Stimuli-Dependent and State-Dependent Effects of Emotion on Children's Executive Functions and Intentional Forgetting: Associations With Age and Socio-Emotional Adjustment.

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List of Papers

1. Augusti, E.-M., Torheim, H. K., & Melinder, A. (2012). The effect of emotional facial expressions on children's working memory: associations with age and behavior. (Under review).

2. Augusti, E.-M., & Melinder, A. (2012, Accepted). The effect of neutral and negative color photographs on children's item directed forgetting. *European Journal of Developmental Psychology*. doi: 10.1080/17405629.2012.686741

3. Augusti, E.-M., & Melinder, A. (2012). Maltreatment is associated with specific impairments in executive functions: insights from differential testing. (Submitted).

General summary

Executive functions (EFs), abilities central to goal directed and purposeful behavior, have been identified as important for children's social, emotional, and cognitive functioning. During childhood, significant improvements in EF take place, and this development lasts well into adolescence and young adulthood. Recent empirically based models and studies have identified challenges to how individuals act in a deliberate and functional way when confronted with emotional situations or information. This impairing effect of emotion on top-down cognitive processes may have far reaching consequences as children often are part of situations where emotions are expressed, experienced, or both. Additionally, neural structures associated with EF are thought to be sensitive to long lasting effects of stress and high emotional reactivity. Thus, both stimulus-driven effects and state-dependent effects of emotion seem to negatively affect EF. To date most research on stimulus-driven and state-dependent effects of emotion on EF has focused on the ability to regulate emotional stimuli cognitively in clinical groups of children and adults. The typical developmental trajectory is still understudied, as well as how it develops in children who live under stressful life experiences. To address this void, the aim of the present thesis is twofold.

The *first* aim of this thesis is to investigate how emotional information affects EFs, in other words the stimulus-driven effects of emotion on EF. It is assumed that being able to consciously control cognitions while facing emotional information, will contribute to a better ability to function in complex emotional and social situations. Thus, the efficiency of EFs when confronted with emotional stimuli might give insights to how children deal with emotional information when at the same time trying to accomplish goals. The two first papers of this dissertation investigate how facial expressions and complex color photographs affect children's working memory and intentional forgetting respectively. Somewhat different results emerged in the two first papers, but one main conclusion was that emotional

information seems to interfere with cognitive processes, and that stimuli of negative valence in particular challenge the execution of cognitive tasks.

The *second* aim was to investigate the state-dependent effects of emotion (i.e., stress) on EF, by assessing neurocognitive functioning in children who have endured maltreatment. Maltreated children are found to experience many challenges ranging from impaired academic achievements to psychiatric problems, all of which are highly associated with EF. The third paper identified impaired working memory in maltreated children compared to their non-maltreated peers. This finding suggests that long-lasting exposure to stress might hamper specific EFs rather than globally impairing higher order cognitive functions.

In conclusion, findings presented in the present dissertation identify stimulus-dependent and state-dependent effects of emotion on EFs. Possible implications of the present findings may be an increased understanding of underlying, neurocognitive factors associated with children's emotional and social functioning.

Introduction

Linking emotion and cognition-definitions

Emotion and cognition are two intertwined and highly interrelated constructs (Blair, 2002; Blair & Dennis, 2010; Dolan, 2002; Pessoa, 2008, 2009; Zelazo, Qu, & Kesek, 2010). In fact, recent theories propose that cognition and emotion cannot be viewed separately, but rather have to be considered jointly (Pessoa, 2008, 2009) or as operating on a continuum (Bunge & Zelazo, 2006). In the advent of a more refined understanding of the neural underpinnings of behavior, as realized by the use of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), it has become clear that emotion and cognition are highly linked (Zelazo et al., 2010). The extensive literature on emotion-regulation development has indirectly or directly associated emotional adjustment with cognitive development (see, Eisenberg, Hofer, & Vaughan, 2007, for a review). In addition, literature on mood disorders in children reveal that in particular the emotion-cognition interaction is disturbed in these children (e.g., Ladouceur et al., 2006). Lastly, models on social and affective information processing sheds light on the important interaction between emotion and cognition in relation to social and affective development (Crick & Dodge, 1994; Halberstadt, Denham, & Dunsmore, 2001; Izard, 1984; Lemerise & Arsenio, 2000).

The models describing children's development as it pertains to their ability to integrate cognitive and emotional competencies have used several definitions of both emotion (e.g., motivation, stress, reward) and cognitive control (e.g., information processing, emotion-regulation, effortful control, appraisal, emotional intelligence). In the present dissertation emotion is divided into two categories – stimuli-dependent and state-dependent. Stimuli-dependent factors, such as the processing of social-emotional cues like facial expressions and color photographs of different valence, are how emotion is operationalized in Papers I and II.

In Paper III state-dependent emotional factors are assessed and presently defined as maltreatment related stress.

As new and refined subdivisions of cognition have been established in the cognitive and neurocognitive literature, the present thesis will mainly use models defining cognition as executive functions (Efs). EF are related to for instance children's academic achievements in general (Bull, & Scerif, 2001; Gathercole & Pickering, 2000), memory (Ardila, & Rosselli, 1994; Baddeley, 1986; Davidson, Amso, Anderson, & Diamond, 2006), and socio-emotional functioning (Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006) such as emotion regulation (Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; Jahromi & Stifter, 2008), behavioral regulation (Aronen et al., 2005; Cole, Usher, & Cargo, 1993), and theory of mind (Melinder, Endestad, & Magnussen, 2006; Moses, 2001; Perner, Lang, & Kloo, 2002). Additionally, EFs have been associated with abilities to intentionally forget (e.g., Lehman, Srokowski, Hall, Renkey, & Cruz, 2003). To conclude, EF and the development of these capacities are associated with a significant portion of children's abilities and are related to children's development into well-adapted adults.

The development of executive functions

EFs may be defined as skills essential for purposeful, goal-directed activity (Anderson, 1998). The development of EF is mainly ascribed to the protracted development of the prefrontal cortex (Welsh, Pennington, & Groisser, 1991). Miyake et al. (2000) proposed a model of EF, comprising *shifting* between mental sets or tasks, *updating* and monitoring of information in working memory, and *inhibition* of dominant responses. These three sub-sets of EF are inter-related but also meaningfully dissociable abilities (Miyake et al., 2000). All three components of EF develop throughout childhood, however not simultaneously, further supporting the division between the three different sub-types of EF (Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). Moreover, neuroscientific studies of EF have revealed different areas of the brain mainly involved in the three types of EF described above (Huizinga et al., 2006). The present thesis addresses all three constructs.

Set shifting. Set shifting refers to the ability to flexibly switch between tasks and adjust to the current task requirements (Crone, Bunge, van der Molen, & Ridderinkhof, 2006; Miyake et al., 2000). Set shifting has been found to reach adult levels in adolescence (Crone et al., 2006; Huizinga et al., 2006). What is commonly measured in tasks assessing set shifting is the ability to switch between task requirements, and the dependent measure is often the time or accuracy of responses subsequent to a shift of task requirements termed switch costs (Huizinga & van der Molen, 2011). For instance, such tasks might be to sort cards on the basis of color of shapes depicted on the cards, and then switch to sort the same cards based on the number of shapes on each card. Commonly, what rule applies varies between blocks allowing for the comparison of performance when the rule is held constant and after changing the response rule. The common finding is that accuracy and response time is negatively affected when changing the rule between trials compared to when keeping the rule constant (Monsell, 2003). Moreover, children perform poorer than adults on such tasks reflected in larger switch costs for younger children compared to adolescents and adults (Cepeda, Kramer, de Sather, 2001; Crone et al., 2006). Developmental differences reported in the literature are attributed to children's increase in cognitive flexibility as they grow older (Cragg & Chevalier, 2010; Davidson et al., 2006). To date, less is known about individual differences that might affect set shifting, and age and task characteristics have so far been the main subject of interest in this research (Cragg & Chevalier, 2010; Monsell, 2003; but see Wagner, Jonides, Smith, & Nichols, 2005 for a recent account of a taxonomy in adult set shifting).

Working memory. Working memory is a cognitive capacity that is important for updating and manipulating information consciously (Baddeley & Hitch, 1974), and it develops throughout the school years, reaching maturity in early adolescence (Gathercole, Pickering, Ambridge, & Wearing, 2004). Working memory is regarded as highly important for children's academic achievements in general, and reading and arithmetic skills in particular (Gathercole et al., 2004). Additionally, recent literature has identified working memory as essential for good regulatory skills (Rueda et al., 2005), for instance through the ability to disengage from distressing thoughts (Van Dillen & Koole, 2007).

Working memory is seen as a complex system with the phonological loop and the visual sketchpad as "slave systems" for the central executive (Baddeley, 1996; Baddeley & Hitch, 1974). The visuospatial sketchpad slave system is responsible for dealing with visual and spatial information in working memory (Baddeley & Logie, 1999). The same is true for the verbal slave system in relation to verbal material (Baddeley, 1996). The two sub-ordinate systems of working memory are developed to deal with domain-specific information (e.g., verbal or visual/spatial) and the central executive mediates higher-order processing (Conklin, Luciana, Hooper, & Yarger, 2007). In recent years, researchers have sought to understand working memory development (e.g., Conklin et al., 2007; Gathercole et al., 2004). The generally accepted domain-general model of working memory in adults (e.g., Baddley, 1986; Engle, Kane, & Tuholski, 1999; but see Shah & Miyake, 1996), has gained empirical support in children from 4 years of age (Alloway, Gathercole, & Pickering, 2006; Gathercole et al., 2004). This research suggests that children have a similar structure to their working memory as adults, and improvements in children's ability to complete working memory demanding tasks are mainly due to an increase in processing capacity as orchestrated by the central executive (Alloway et al., 2006; Gathercole et al., 2004). Furthermore, studies on the understanding of how working memory functioning is organized in the brain and in particular development in brain maturation associated with advances in working memory, have identified a process-specific model of working memory both on a neuroanatomical (D'Esposito et al., 1998; Petrides, Alivisatos, Meyer, & Evans, 1993), and neuropsychological level (Conklin et al., 2007). A process-specific understanding of the neuropsychological underpinnings of working memory suggests that spatial and verbal working memory follow the same developmental trajectory, and that task difficulty reveal developmental differences irrespective of stimulus modality (verbal vs. visual/spatial) indicating development mostly for the central executive (Conklin et al., 2007).

Inhibition. Inhibition is a capacity linked to several domains of children's functioning, both cognitive and social-emotional development (Casey, Giedd, & Thomas, 2000; Davidson et al., 2006; Nigg, 2000). Inhibition has been defined into different types of inhibitory function, two of them being behavioral and cognitive inhibition (Harnishfeger, 1995; Wilson & Kipp, 1998; but see Nigg, 2000 for further differentiation).

