained attention in infancy results in better self-regulatory functions later on.

Conclusions

In combination, the studies included in the present thesis contribute with important steps toward a better understanding of the development of individual differences in executive functions and effortful control in infancy and toddlerhood. To summarize, we have found individual differences in executive functions already by the age of 10 months, indicating steps in the development of rudimentary working memory and inhibition; we have also found significant improvements in both executive functions and effortful control between the ages 12 and 24 months, as well as between 12 and 36 months, although the individual stability over time was weak; and we have found support indicating that the two constructs of executive functions and effortful control are overlapping already in toddlerhood. Moreover, simple inhibition seems to be a central aspect of early executive functions, and in line with the proposition by Garon et al. (2008; 2014) simple inhibition was a good predictor of later working memory. Also sustained attention was found to be a good predictor of later executive functions and effortful control. However, in the continued development from simple to more complex forms of executive functions, the contribution of sustained attention seems to go via simple inhibition. Although many questions remain unanswered, and new ones have arisen due to these findings, these results could potentially lead to an earlier detection of poor development and thereby have clinical implications.

Summary in Swedish

Populärvetenskaplig sammanfattning på svenska

Exekutiva funktioner är en term för de avancerade kognitiva processer som ligger bakom vår förmåga att reglera beteenden och emotioner, och i förlängningen, förmågan att kunna planera och organisera tillvaron på ett sådant sätt att vi når långsiktiga mål istället för att agera impulsivt på det som ligger framför oss för stunden. Inom ramen för termen exekutiva funktioner ryms arbetsminne – förmågan att hålla information i minnet och samtidigt uppdatera eller laborera med den så som vid t.ex. huvudräkning, inhibition – förmågan att stoppa plötsliga impulser eller automatiserade beteenden och istället agera målinriktat, och s.k. *shifting* – förmågan att växla mellan olika regler, instruktioner eller ”mentala set” så som krävs för ett flexibelt agerande. Dessa funktioner utvecklas under hela barndomen och långt in i tonåren, men tidigare studier har visat att de i sina mest enkla och basala former finns redan under det första levnadsåret. D.v.s., även mycket små barn kan hålla enkel information i arbetsminnet eller hejda impulsen att t.ex. utföra ett invant beteende.

Effortful control är en term från temperamentslitteraturen som anses ligga mycket nära det som omfattas av exekutiva funktioner. Vissa anser till och med att begreppen är helt överlappande. Effortful control kan dock beskrivas som ett lite bredare begrepp än exekutiva funktioner, och inkluderar även mer emotionella och motivationella aspekter av självreglering. Ett par exempel på beteenden hos små barn som reflekterar höga nivåer av effortful control är att kunna vänta på något man gärna vill ha och att klara av att sluta utföra en viss aktivitet när en förälder säger till en att sluta.

Trots att både bristande exekutiva funktioner och låga nivåer av effortful control i upprepade studier har visat sig vara relaterat till ett stort antal negativa utfall under barn- och ungdomsåren, så som t.ex. utagerandeproblem, sämre skolresultat, och svårigheter med sociala relationer, så vet vi fortfarande mycket lite om hur dessa funktioner utvecklas under den tidiga delen av barns liv. Att kunna upptäcka risker i utvecklingen av exekutiva funktioner och effortful control redan på ett tidigt stadium skulle i förlängningen med stor sannolikhet öka chanserna att sätta in stödinsatser innan de problematiska utfallen hunnit göra sig gällande.

Syftet med denna avhandling var att undersöka hur individuella skillnader i exekutiva funktioner och effortful control ser ut redan under barnets första levnadsår, och hur dessa funktioner sedan utvecklas fram till tre års ålder. Mer specifikt så syftar Studie I till att undersöka individuella skillnader i exekutiva funktioner vid 10 månaders ålder, och om och hur dessa skillnader är relaterade barnens aktivitetsnivå och uppmärksamhetsspann. I Studie II undersökte vi dels hur exekutiva funktioner och effortful control utvecklades från åldrarna 12 till 24 månader, hur de två begreppen var relaterade till varandra, och om de individuella skillnaderna var möjliga att förutspå utifrån bedömningar av barnens uppmärksamhet under lek vid 12 månaders ålder. I Studie III undersökte vid hur individuella skillnader i mycket enkla former av exekutiva funktioner vid 12 månaders ålder var relaterade till lite mer utvecklade och komplexa former vid 24 och 36 månader. Studie III syftade också till att undersöka hur uppmärksamhet under lek förhöll sig till de exekutiva funktionernas utveckling över dessa åldrar.

Resultaten från studierna visade att redan vid 10 månaders ålder kan ganska tydliga individuella skillnader i exekutiva funktioner urskiljas. Dessutom fanns att barn som presterade sämre på uppgiften som var avsedd att mäta exekutiva funktioner skattades som mer aktiva av sina föräldrar än barnen som presterade bättre. Individuella skillnader i exekutiva funktioner var dock inte relaterat till skillnader i uppmärksamhetsspann vid denna ålder. Resultaten från de två longitudinella studierna visade däremot att uppmärksamhet under lek predicerade både exekutiva funktioner och effortful control vid 24 månaders ålder (Studie II) och exekutiva funktioner vid 36 månader (Studie III). Dessa studier visade också på en utveckling och förbättring i självregleringsfunktionerna över tid, men att stabiliteten på individnivå genomgående var mycket svag. D.v.s., generellt presterade barnen bättre på uppgifterna för exekutiva funktioner med stigande ålder, men för enskilda barn betydde inte nödvändigtvis god prestation vid 12 eller 24 månaders ålder att de också presterade bra på uppgifterna vid t.ex. 36 månader. Dessa resultat är i linje med våra förväntningar baserade på resultat från andra forskares tidigare studier. I Studie III fann vi att en mycket grundläggande form av inhibition, att kunna motstå frestelsen att ta en attraktiv leksak som lagts framför en, predicerade mer komplexa former av arbetsminne två år senare. Denna typ av inhibition hade också samtidiga samband med uppmärksamhet. Detta tyder på att både uppmärksamhet och inhibition utgör centrala aspekter i den tidiga utvecklingen av självregleringsfunktioner så som exekutiva funktioner och effortful control.

Sammanfattningsvis så bidrar resultaten som presenteras i denna avhandling till små steg framåt i förståelsen av den tidiga utvecklingen av exekutiva funktioner och effortful control, funktioner som är viktiga för regleringen av beteende och emotioner. Även om många frågor kvarstår, och nya hela tiden formuleras, så bidrar denna ökade förståelse till möjligheten att på ett tidigt stadium upptäcka risk för problematisk utveckling, och på längre sikt förhoppningsvis till ökade möjligheter att redan under de första levnadsåren kunna sätta in stödjande interventioner i de fall det behövs.

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