Cognitive inhibition, which is most relevant for the present thesis, is defined as "…the suppression of previously activated cognitive contents or cognitive processes" (Wilson & Kipp, 1998, p. 87). Behavioral inhibition is considered the control of motor movements, developing before cognitive inhibition (Wilson & Kipp, 1998). Moreover, Harnishfeger (1995) has also identified automatic and intentional inhibitory processes within these two types of inhibition. This is further supported empirically (e.g., Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006) and suggested in theoretical models of inhibition (e.g., Nigg, 2000). Between childhood and adolescence the ability to cognitively inhibit irrelevant information greatly improves, which allows for a more efficient processing of information by resisting interference from irrelevant information (Dempster, 1992; Harnishfeger & Bjorklund, 1993; Wilson & Kipp, 1998). Nigg (2000) proposed a taxonomy of inhibition more differentiated than the dichotomy suggested by Harnishfeger (1995). According to Nigg (2000) three main categories of inhibition can be derived from the extensive literature on inhibition on both adults and children, these are: automatic inhibition of attention, executive inhibition, and motivational inhibition. Harnishfeger's (1995) behavioral and cognitive inhibitory function are both considered executive in nature, but only expressed differently according to different task demands. In the motivational inhibition category, Nigg (2000) identifies emotional and social stimuli as central, however it is suggested that this type of inhibition is not yet fully understood. In particular it is uncertain how specifically emotional cues interact with inhibitory functions, although recent studies have started to address this (e.g., Hare et al., 2008, Rosenberg-Kima & Sadeh, 2010).

Intentional forgetting

Intentional forgetting is thought to facilitate cognitive processes by allowing the individual to expel outdated information from consciousness and therefore release cognitive capacity for new tasks (Wilson & Kipp, 1998). Intentional forgetting is closely associated with EF such as inhibition (Fawcett &Taylor, 2008; Lehman, McKinley-Pace, Wilson, Slavsky, & Woodson, 1997; Lehman et al., 2003) and selective rehearsal (Lehman, McKinley-Pace, Leonard, Thompson, & Johns, 2001), which is thought to reflect working memory capacity (Woody-Dorning & Miller, 2001). Directed forgetting (DF) is a method by which intentional forgetting is studied (for reviews, see Basden & Basden, 1998; Bäuml, 2008). The two most commonly reported DF procedures are list (e.g., Bray, Justice, & Zahm, 1983; Harnishfeger & Pope, 1996; Howe, 2005), and item (e.g., Lehman et al., 2001; Lehman et al., 2003; Posnansky, 1976) DF. What distinguishes these two methods of DF is the timing of the cue to either forget or remember the item(s) presented. In the list-method, a series of words are presented consecutively before an instruction to either forget or remember the list is presented, followed by a second list of words with a new instruction to forget or remember. The item method is different in that memory instructions are presented immediately after each stimulus; cues to forget or remember are presented after each item presented in the test. Both in the list and item DF a memory test is administered after studying the stimuli and receiving the memory instructions. What is commonly reported in both types of DF is better memory for to-be-remembered stimuli (i.e., R-stimuli) than to-be-forgotten stimuli (i.e., F-stimuli) (Bäuml, 2008; Lehman & Bovasso, 1993; Woodward & Bjork, 1971). List DF is only evident at recall, not recognition, whereas the item DF effect is reflected in recognition memory as well as recall. The reason why list DF does not produce effects at recognition is explained by the elicitation of inhibited memories when re-presenting stimuli at recognition (Bäuml, 2008), this is not the case when memory cues have been presented item-by-item, not allowing the F-stimuli to be consolidated in memory. For the present dissertation, item DF is of particular interest as this approach is best suited for non-verbal material allowing to test the DF effect at recognition.

A gradual development is reported in children's item DF (Lehman et al., 2001; Lehman, Morath, Franklin, & Elbaz, 1998). For instance, children in 1st, 2nd, and 3rd grades show DF effects in the item version, but to a smaller degree than adults (Lehman & Bovasso, 1993; Posnansky, 1976; Wilson & Kipp, 1998). Two different explanations exist for the item DF effect; the selective rehearsal account (e.g., Lehman & Bovasso, 1993; Lehman et al., 2001) and the more recent inhibition at encoding explanation (Lehman et al., 2003). According to the selective rehearsal account one withholds rehearsal of F-stimuli and encodes R-stimuli more elaborately (Lehman et al., 2001). Rehearsal strategies in memory are present already in 2^{nd} grade (Kron-Sperl, Schneider, & Hasselhorn, 2008), but the rehearsal strategy observed in young school-aged children is characterized by a less efficient approach, to rehearse one item at a time, and not cumulatively (Lehmann & Hasselhorn, 2007). The shift from using an item-by-item approach of rehearsal to be efficient in applying a cumulative rehearsal strategy is thought to take place between 9 – 10 years of age and is partly a result of children's improving meta-memory skills (Lehmann & Hasselhorn, 2007). This development in strategy use seems to underlie the development reported in children's item DF for words, as children during this period in life also show increasing item DF effects (e.g., Lehman et al., 2001, Lehman et al., 2003).

Attentional inhibition during encoding is an alternative explanation for the item DF effect (Zacks, Radvansky, & Hasher, 1996). According to this view one inhibits the rehearsal of to-be-forgotten items and exempt them from selective reprocessing in memory. This view has gained support from studies on adults identifying active inhibitory efforts as operating during encoding in an item DF paradigm (Paz-Caballero, Menor, & Jimenez, 2004; Wylie, Foxe, & Tylor, 2007). The inhibition at encoding (i.e., attentional inhibition) explanation has only been explored once in children using words as stimuli (Lehman et al., 2003). In this study Lehman and colleagues found that highly associated information imposed additional control demands above and beyond what can be mastered through children's selective rehearsal strategies. This was interpreted as evidence for the use of inhibition at encoding in item DF, especially when using highly associated words as stimuli.

Models of the effect of emotion on executive functions

EF are thought to be highly linked to neural structures in the brain and their development (Best, Miller, & Jones, 2009). As a consequence, models and hypotheses that are neuroscientifically based guide the assumptions put forth in the present dissertation to predict behavioral outcomes. Importantly, neuroscientific measures (i.e., EEG and fMRI) are not used in the present dissertation.

Today, the literature on adults provides several models through which the effect of emotion on EF is described (e.g., Cunningham & Zelazo, 2007; Dolan, 2002; Pessoa, 2008, 2009; Phillips, Drevets, Rauch, & Lane, 2003; Phillips, Ladouceur, & Drevets, 2008). Common for these models of EF and emotion is that they all identify highly connected structures in the brain associated with both EF and emotion. According to Pessoa's dual competition model, emotion and EF engage some of the same neural structures in the brain and cannot be considered separately (see Figure 1; Pessoa, 2008, 2009). In particular, the anterior cingulate cortex (ACC) is considered the major structure integrating affective signals in the brain with cognitive control signals from the prefrontal cortices (PFC; Pessoa, 2009). The dorsal part of the ACC incorporates input from the brains PFC, whereas the rorstral site of the ACC is responsible for the integration of input from limbic structures such as the amygdala (Bush, Luu, & Posner, 2000). Affective signals can either impair or enhance cognition depending on the emotional input (Pessoa, 2009). In the dual competition model, a differentiation is made between high-threat and low-threat information. High-threat information will receive prioritizing in attention and thereby affect EF negatively by consuming neural resources normally used in cognitive control tasks. At the same time, threat will recruit multiple PFC sites, these various parts of the PFC are involved in specific EF tasks. For instance, the dorsolateral PFC has been found to be particularly involved in working memory. The ACC is thought of as the major structure that sends out signals in part affecting PFC structures and subsequently associated behaviors. On a behavioral level this would make EF less flexible and affect behavior negatively when confronted with emotional information. When low-threat or positive stimuli are presented, the processing that follows will benefit and not be hampered by the emotional significance of the stimulus. The behavioral consequence of the non-threat stimulus on cognition should therefore only be detectable in adults suffering from specific types of psychopathology and not in healthy individuals (Pessoa, 2009). To sum up, neural structures underlying emotional and cognitive interactions are thought to compete for the same neural resources, which in turn may result in poorer EF when faced with high-threat emotional stimuli in particular (Pessoa, 2009).

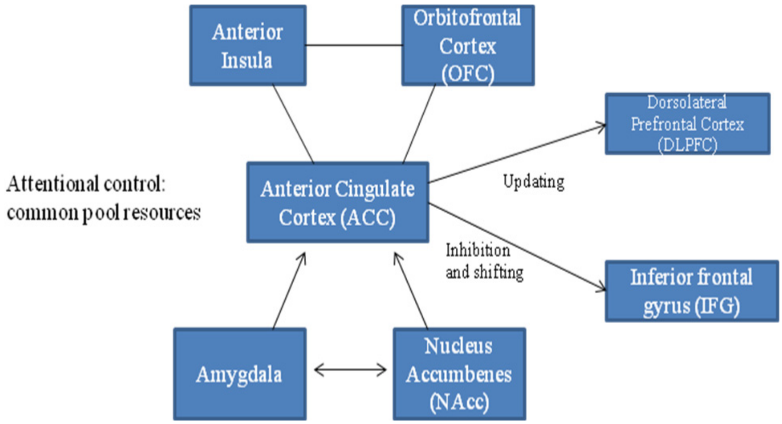

Figure 1. An illustration of the main functions of the dual competition model and their interaction. Adapted from Pessoa (2008, 2009).

From a developmental perspective, Casey, Getz, and Galvan (2008) have proposed a discrepancy in adolescents' maturational level of structures important for EF compared to structures involved in emotion processing (see Figure 2). They propose that limbic structures such as for instance the Nucleus accumbenes (NAcc) has a more rapid development and reach mature functioning at a much earlier age than what areas of the PFC do (Casey et al., 2008). This developmental dissociation is proposed to affect older children and adolescents' ability to act deliberately and goal-directed when faced with emotional information or motivationally charged situations (Casey et al., 2008; see Crone, 2009, for a review on this topic). Thus, Casey and colleagues (2008) propose that a higher emotional activation and poorer abilities to regulate and control emotional reactions will lead to an inability to act goal directed and avoid risky behavior and poor decisions well into adolescence.

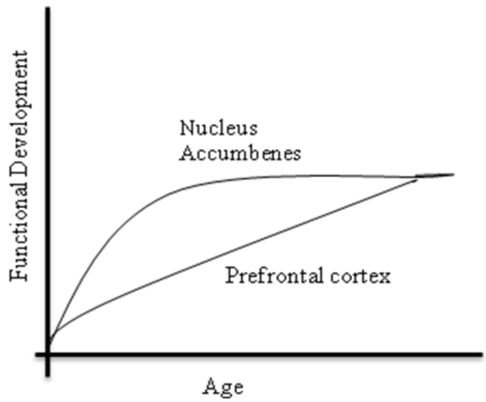

Figure 2. An illustration of the proposed dissociation of the developmental trajectories of limbic versus cortical regions of the brain during childhood and adolescence. Adapted from Casey et al., 2008

One of the main findings in the neuroscience literature is that structures mainly involved in emotional processing mature and act more adult-like prior to structures associated with higher-order cognition, this results in a developmental dissociation between brain structures and their effects on behavior (Bell & Wolfe, 2004; Blair, 2002; Casey et al., 2008). Children's attention towards emotional situations and stimuli are found to be very similar to adults' (e.g., LoBue, 2009; LoBue & DeLoache, 2008), whereas the ability to execute cognitive control, and functions associated with the ability to distract oneself from such attention grabbing information, is still developing (Best et al., 2009; Rueda et al., 2005; Zelazo & Cunningham, 2007).

Stimuli-driven effects of emotion on executive functions - empirical contributions

As indicated above, children have to actively use their EF to adjust appropriately to different situations, also when these situations are of an emotional nature. For instance, working memory capacity (WMC) has been linked to emotion regulation in young adults, in that higher levels of WMC are associated with better emotion regulation strategies

(Schmeichel,Volokhov, & Demaree, 2008). The assumption is that the ability to distract one self from emotional information is adaptive in that one interrupts the attention to the negative stimuli that causes a negative mood (Van Dillen & Koole, 2007). Hence, better WMC allows for the more efficient distraction from negative information. The flip side of this is that poorer WMC will potentially result in an unsuccessful regulation of emotional input. In a study on adults investigating stimuli-driven effects of emotion on working memory, adult participants evinced slower reaction time to fearful facial expressions compared to neutral expressions (Kensinger & Corkin, 2003).

Recent research suggests that emotional information impairs inhibitory functioning. In a recent study, typically developing children evinced poorer inhibition when they were asked to withhold responses towards negative facial expressions compared to neutral facial expressions using an emotion-inhibition task (Rosenberg-Kima, & Sadeh, 2010). Moreover, success rate on the so called Balloon task (Rosenberg-Kima, & Sadeh, 2010) was significantly associated with emotional functioning in these children. Specifically, children with more internalizing symptoms, anxiety/depression symptoms, and total behavioral problems all showed poorer performance on the emotional facial expression part of the task compared to peers not experiencing the same degree of emotional and behavioral difficulties. Hare and colleagues (2008) found a similar effect of emotion on inhibition in an emotional go/nogo task with children, adolescents, and adults. Fearful faces were associated with slower response time in all age groups, whereas happy faces enjoyed the fastest responses (Hare et al., 2008). Children and adolescents were significantly slower than adults in responding, especially in response to negative facial expressions. Importantly, on a neurobiological level, adolescents showed more activation in amygdala than both children and adults, supporting Casey et al.´s (2008) model described above. However, one limitation of this study is the relatively small sample sizes within each age group, especially in the child group, which calls for careful interpretation of the behavioral findings.

Emotionality in picture item DF tasks is to our knowledge only explored in adults, and to date this research has resulted in somewhat mixed findings (Hauswald, Schulz, Iordanov, & Kissler, 2010; Nowicka, Marchewka, Jednoróg, Tacikowski, & Brechmann, 2011). Both studies indentify inhibition at the core of successful item DF for color photographs. Nowicka and colleagues (2011) suggest that in particular negative pictures are subject to inhibition at encoding when cued to be forgotten, supported by the large frontal brain activation registered. Failing to selectively encode negative pictures (e.g., Hauswald et al., 2010), might be due to the impaired inhibitory function when processing negative information in particular. However, in this study the researchers noted that inhibition was crucial regardless of valence, but that negative information interfered more with inhibitory functioning, supporting Pessoa's dual competition model (2009).

Taken together, research on working memory and inhibition show that emotional stimuli challenge EF more than what neutral information does. This is also supported in the literature on item DF. However, according to the literature so far, it is still unknown how some of these abilities develop. It seems paramount to identify typical developmental trajectories as the effect of emotion on EF seems to be disturbed in clinical and sub-clinical groups of individuals.

Individual differences in executive functions and emotion processing

In order to understand individual differences and why some people struggle more with the ability to process and respond to emotional information adaptively Phillips and colleagues (2003, 2008; see Figure 3) take an emotion regulation perspective on the association between emotion and EF. They hold that two neural systems are involved in emotion processing. A predominantly ventral system is responsible for the identification of the emotional stimulus and in determining its significance, to produce an affective state, and in automatic regulation of the state produced (Phillips et al., 2003). The dorsal system is defined as crucial for the effortful regulation of the affective state and responses produced by the ventral system (Phillips et al., 2003). On the neurobiological level the dorsal system is associated with structures in the brain also involved in several EF. Therefore, deficits in regions predominately affecting EF might from an early age be associated with risk for developing affective disorders, as these functions are considered crucial for the top-down regulation of emotional reactions (Phillips et al., 2003). In the recent revision of the emotion regulation model, Phillips and her colleagues (2008) differentiate between voluntary and automatic regulatory skills, and hold that in particular willful regulation involve structures such as ventrolateral PFC and dorsolateral PFC. In addition, dorsal parts of the ACC are considered to be involved in automatic *and* voluntary regulation as is the dorsomedial PFC. Thus, the recent revision has more finegrained definitions of different neural structures' role in emotion processing than the original model.

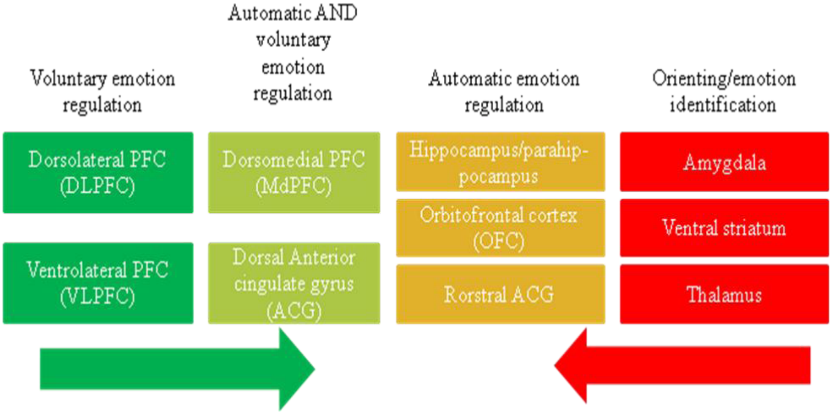

Figure 3. A simplified illustration of Phillips et al.'s (2008) model depicting the brain structures involved in the various stages of emotion regulation, and their interaction.

The way in which emotional information is processed and acted upon has been closely linked to affective disorders in children, adolescents, and adults (see, Banich et al., 2009; Elliot et al., 2011, for recent reviews). In two recent studies, Ladouceur and colleagues (2005, 2009) investigated how emotional stimuli could distract children and adults from completing a non-emotional working memory task. Children and adults with higher degree of trait anxiety (Ladouceur et al., 2009) or with a depression, anxiety, or comorbid depression and anxiety diagnosis (Ladouceur et al., 2005) were more distracted by negative emotional information than were healthy controls.

Children with anxiety symptoms, show a profound bias towards negative stimuli (i.e., fear), which is thought to impede on inhibitory functioning in this group of children (see, Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & vanIJzendoorn, 2007, for a comprehensive meta-analysis). Recently, the negativity bias often observed in children suffering from mood disorders was tested in tandem with an inhibition task, the emotional Go/NoGo task (Ladouceur et al., 2006). Interestingly, these researchers found differentiated patterns of inhibition in children with depression and anxiety respectively. Children with depression showed faster reaction time (RT) to trials depicting sad facial expressions, suggesting a negativity bias towards information conveying sadness. However, anxious individuals showed slow RTs to trials with neutral facial expressions when these were embedded between angry facial expressions, indicating an inability for the anxious individuals to disengage from threat-related information (Ladouceur et al., 2006). Studies investigating the effect of emotionally salient information on cognition in trauma-exposed individuals report that children exposed to severe trauma (e.g., sexual abuse, physical abuse, neglect) process in particular threat-related information differently than non-traumatized controls (e.g., Becker-Blease, Freyd, & Pears, 2004; Dalgleish, Moradi, Taghavi, Neshat-Doost, & Yule, 2001), especially when children are experiencing trauma-related psychopathology such as Post-traumatic stress disorder (PTSD) (Moradi, Taghavi, Neshat-Doost, Yule, & Dalgleish, 1999).

In sum, children and adults with different mood disorders show poorer abilities to exert cognitive control over emotional stimuli than healthy peers, a pattern that is thought to tap neurocognitive underpinnings of mood disorders and other types of psychopathology (Phillips et al., 2003, 2008). One group of children who are at risk for developing some of the disorders described above is children living under stressful circumstances and experience maltreatment.

State-dependent effects of emotion on executive functions-the case of child maltreatment

Child maltreatment is broadly defined as acts of omission such as neglect, or acts of commission, for instance physical and sexual abuse (Bottoms et al., 2008). Often the same child may endure more than one type of maltreatment. Emotional maltreatment for instance is one type of maltreatment defined by both acts of commission and omission (Bottoms et al., 2008). Child maltreatment is identified as a major threat to children's well-being in the western world. A significant number of children live under stressful and neglectful life circumstances and the prevalence of child maltreatment is increasing (Dekker, 2009). Maltreatment has a profound impact on children's development, and is associated with the development of both physical and psychological deficits (Appleyard, Egeland, VanDulmen, & Sroufe, 2005; Watts-English, Fortson, Gibler, Hooper, & DeBellis, 2006). Two lines of research suggest that children who have been maltreated will experience challenges with EFs.

Several studies have linked the development of emotional difficulties to maltreatment (e.g., depression, anxiety, PTSD; Bottoms et al., 2008; MacMillan et al., 2001; Chicchetti & Toth, 1995). Many of these maltreatment related emotional problems are associated with higher interference from emotional stimuli while trying to accomplish cognitive tasks also in non-maltreated groups of individuals (e.g., depression, Ladouceur et al., 2005; anxiety, Ladouceur et al., 2005, 2009). Phillips et al.'s model (2003, 2008) holds that poor EF is associated with deficits in effectively regulating emotions. Thus, this line of reasoning suggests that the common psychiatric problems reported in maltreated children are associated with poorer EF, and that it is not maltreatment per se but rather maltreatment-related psychopathology that will lead to impaired EF in this group of children.

According to Lupien, McEwen, Gunnar, and Heim (2009) and the life cycle model of stress, maltreatment related stress may in and of itself result in problems with tasks relying on the PFC. The PFC is thought to be particularly vulnerable to stressors during the adolescent years which Lupien et al. (2009) define as between 8-18 years of age. Such enduring stress is associated with a dysregulated hypothalamic pituitary adrenal (HPA) axis resulting in elevated levels of the glucocorticoids (i.e., cortisol in humans) during adolescence, and blunted or lower cortisol levels in adulthood (Bremner, 2003; Bremner et al., 2003; Loman & Gunnar, 2010). Studies on stress and anxiety have underlined how elevated levels of worry and anxiety might particularly affect the right PFC (see Davidson, 1994; Davidson & Irwin, 1999; Shackman et al., 2006). From this perspective it is informative to test whether maltreatment related stress may result in specific patterns of EF impairment. According to the life cycle model of stress, maltreatment per se may result in lower levels of EF due to the stress sensitive system's effect on neural structures important for EFs.

In fact, some studies have found support for impaired cognitive functioning in maltreated children. In a community sample of school-aged children researchers reported a significant association between familial-trauma exposure and poorer EF (DePrince, Weinzierl, & Combs, 2009). DePrince et al. (2009) conclude that this association might be one important avenue through which to understand emotional, psychiatric, and academic difficulties in trauma exposed individuals. Similar negative associations between EF and cognitive development in general was reported in children who had been removed from their biological parents by the child protective services and placed in foster care already at the age of three years (Pears & Fisher, 2005). Beers and De Bellis (2001) studied EF in a small sample (n=14) of maltreated children suffering from PTSD, and compared those to non-maltreated peers. Main results from this study were that maltreated children showed poorer EF in general compared to typically developing children. However, none of the above-mentioned studies simultaneously tested the effect of psychopathology versus maltreatment only, precluding an understanding of the mechanisms through which EF might be impaired in maltreated children. Moreover, studies on maltreated children's EF have to date not used models of EF in line with the division proposed by Miyake et al. (2000). This division of EFs has also has been supported in neuroscientific studies identifying different main areas of the PFC as subserving the three different aspects of EF (e.g., Aron, Robbins, & Poldrack, 2004; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006; Smith & Jonides, 1999). Thus, this model suggests a differentiation between EF that also might give insights into what in particular children struggle with when exposed to maltreatment-related stressors.

Emotional processing development

There are very few studies on children's cognitive development and its interaction with emotional stimuli that have used age-normed emotional stimuli, especially in relation to non-verbal material. Several studies on children rather use stimuli that only have been rated by adults, and conclusions regarding children's responses to these stimuli are therefore partly occluded by the fact that children's own ratings of stimuli have been neglected. For instance, different lines of research suggest that children, adolescents, and adults differ in their amygdala response to facial expressions (e.g., Hare et al., 2006; Guyer et al., 2008; Thomas et al., 2001). Children and adolescents 9-17 years of age showed greater amygdala activation in relation to fearful faces than adults (Guyer et al., 2008; but see Thomas et al., 2001), suggesting that children respond more strongly to fearful stimuli than adults do, at least on a neurological level. Yet another study using behavioral measures of arousal and valence found the quite opposite effect of valence on ratings of arousal. In a developmental study on behavioral ratings of images, McMains (1997) found that younger children rated negative pictures as less arousing than did adolescents and adults. Thus, it seems important to use age-normed emotional stimuli when assessing the effect of emotion on EF so as to reassure that the stimuli used have the intended emotional effect on which the hypotheses are based.

Facial expressions

In recent research, identification of facial expressions has been studied across age and it seems to follow a gradual developmental trajectory (Herba, Landau, Russell, Ecker, & Phillips, 2006; Herba &Phillips, 2004). Positive emotions are recognized prior to negative emotions, and the speed and accuracy by which they are recognized increases with age (DeSonneville et al., 2002; Herba et al., 2006). More specifically, research findings indicate a major improvement in correctly labeling emotional facial expressions between 7-10 years of age (DeSonneville et al., 2002). Although there is a development in children's ability to label facial expressions correctly, recent visual attention research has demonstrated that threat related facial stimuli (i.e., anger and fear) and non-threat related negative facial expressions (i.e., sadness) are detected much faster than happy and neutral facial expressions by children, as well as adults (LoBue, 2009). Thus, although the actual labeling of facial expressions undergo development during the childhood years and reach adult levels late in development (e.g., school-age), visual detection of, and preferential looking at threat stimuli is superior from an earlier age (i.e., infancy) (see Leppenän, 2011, for a review). Thus, negative facial expressions grab the viewers attention faster (LoBue, 2009), but children's ability to disengage from this type of information is still not yet fully explored and part of what will be addressed in the present thesis.

Processing other emotional information

In a pioneering study on children's detection of threatening information (i.e., snakes), LoBue and DeLoache (2008) reported in a series of experiments that children, similarly to adults (Öhman, Flykt, & Esteves, 2001), showed an enhanced ability to detect a picture of a snake in a matrix consisting of other pictures of either frogs or caterpillars. This enhanced attention to snakes was attributed to an evolved threat bias in humans (Öhman & Mineka, 2001). Hence, it seems as if information that is adaptive and survival oriented for humans enjoys preferential processing from an early age. McMains, Bradley, Berg, Cuthbert, and Lang (2001) investigated children's behavioral and physiological responses to emotional and neutral pictures and compared those reactions to adults' evaluation of the same pictures. One of the main findings was that both children and adults rated the pictures similarly on scales of valence, arousal and perceived dominance. However, greater variability on the physiological measures across age was revealed. Children showed several physiological indicators (e.g., skin conductance, heart rate, startle response) of increased arousal while viewing particularly unpleasant pictures, whereas adults only partly revealed similar response to the same pictures (McMains et al., 2001). This difference in reactivity as a function of age might be due to the nature of the pictures included in the experiments, as they were selected to be suitable for children to view, rendering the pictures less intense on valence and arousal than what is commonly used as picture stimuli in studies on adults (McMains et al., 2001). When using emotional stimuli in cognitive tasks it is important to control for this age related bias in how pictures are rated across age in order to be able to give a definite answer as to whether the effects reported are due to differences in emotional reactions to the stimuli, differences in EF or a combination of both. Presently, few efforts are done in this regard, the present dissertation studies using emotional stimuli, children´s own ratings of emotional valence and arousal are therefore retrieved and employed.

Main research objectives

Paper I

With models of the emotion-EF interaction (e.g., Casey et al., 2008; Pessoa, 2008, 2009; Phillips et al., 2003) in mind, the present study sought to investigate the effect of different emotional facial expressions on working memory in a child sample. From a developmental perspective, the aim of Paper I was to address the behavioral effects of the proposed dissociation in maturational levels of different brain regions involved in emotion and EF in typically developing children. As working memory has been associated with emotion regulation abilities, we further investigated the effect of emotion on working memory in relation to children's emotional adjustment as indexed by the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001).

Paper II

The aim of Paper II was to assess children's intentional forgetting for color photographs of negative and neutral valence. Intentional forgetting is considered an adaptive cognitive process relying on EFs such as inhibition and working memory. However, to date little is known about children's ability to intentionally forget material rich on information, such as color photographs. The effect of emotion on such processes is understudied developmentally, but research on emotion and memory in both children and adults hold that emotional information is encoded more deeply and elaborated more strongly in memory than neutral information. Hence, children's ability (or lack thereof) to intentionally forget negative and neutral color photographs might inform us on the mechanisms associated with the encoding of emotional and pictorial information in memory. Moreover, the present study might shed light on how EF dependent encoding strategies affect later memory.

Paper III

The main objective in paper III was to investigate neurocognitive functioning in maltreated children compared to their non-maltreated peers. Numerous empirical studies and theoretical reviews report neurological changes and brain alterations in maltreated children that should be reflected in sensitive neuropsychological tests on EF. A significant portion of children's well-being and functioning is related to EF, therefore it seems paramount to start to identify specific associations between maltreatment and EF. Findings from such studies may guide interventions in at risk populations.

Materials and Methods

Participants and procedures

In total, 127 children between the ages of 8-12 years were recruited to participate in the study on which the present thesis is based. Out of these 127 children, 23 were categorized into the maltreatment group based either on whether they were recruited through the child protective services (CPS) or domestic violence shelters and/or if the parent reported that the child had endured any type of abuse or neglect. For Paper I, Study 1, another 72 children between 9-12 years of age were recruited to provide a baseline for the recognition of emotion expressions in the age group included in Paper I, Study 2 (see Figure 4 for an overview of participants).

For Paper I, Study 1, four elementary schools in Oslo and nearby areas were willing to participate. In this study, all participation took place at the school. Children who had obtained consent from their parents were invited to participate during school hours.

Additionally, sixteen elementary schools in Oslo and nearby areas agreed to distribute information letters to their students about the main study on which all three papers are partly or entirely based upon. These letters were sent home with the student for the parent to read and decide whether the child should participate in the study. Families who decided to volunteer to participate were asked to sign a consent form attached to the letter and give this to the child's teacher. The researcher then picked up signed consent forms from the schools that had distributed letters. All families that consented to be further approached for participation were called by the researchers and an appointment was then made to meet in a quiet room at the Department of Psychology, University of Oslo, at a convenient time for the family, after school and work hours.

Lastly, children who were included in the group of maltreated children were primarily recruited through four CPS offices and three domestic violence shelters in Oslo and nearby areas. However, five children were recruited through schools as described in the abovementioned procedure. CPS offices were approached with information about the study and asked to present this study to clients they thought were in a situation where they could participate. All children who were approached had to be living with their biological parents due to the requirement that biological parents had to consent to their child's participation in the present study. If the family agreed to be contacted by the research team, the CPS would give us the family's contact information for further arrangements. When children were recruited through domestic violence shelters, doctoral student (EMA) was allowed to spend time at the shelter and approach mothers who had children who fulfilled the inclusion criteria of in the study.

All children met the researcher once and completed all tests during one testing session, participation lasted for approximately 2 hours (including breaks). Parents accompanied their child, but were not present in the room where the actual testing took place. Parents waited for their child in a nearby room and saw their child during breaks only. This measure was taken to minimize distraction during testing, and to assure that the child and parent could provide information in confidentiality.

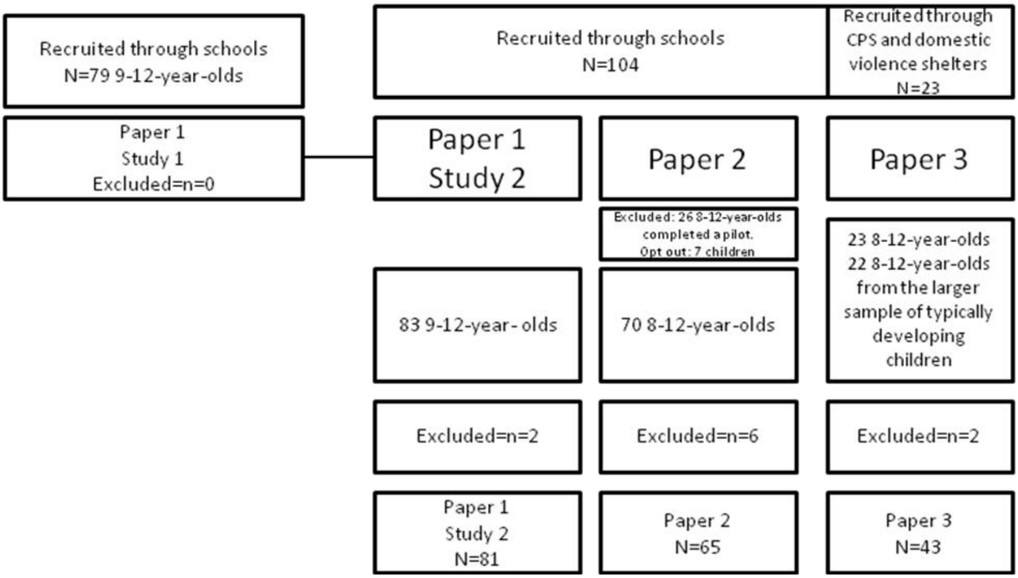

Figure 4. Overview of the samples included in the three papers comprising the present dissertation.

Table 1

Index of Theoretical Framework, Age Groups, Stimuli, Dependent Variables, Covariates, and Main Statistical Approach of the Three Papers of this Dissertation.

Paper #	Theoretical Framework	Age groups	Stimuli	Dependent variable	Covariates	Main statistical approach
I	1. Pessoa's dual competition model. 2. Casey et al.'s developmental model. 3. Phillips and colleagues' emotion-regulation model.	9-12-year-olds	Facial expressions: Sad, Happy, Neutral, and Fear	Emo-N-Back (d', C): *neutral facial expressions* *sad facial expressions* *happy facial expressions* *fearful facial expressions*	Child Behavior Checklist (CBCL; Subscales: Internalizing, Externalizing, and Total problems)	4(emotion) X 2(age) mixed between and within repeated measures ANOVA 4(emotion) X 2(age) ANCOVA
II	1. Pessoa's dual competition model.	8-12-year-olds	Naturalistic Color Photographs: Negative and Neutral	Item Directed Forgetting (Hits, false alarms, P_r, B_r): *to-be-forgotten neutral pictures* *to-be-forgotten negative pictures* *to-be-remembered neutral pictures* *to-be-remembered negative pictures*		2(instruction) X 2(emotion) X 2(age) mixed between and within repeated measures ANOVA
III	1. Lupien's life cycle model of stress. 2. Phillips and colleagues' emotion-regulation model.	8-12-year-olds		CANTAB Spatial Working Memory (SWM; Working memoy): *Errors* *Strategy* CANTAB Extra/Intradimensional set shift task (IED; Set shifting): *Pre-ED errors* *ED errors* *Stages* D-KEFS color-word interference test, condition 3 (Inhibition): *Errors* *Time* *Contrast*	Wechsler Abbreviated Scale of Intelligence (WASI; vocabulary and matrix reasoning) Child Behavior Checklist (CBCL; Subscales: Internalizing, Externalizing, and Total problems) Trauma Symptom Checklist for Young Children (TSCYC; Subscales: Depression, Anxiety, PTSD, Dissosiation)	Univariate ANOVAs Corrlations

Note. d', measure of memory accuracy; C, response bias; Pr, measure of memory accuracy, Br, response bias; CANTAB, Cambridge Neuropsychological Test Automated Battery; D-KEFS, Delis-Kaplan Executive Function System; ANOVA, analysis of variance; ANCOVA, Analysis of covariance

Stimuli and rating scales

Paper I. A subsample of pictures from The Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998) formerly used in the Emo-n-back (Landrø et al., 2009) was included in the present study. In total 120 pictures from the KDEF were used in the Emo-n-back depicting equal numbers (i.e., 30) of Neutral, Sad, Happy, and Fearful facial expressions (Figure 5). Each expression was photographed from the front and pictures were color photographs of amateur actors, half male and half female within each emotion. For the emotion rating children were given the option to choose the label best describing the facial expression as happy, fear, sad, neutral, or other. If the "Other" option was chosen, the child had to come up with another label considered more appropriate in their opinion. Additionally, on a separate page, children were asked to rate the intensity of the emotional expression on a 9-point Likert scale from 1 ("not at all") to 9 ("very much") related to the degree to which the picture expressed the emotion they chose. They were also provided with the Self-Assessment Manikin (SAM; Lang, 1980), a graphic illustration of a person experiencing inner feelings. Based on the child friendly SAM (McMains et al., 2001) children had to indicate the degree of arousal experienced when viewing the emotional facial expressions. The SAM figure was placed on a 9-point Likert scale where 1 indicates feeling calm and 9 is feeling aroused.

Paper II. A set of 80 color photographs was used. Eighteen pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) were included and the remaining pictures were retrieved from the Developmental Affective Photo System (DAPS; Cordón, Melinder, Edelstein, & Goodman, 2011). Half of the pictures were neutral (e.g., landscapes, street life, and social situations) and the other half negative (e.g., wounded people, battle scenes, accidents). All pictures were coupled with another picture in the final picture set that was matched on content and valence. Thus, 40 matched pairs of pictures were included in the final sample, where one half of the pair was presented at study phase *and* recognition phase, where as the other picture in the pair was presented only at recognition. Figure 2 depicts a sample of the pictures used in the experiment. The pictures within each emotion category (i.e., neutral and negative) differed significantly on valence $t(78)=-4.73$, $p<.001$.

Cognitive and neurocognitive measures

Emo-n-back. The *Emo-n-back task* (Landrø et al., 2009) is a cognitive control, working memory task with emotional stimuli. The task was administered on a 15” screen Dell lap top computer. The task requires the participant to push the button 1 (one) every time two identical facial expressions are displayed successively. The four emotional facial expressions included in the task are neutral, sad, happy, and fear (see Figure 5). The Emo-n-back was programmed in E-prime, E-studio software package (Psychology Software Tools, Inc.). Pictures of different males and females were presented randomly, as was the emotion displayed. The test consists of 3 blocks with 120 trials in each block, each block containing 8 targets of each facial expression; a total of 24 hits per emotion were possible. The facial expressions were shown for 1500 ms each with 1000 ms interval of a fixation point between each picture stimuli. All facial expressions were obtained from the validated images in KDEF (Lundqvist, 1998), and were age normed as reported in Paper I, Study 1. The images were set on a black background; borders and image resolution were adjusted. Prior to the actual task, a practice task was employed. During the practice task, written feedback on the computer screen was given for correct responses (“correct!”), false responses (“wrong!”) and when the participant missed a response (“you should have responded!”). The feedback was only given during the practice task, which was either terminated after reaching 80% correct responses or after 150 trials depending on which came first. In the actual task no feedback was given as to whether the response was correct or not. The main variables of interest were proportion of hits for each of the four different facial expressions, as well as proportion of false alarms.

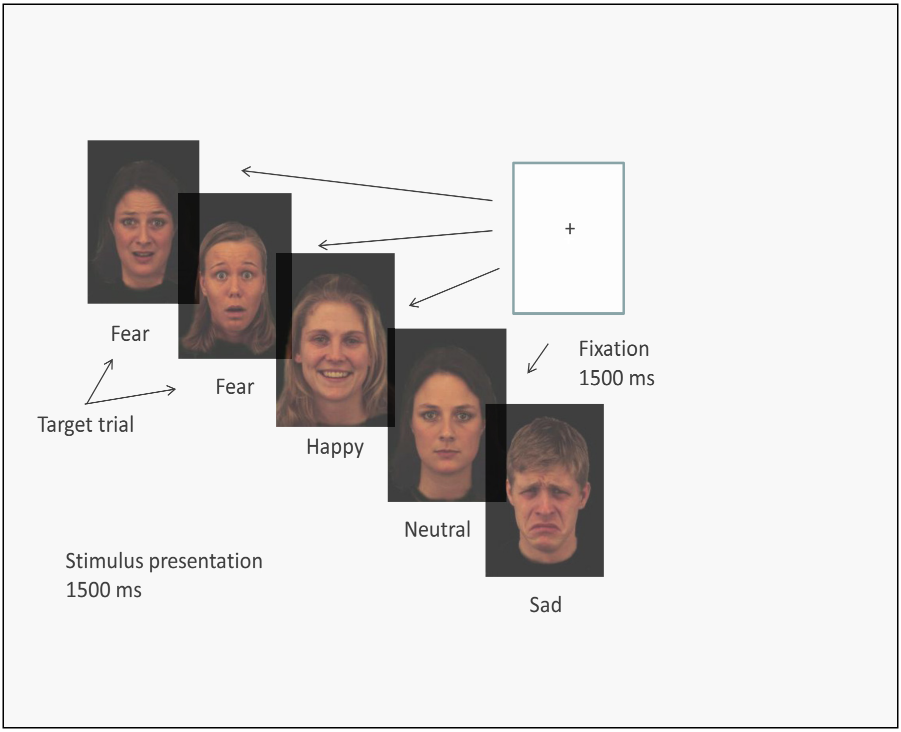

Figure 5. Illustration of the Emo-n-back stimuli and design. Children viewed each facial expression for 1500 ms and had the same amount of time to respond whether two facial expressions in a row depicted the same emotion (e.g., fear-fear).

Item directed forgetting (DF) task. The DF task conformed to the item version of the DF paradigm and consisted of 40 pictures, 20 to-be-forgotten pictures and another 20 to-be-remembered pictures. Twenty out of these 40 pictures were neutral and 20 were negative in content, cues to remember and forget were randomly assigned to the pictures presented in the study phase so that half of the pictures were cued Forget (i.e., 20 pictures) and the other half cued Remember (i.e., 20 pictures). The 40 pictures at study phase were presented at a continuous sequence for 2000 ms each. After each picture, a signal to either forget (red circle) or remember (green circle) the picture just seen was presented for another 2000 ms. A fixation cross was presented after each forget/remember cue for another 1500 ms before the next picture was presented (see Figure 6 for an illustration of the design and material). All participants were instructed to try to memorize the pictures with a to-be-remembered cue (green circle) presented right after the picture, and try to forget pictures followed by a red circle (to-be-forgotten). A distracter task was then administered, lasting for about 20 minutes. Subsequently, the recognition test was administered, all 40 pictures from study phase were presented as were 40 new matched pictures never presented to the participants before. The 80 pictures were presented in a random order for 500 ms each. Participants had to perform an old-new decision by pressing one ("1") for old pictures and two ("2") for new pictures on a computer keyboard. Participants were instructed to make an accurate and fast judgment as possible, but there was no time limit for the response. The DF test was programmed in E-prime, E-studio software package, version 2 (Psychology Software Tools, Inc.).

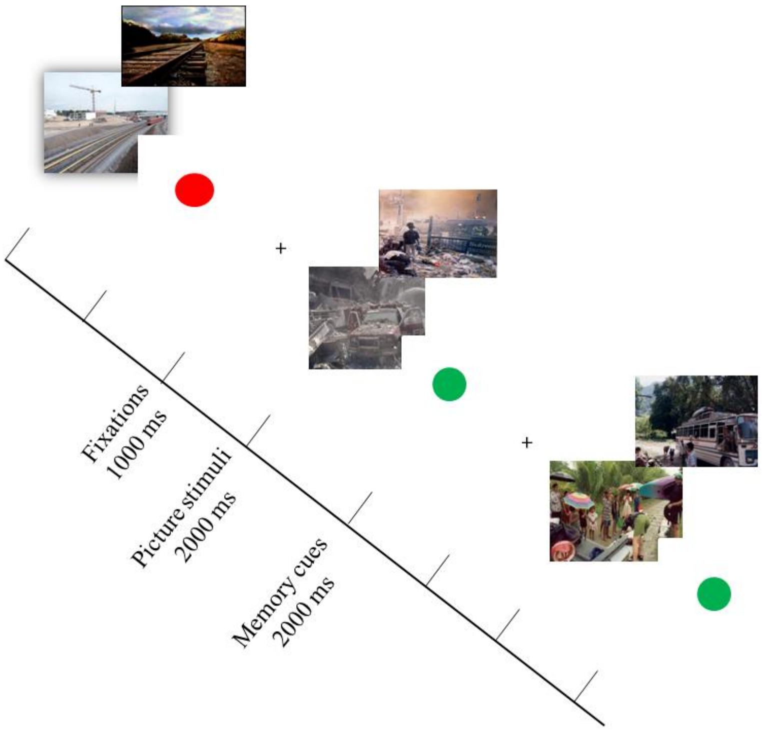

Figure 6. Study design and sample of stimuli used in the Directed Forgetting task. Red and green circles depict memory cues, forget and remember respectively.

Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999). The WASI provides a brief estimate of intelligence which is normed for the ages 6 through 89 years. The WASI consists of four well-known subtests; vocabulary, block design, similarities, and matrix reasoning. In the present study, only vocabulary and matrix reasoning was administered. The primary variable of interest was the two-subtest total intelligence quotient (IQ).

Cambridge Neuropsychological Test Automated Battery. Executive function tests were selected from the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, 2006). CANTAB has reached high validity in measuring the different components of EF (Fray, Robbins, & Sahakian, 1996; Robbins et al., 1998; Sahakian & Owen, 1992), also in children (DeLuca et al., 2003; Luciana & Nelson, 2002). In particular CANTAB has been considered as particularly sensitive to brain-behavior associations (Luciana & Nelson, 2002). The tests used in the present study are the Spatial Working Memory (SWM) test and the Intra/Extradimensional Set Shift (IED) task.

The *SWM test* measures updating and monitoring in working memory. The screen displays a number of boxes. The participant has to find blue, squared tokens in each box. Gradually, the number of boxes increases from three to eight. Touching a box where the participant already has found a token is considered an error. The participant decides the order in which each box is visited. The variable of interest for the current paper is total errors, reflecting the number of errors (i.e., number of times revisiting boxes that already had had a hidden token behind it). Hence, low score on the SWM indicates good working memory (i.e., fewer errors). A SWM strategy variable was also computed. This measure indicates whether the participant uses an efficient strategy to remember where blue tokens were previously found. A high score on this variable represents poor use of an efficient strategy.

The *IED task* is designed to assess set shifting abilities. In the IED task the subject is presented with two simple, color-filled shapes. The subject must learn which of the two stimuli is correct by touching it, and continue to do this until the criterion is reached. During the task, a dimensional shift is imposed, that is, for the answer to be correct the participant has to be able to differentiate between the color-filled shapes and white lines drawn on or next to the shapes. Both general set shifting as indexed by the number of errors prior to the extradimensional shift and number of errors on the extradimensional shift variables as well as stages reached (i.e., 1-9) are included in the present study.

Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference Test (Delis, Kaplan, & Kramer, 2001). The D-KEFS color-word interference test is similar to the Stroop task, characterized by inhibiting prepotent responses to read color words, and instead name the color in which each word is printed. The D-KEFS color-word interference test is a set of four cards, beginning with the two screening cards to name colors and to read color names respectively. The actual test is first to inhibit the natural response to read words instead of naming colors, followed by the fourth and last task to switch between mental sets of either naming the colors in which words are printed or read the color words. Thus, switching between two different sets of rules. In the present study, scaled scores on number of errors on the 3rd condition, inhibiting automatic responses, and the associated response time measure for this condition are used as an index of inhibition. The reason for choosing this measure among the different Stroop conditions is because it is considered as the condition that measures inhibition in particular.

Symptom scales

Child Behavior Checklist/6-18 (CBCL; Achenbach & Rescorla, 2001). The CBCL is administered to parents asking them to rate their children's social, academic, behavioral strengths and weaknesses. Out of several types of scales indicating the presence of psychiatric symptoms above or below a clinical cut off, the present study is based on the three scales *internalizing*, *externalizing* and the combination measure *total problems*. A higher score on either scale is associated with more symptoms on problems associated with these categories. All three scales have reached good reliability (Cronbach's α=.90-.97).

Trauma Symptom Checklist for Young Children (TSCYC; Briere et al., 2001). The TSCYC is a 90-item parent-report measure on children's trauma- and abuse-related symptomatology. Responses were given on a 4-point scale ranging from "never" to "almost all the time", and the respondent was asked to only consider the child's behavior during the last month. Eight clinical scales are derived from the checklist as well as two reporter validity scales. In the present study, the clinical scales will be reported. These are, post-traumatic stress-Intrusion (PTS-I), post-traumatic stress-Avoidance (PTS-A), post-traumatic stress-Arousal (PTS-AR), post-traumatic stress-total (PTS-TOT), Sexual concerns (SC), Dissociation (DIS), Anxiety (ANX), Depression (DEP), and Anger/Aggression (ANG). Clinical scales on the TSCYC have all reached good reliability (Cronbach's α=.87-.93). Of interest in the Paper III were clinical symptom scales associated with common psychological sequelae after child maltreatment, PTS-TOT, DIS, ANX, and DEP.

Ethical considerations

The study was carried out in accordance with the Helsinki Declaration and approved by the Regional Committee for Medical Research Ethics (REK sør-øst) and the Norwegian Social Sciences Data Services (NSD). All participants and their parents received written information. Before participation was commenced, parents had to sign a consent form. Children were rewarded a gift certificate of NOK 100 (US$ 17) for their participation serving as compensation for travelling expenses.

Research including vulnerable groups, such as children in general and in particular children who have been exposed to adverse life experiences such as maltreatment, merit careful ethical consideration. To this end, parents were given thorough written information regarding the study. In the information letter the researcher's e-mail and telephone number was provided in order for the parent to easily contact the researcher for questions prior to consenting to participation. Additionally, the principle of research participation as voluntary, and the right to at any time withdraw from all or some parts of the study, was clearly stated throughout the information the parent and the child received orally and written. Given that some of the stimuli used (Paper II) were of negative content, parents were also explicitly informed about this in the letter and also told that if they chose to let their child participate in the study, they would be given the chance to review the pictures in advance and then decide whether their child should be exposed to these pictures. If the parent decided not to let their child view these pictures it would not affect the rest of the testing procedure other than the task including these pictures.

When the child and parent met the researcher, ample time was devoted to building rapport with the child and the parent. The entire testing procedure was described and the parent viewed the picture stimuli the child would be exposed to if the parent agreed. Parent and child were shown the rooms where testing would take place and the child was reassured that the parent would be waiting at the designated room after the testing. During testing, the researcher would monitor the child's behaviors in order to make sure that he or she was comfortable. The researcher would always suggest breaks in between tests so that the child could see the parent.

Children are not always comfortable in stating their own needs, and the researchers running participants were therefore trained in working with children and instructed to carefully evaluate the child's needs even if the child did not explicitly express discomfort. When difficult topics were discussed (e.g., traumatic experience), special care was taken in making the child comfortable sharing personal information, and the child was also reassured that there was no requirement to disclose any information to us unless they felt it right. Children who chose to tell about negative episodes in their lives were reassured about the confidentiality with which they shared this information, and the researcher would always ask the child how he or she felt sharing personal information with the researcher. During debriefing all children were thanked for their time and valuable contribution to research. Children were also encouraged to ask questions during testing, but also after. Debriefing first took place with the child alone and subsequently with the child and parent together.

In sum, several measures were employed to make sure that children and their parents felt that participation was a voluntary, confidential, and meaningful experience.

Statistical analyses

All data were analyzed using The Statistical Package for the Social Sciences (SPSS; Inc., Chicago, IL) for Windows (version 16.0) and the upgraded version 18.0 (PASW statistics; Inc., Chicago, IL).

Paper I, Study 1. Analysis investigating children's ability to identify emotional facial expressions correctly was based on the unbiased hit rate (H_u) as proposed by Wagner (1993). H_u considers jointly the probability that a stimulus is correctly identified when it is presented and that the response is correctly used if used at all (Wagner, 1993). H_u, which is based on frequencies in the participant's confusion matrix, is expressed in proportion scores. The proportion scores have to be arcsine transformed before statistically analyzed, which means that 0 is the lowest possible score and 1.57 (i.e., the arcsine of 1) is the highest possible score. Preliminary analysis using one-way analysis of variance (ANOVA) was employed to assess gender differences. The main analysis conformed to a 4(Emotion; Neutral vs. Sad vs. Happy vs. Fearful) X 4(Age; 9- vs. 10- vs. 11- vs. 12-year-olds) mixed repeated measures ANOVA with emotion as within-subjects factor and age as between-subjects factor. Bonferroni corrections were used on all post-hoc comparisons.

Additional analysis investigating the effect of arousal and intensity respectively were also employed conforming to the similar 4(Emotion; Neutral vs. Sad vs. Happy vs. Fearful) X 4(Age; 9- vs. 10- vs. 11- vs. 12-year-olds) mixed repeated measures ANOVA with arousal and intensity as within-subjects factors and age as between-subjects factor.

Paper I, Study 2. In order to operationalize working memory for emotional facial expressions, we transformed hits and false alarm rates on the Emo-n-back to d' scores using Wixted and Lee's (n.d.) procedure. According to the standard d' procedure rates of zero and one were adjusted by the formula 1/(2N) where N is the total number of false alarms and hits (Wixted & Lee, n.d., http://psy2.ucsd.edu/~kang/sdt/sdt.htm). Thus, a positive d' score reflects that hits are endorsed more than false alarms. The opposite pattern is found (i.e., negative d' values) when children respond with more false alarms than hits. The response criterion set by the child was also calculated using *C.* A *C* value above 0 is considered conservative whereas a response criterion below 0 is regarded as liberal. This means that children who employ a conservative bias are more likely to miss than to falsely endorse items (i.e., false alarm), whereas the opposite is true for liberal response biases-to rather avoid misses resulting in increased rates of false alarms. Potential gender differences were assessed by performing a one-way ANOVA. For d' and *C* on the Emo-n-back two separate analyses were conducted using mixed within- and between groups repeated measures ANOVA. When violations of the assumption of sphericity were present, multivariate tests, Wilk's lambda (λ), are reported. Post-hoc comparisons using the Bonferroni corrections were employed to investigate specific relations between emotions in the Emo-n-back. Pearson's correlations (age partialled out) were used to calculate relations between Emo-n-back d' measures and CBCL variables. Associations between CBCL on types of emotions displayed in the Emo-n-back task were explored by employing analysis of covariance (ANCOVA) entering one

CBCL variable at a time as a covariate. All results reported are significant at a p=.05 level or below.

Paper II. Hits and false alarms were calculated for each of the four conditions respectively: neutral to-be-forgotten pictures, negative to-be-forgotten pictures, neutral to-be-remembered pictures, and negative to-be-remembered pictures. Mixed within- and between groups repeated measures analysis of variance (ANOVA) with memory instruction at encoding and picture valence varied within subjects, and age as a between subjects factor, was employed for hits and false alarms respectively. Additionally, two-high-threshold (P_r) discrimination accuracy measure was also calculated for the four dependent measures described above (Snodgrass & Corwin, 1988). This is a measure of the accuracy with which participants were able to distinguish old from new pictures at recognition, and was calculated based on hits and false alarms using Snodgrass and Corwin's (1988) formula, [P_r=H-FA][1]. Similarly, the response criterion, B_r [B_r=FA/1-Pr], was calculated to assess the response bias applied by children in the present experiment. A value above 0 indicates that children are more prone to respond "yes", whereas a value below 0 is equivalent to a higher tendency to say "no" to whether one has seen a stimulus before. Again, mixed within- and between groups repeated measures ANOVA is reported for the two latter response measures P_r and B_r. Results with a p=.10 or below will be reported and commented on.

Paper III. First, for screening purposes Chi-square analysis and One-way ANOVAs will be carried out to investigate differences between the two groups on demographic variables such as gender and ethnicity. Additionally, trauma related psychopathology was assessed and differences between the maltreated and non-maltreated children on these variables were investigated also using one-way ANOVA. To explore the association between neuropsychological functioning and trauma related psychopathology, Parsons' correlations

[1] Note that calculations of hits and false alarms are corrected according to Snodgrass and Corwin's (1988) recommendation before used in the calculation of P_r and B_r.

were employed for each group (i.e., maltreatment/no-maltreatment) separately. In the case of significant correlations in either or both groups, the significant psychopathology measures were included in the main analysis as covariates. To explore group differences on the main neuropsychological variables all variables were standardized using Z scores and subsequently sub variables addressing same neuropsychological function were combined into one mean Z score. First, three two-way ANOVAs were carried out entering separately three mean scores; SWM, IED, and inhibition as dependent variables. Fixed factor was the two groups of maltreated and non-maltreated children respectively. If any significant differences between the groups emerged on any of the mean variables, separate two-way ANOVAs were carried out to investigate the specific associations between maltreatment status and the different neuropsychological variables.

Results

Paper I, study 1.

Preliminary analysis. To investigate the effect of gender, three one-way analyses of variance (ANOVA) were conducted. In all analyses gender was the independent variable, and the four facial expressions happy, neutral, fear and sad, were independent variables for hit rates, arousal, and intensity respectively. No gender differences were revealed for hit rate, valence, or arousal. Thus gender is not considered in any further analyses.

Hit Rate. This analysis conformed to a 4(Emotion; Neutral vs. Sad vs. Happy vs. Fearful) X 4(Age; 9- vs. 10- vs. 11- vs. 12-year-olds) mixed repeated measures ANOVA with emotion as within-subjects factor and age as between-subjects factor. Analysis showed a main effect of emotion, $F(3,192)=54.4$, $p<.001$, $\eta_p^2=.46$, post-hoc comparisons with Bonferroni corrections indicated that Happy facial expressions enjoyed a significantly higher hit rate than any of the other emotional expressions ($p<.001$), but the remaining emotional expressions did not differ significantly from each other in percentage of hit rate. No significant main or interaction effects of age or gender were revealed.

Arousal and intensity ratings. Two repeated measures ANOVAs were conducted for arousal and intensity respectively; arousal and intensity ratings for each emotion category were varied within subjects, whereas age was inserted as a between-subjects factor. A main effect of emotion was revealed in relation to arousal, $F(3,66)=41.85$, $p<.001$, $\eta_p^2=.66$. Bonferroni comparisons showed a significantly lower arousal rating for neutral faces compared to all the other facial expressions included in the task ($p<.001$), none of the other emotions differed significantly from each other on arousal (see Table 1). No other significant main or interaction effects were revealed. Regarding intensity, a main effect of emotion was revealed, $F(3,66)=31.67$, $p<.001$, $\eta_p^2=.59$. Bonferroni corrected comparisons showed a significantly higher intensity rating for happy faces compared to all the other facial expressions included in the task ($p<.001$), none of the other emotions differed significantly from each other in emotional intensity. Similar to the arousal analysis, no other main or interaction effects were significant in the analysis of the intensity ratings.

Paper I, study 2.

Preliminary analysis. Gender differences were explored using a one-way ANOVA. No significant gender differences emerged (*F*s=3.8-.06, *p*s>.05), thus gender is not considered in further analysis.

Effects of emotion and age on the Emo-n-back task. A 4(Emotion; neutral vs. sad vs. happy vs. scared) X 2(Age; 9-10- vs. 11-12-year-olds) mixed within and between repeated measures ANOVA was employed to investigate the effects of emotion on Emo-n-back performance as a function of age. Multivariate tests showed a main effect of emotion, $\lambda=.16$, $F(3,77)=136.0$, $p<.001$, $\eta_p^2=.84$. Bonferroni corrected post-hoc comparisons revealed a significant difference between emotions, (*p*s<.001). The order of discriminability from best to worse for all age groups was: happy, neutral, fearful and sad (see Figure 2). The emotion X age interaction did not turn out significant. However, there was a significant over all effect of age, $F(1,79)=6.2$, $p<.01$, $\eta_p^2=.07$. Post-hoc tests using Bonferroni corrections showed that the youngest children performed significantly poorer over all on the Emo-n-back compared to the older age group included ($p=.02$).

Response bias (C) as a function of emotion, and age was also investigated using a 4(Emotion; neutral vs. sad vs. happy vs. scared) X 2(Age; 9-10- vs. 11-12-year-olds) mixed within and between repeated measures ANOVA. Analysis showed a main effect of emotion, $\lambda=.37$, $F(3, 77)=43.7$, $p<.001$, $\eta_p^2=.63$. Bonferroni corrected post-hoc comparisons revealed a significant difference between neutral and happy, and neutral and fearful expressions. In particular, response bias to neutral facial expressions was significantly more conservative than response bias for happy faces, and less conservative compared to fearful faces. Lastly, children applied a significantly stricter criterion in response to fearful facial expressions compared to all other facial expressions in the Emo-n-back (all ps<.05; see Figure 3). No main or interaction effects related to age were significant.

Emo-n-back and individual differences. Controlling for age, several partial correlations were significant, indicating an association between individual differences on the CBCL (see Table 2) and performance on the Emo-n-back task. Scores on CBCL total problems scale was negatively associated with all but neutral d' scores on the Emo-n-back, indicating that more symptoms on this particular symptom scale was associated with poorer performance on the Emo-n-back for the emotions happy, $r=-.303$, $p<.01$, sad, $r=-.266$, $p=.01$, and fear, $r=-.262$, $p=.01$. Children with more internalizing problems were less proficient in performing the Emo-n-back task for fear, $r=-.237$, $p=.02$, and happy facial expressions, $r=-.249$, $p=.01$. Higher scores on the externalizing symptom scale were negatively associated with working memory for sad facial expressions, $r=-.199$, $p=.04$.

To further investigate associations between Emo-n-back performance and individual differences, three mixed between and within repeated measures ANCOVAs were employed. The within subjects factor was always d' scores for the different emotional facial expressions in the Emo-n-back. Age was entered as a between subjects factor and CBCL externalizing, CBCL internalizing and CBCL total problems symptoms scales were entered, one at a time, as covariates.

CBCL externalizing. Externalizing symptoms was not a significant covariate when entered into the ANCOVA.

CBCL internalizing. When entering the CBCL internalizing subscale as a continuous covariate, the above reported main conclusions were not altered, thus the main effects of emotion and age were still significant. However, the covariate did turn out significant, $F(1,75)=4.1$, $p=.04$, $\eta_p^2=.05$. This underscores the correlations reported above, that internalizing problems are negatively associated with performance on the Emo-n-back.

CBCL total problems. When entering CBCL total problems symptoms scale, accounting for both symptom scales above and additional behavioral problems, the main conclusions regarding effects of emotion on working memory and age remained significant. Moreover, CBCL total problems turned out as a significant covariate, $F(1,75)=6.8$, $p=.01$, $\eta_p^2=.08$, meaning that children with more symptoms reported on the CBCL total problems scale performed poorer on the Emo-n-back.

Paper II.

Preliminary results

There were no significant differences based on gender or ethnicity on either of the dependent DF measures. Thus, gender and ethnicity is not further considered in the analyses.

DF, emotion and age

Recognition performance. Hits and false alarms were entered separately into the 2(Instruction; forget vs. remember) X 2(Emotion; neutral vs. negative) X 2(Age; 8 - 9 years vs. 10 -12 years) repeated measures ANOVA. For hits, a main effect of instruction was revealed, $F(1,63)=8.1$, $p<.01$, $\eta_p^2=.11$. Planned comparisons with Bonferroni correction, revealed that memory for R-pictures were enhanced compared to the recognition memory for F-pictures ($p<.01$). A significant main effect of emotion emerged, $F(1,63)=15.3$, $p<.01$, $\eta_p^2=.20$. Planned comparisons with Bonferroni correction revealed a significantly higher proportion of hits to negative pictures compared to neutral photographs ($p<.01$). Lastly, a trend of an instruction and emotion interaction was also evident, $F(1,63)=3.1$, $p=.08$, $\eta_p^2=.05$. Post-hoc t-tests revealed that only neutral pictures enjoyed a significant DF effect $t(1,64)=-3.1$, $p<.01$, compared to negative pictures, $t(1,64)=-.76$, n.s.. No main or interaction effects of age emerged.

For false alarms, only a significant main effect of emotion was revealed, $F(1,63)=25.1$, $p<.01$, $\eta_p^2=.29$. Planned comparisons with Bonferroni correction, revealed a significantly higher proportion of false alarms to negative compared to neutral photographs ($p<.01$). No other main or interaction effects were significant.

Discrimination accuracy and response bias. Similar to the hits and false alarms analyses, P_r, was entered into a 2(Instruction; forget vs. remember) X 2(Emotion; neutral vs. negative) X 2(Age; 8 - 9 years vs. 10 -12 years) repeated measures ANOVA. Analysis revealed a main effect of instruction during study phase, $F(1,63)=6.2$, $p=.02$, $\eta_p^2=.09$. Planned comparisons with Bonferroni correction, revealed that memory accuracy for R-pictures were enhanced compared to memory accuracy for F-pictures ($p<.01$). The between-subjects factor age came out significant, $F(1,63)=4.0$, $p=.05$, $\eta_p^2=.06$, indicating that older children had a more accurate memory than the younger age group. No other significant main or interaction effects were revealed for discrimination accuracy.

Lastly, a repeated measure ANOVA similar to the one described above was employed, entering the response bias criterion (B_r) set by the child when responding at the recognition test as our dependent measure. Analysis revealed a main effect of emotion, $F(1,63)=46.5$, $p<.01$, $\eta_p^2=.42$, post-hoc planned comparisons with Bonferroni corrections revealed that children were more conservative when responding to neutral items compared to negative items ($p<.01$). No other main or interaction effects emerged.

Paper III.

Demographic, psychometric, and clinical characteristics

Chi-square analysis revealed no significant difference on ethnic origin between the two groups, and ethnicity was therefore not considered in any further analysis investigating group differences. To assess differences on symptoms of trauma-related psychopathology, a one-way ANOVA was carried out on all relevant variables from the TSCYC and CBCL. Children in the maltreatment group were assessed by their parents to have significantly more problems on several of the symptom scales, as compared to the contrast group. Gender differences were also explored using a one-way ANOVA, however, no significant gender differences were revealed on either the neuropsychological measures or the trauma related psychopathology measures included in the present study. Thus, gender will be collapsed across all analysis. In addition, a one-way ANOVA was carried out to investigate any significant associations between group and IQ scores, there was no significant difference in IQ scores between the two groups which as a result controls for the effect if IQ on any EF associations. That is, maltreated (M=89.05, SD=10.85) and non-maltreated (M=95.68, SD=10.57) children had similar IQ scores. Lastly, to assess potential associations between psychiatric symptoms and the dependent measures on EF, correlations were performed between variables on the TSCYC, CBCL and EF measures. None of the symptom scales included in the present paper correlated significantly with any of the EF measures. Thus, symptom scales are not included in any further analysis.

Performance on EF tasks

SWM variables. Significant group differences were revealed on the SWM measure, $F(1,40)=4.20$, $p=.05$, $\omega^2=.07$, when the SWM mean score was entered as the dependent variable. Maltreated children performed significantly poorer on this measure compared to the non-maltreated children (see Table 1; $p=.05$, $r=.31$).

Furthermore, a significant main effect of group was revealed in relation to the SWM strategy adopted by the children, $F(1,40)=5.70$, $p=.02$, $\omega^2=.12$. Post-hoc comparisons revealed that maltreated children showed significantly poorer performance on the strategy use than their non-maltreated peers (see Table 1; $p=.02$, $r=.36$).

No significant group differences were revealed when employing a univariate ANOVA to assess group differences on the SWM error score.

IED variables. No significant group differences were revealed on either the IED mean score or any of the sub scales on which the mean IED score is based.

Inhibition variables. No main effects of group were found in relation to the mean score on the inhibition variable.

Summary of Papers

Paper I: The Effect of Emotional Stimuli on Children's Working Memory: Associations with Age and Behavior

Studies on adults have revealed a disadvantageous effect of negative emotional stimuli on executive functions (EF), and it is suggested that this effect is amplified in children. The present study's aim was to assess how emotional facial expressions affected working memory across age, using a working memory task with emotional facial expressions as stimuli. Additionally, we explored how degree of internalizing and externalizing symptoms in typically developing children were related to performance on the same task. However, before employing the working memory task with emotional facial expressions as stimuli, an independent sample of 9-12-year-olds was asked to recognize the facial expressions intended to serve as stimuli on the working memory task, and to rate the facial expressions on intensity and arousal to obtain a base line for how children during this age recognize and react to facial expressions. The first study revealed that children rated the facial expressions with similar intensity and arousal across age. When employing the working memory task with facial expressions, results revealed that negatively valenced expressions impaired working memory more than neutral and positively valenced expressions. The ability to successfully complete the working memory task increased between 9-12 years of age. Children's internalizing symptoms and total problems were associated with poorer performance on the working memory task with facial expressions. Results on the effect of emotion on working memory are discussed in light of recent models on how emotional information might interact and interfere with cognitive processes such as working memory.

Paper II: The Effect of Neutral and Negative Color Photographs on Children's Item Directed Forgetting

Intentional forgetting is an active process relying on cognitive mechanisms (e.g., rehearsal strategies and inhibition) developing during the elementary school years. Color photographs might be rehearsed differently in memory than words, and therefore result in a different developmental pattern of intentional forgetting than previously acknowledged. Moreover, negative material is thought to be particularly reliant upon inhibitory mechanisms in order to not be encoded in memory. Thus, children's item DF might develop differently both in relation to color photographs in general and for negative pictorial stimuli in particular. The aim of the present study was to investigate item Directed Forgetting (DF) for color photographs of neutral and negative valence in sixty-five school-aged children (8-12 years of age). In the present study, a DF effect was revealed irrespective of age for neutral images as well as negative images. Results are discussed in relation to potential mechanisms underlying item DF for color photographs and how these affect development of intentional forgetting.

Paper III: Maltreatment is Associated with Specific Impairments in Executive Functions: Insights from Differential Testing

Child maltreatment is associated with a host of adverse consequences. However, few studies exist that map maltreated children's performance on neurocognitive tests particularly sensitive to brain and behavior associations. The aim of the present study was to investigate whether maltreated children (*n*=21) differed in their executive functioning compared to their non-maltreated peers (*n*=22). Tasks aimed at measuring set shifting, spatial working memory (SWM), and inhibition from the Cambridge Neuropsychological Automated Test Battery and the Delis-Kaplan Executive Function System were administered. Trauma-related symptomatology and general emotional and behavioral adjustment was assessed. Maltreated children performed significantly poorer compared to their non-maltreated peers on the SWM task, in particular SWM strategy. No differences were revealed between the two groups on measures of set shifting and inhibition. Symptoms of psychopathology were not significantly related to performance on the executive functions tests. The present results suggest an association between maltreatment-related stress and SWM strategy.

Discussion

Main findings

The main finding of the present dissertation is that negatively valenced material is associated with impaired EF compared to when neutral (Paper I and II) and positive stimuli (Paper I) are presented. This finding is in line with the dual competition model which states that negative material will consume neural capacity, and this impairs the ability to perform EF tasks successfully, relative to when confronted with positive or neutral information (e.g., Pessoa, 2008, 2009). Age differences were only partly revealed in the present dissertation. In Paper I, Study 2, 9-10-year-olds were significantly poorer in performing the Emo-n-back task regardless of emotional facial expressions compared to 11-12-year-olds. This suggests a general development in processing capacity in working memory similar to what has been suggested in studies on working memory without emotional stimuli (e.g., Gathercole et al., 2004).

A slightly different perspective was taken in Paper III, complementing Papers I and II. In the two first papers of the present dissertation, the stimulus dependent effect of emotion might have temporarily caused attenuation of EF in typically developing children. In comparison, in Paper III, long-term stress and thereby state-dependent effects of emotion, was investigated. The state-dependent effect of emotion appears to have an impact on non-emotional EF tasks in maltreated children.

The effect of emotional stimuli on executive functions

Findings reported in Papers I and II suggest that processing of negative stimuli are consuming capacity to the extent that the child's level of EF is not capable of performing at the same level as when processing neutral or positive information, which is much in line with the dual competition model proposed by Pessoa (2009). In a very recent study it was concluded that hot EF, EF that bears emotional significance, develops more slowly than cool

EF described as cognitive control efforts with no emotional component (Prencipe et al., 2011). Prencipe and colleagues (2011) used well-known EF tasks such as the Iowa Gambling Task and the Delay Discounting as emotional tasks. These tasks have a stronger motivational component than the so called cool EF tasks (e.g., Color Word Stroop, Backward Digit Span). The hot EF tasks used by Prencipe et al. (2011) were targeted as motivational and reward oriented, whereas Papers I and II of this dissertation defined emotionality by use of emotional stimuli. Nevertheless, results from Paper I suggest that resource competition between the processing of negative emotional stimuli and working memory (cf. Pessoa, 2008, 2009) persists during the elementary school-years even if over all working memory capacity increases during the same years.

In addition, findings in Paper II suggest that the effect of emotion on EF has a cascading effect on long-term memory as expressed by a significantly less accurate memory (i.e., more false alarms) for negative pictures compared to neutral ones on a later recognition test. Previous research has shown that immature EF such as inhibition underlies the proportionally higher false alarm rate in children compared to adults (Ruffman et al., 2001). Findings in Paper II suggest that inhibitory functions are even more depleted when faced with emotional information, again much in line with Pessoa's model (2008, 2009). In recent research negative information in particular has been found to increase false memories during recognition (Howe, Candel, Otgaar, Malone, & Wimmer, 2010), supporting the findings in Paper II. In other words, the effects of emotion on EF may have consequences for a range of processes partly or entirely relying on EF.

Paper I revealed that rapid responses and efficient updating of working memory is particularly hampered by fearful and sad facial expressions compared to happy and neutral. In Paper II however, the DF effect was not modified by emotion when statistical analyses were based on a discrimination accuracy measure. It might be that the more pronounced negative effect of emotion on EF reported in Paper I is due to the time constrains added to the Emo-n-back task (Paper I) compared to the item DF task (Paper II). According to Zelazo, Qu, and Kesek (2010) time constrains may interrupt what these authors call a rapid iterative process that enables well-evaluated decisions.

In summary, findings from Papers I and II support models of the relationship between emotion and EF (Pessoa, 2008, 2009). Predictions made by Zelazo et al. (2010) on the growing ability to rapidly process and reprocess emotional information while trying to accomplish EF tasks is supported by the present thesis. Moreover, emotional valence modifies EF abilities and this effect is seemingly more easily detectable when time to react is limited.

Differentiating between negative stimuli. According to Pessoa's dual competition model (2009) a differentiation between types of negative emotional stimuli ought to be made, as stimuli high versus low on threat will affect top-down processes differently. However, contrary to what one would have expected from the dual competition model, children performing the Emo-n-back task in Paper I did perform poorer in response to sad faces compared to the fearful facial expressions. Sad facial expressions are commonly considered less arousing than fearful facial expressions, and are detected at a somewhat slower rate than fearful and angry faces considered high in arousal (LoBue, 2009). At least three possible reasons might underlie the finding in Paper I, Study 2, suggesting that sad facial expressions impair working memory more than fearful faces do.

First, findings in Paper I, Study 1 suggest that children did not perceive sad and fearful facial expressions as different when it came to ratings of arousal. As argued in the introduction, it is important to consider children's own ratings of valence and arousal in order to adequately interpret the stimuli-driven effects of emotion on EF. On a 9-point liker scale, children in the experiment reported in Paper I, Study 1, rated sad and fearful facial expressions between 4 to 5.5 on average. Thus, neither sad nor fearful faces were considered particularly arousing. McMains and colleagues (2001) noted in their study that behavioral and physiological measures of emotion reactivity did not yield the same pattern of results. For instance, behaviorally children and adults did not differ in their ratings of arousal and intensity of color photographs of different valences, whereas skin conductance and heart rate measures revealed significantly more activation in children than adults on the same material. These fidnings demonstrate that it is important to consider emotional recativity on different levels (e.g., behavioral, physiological), and if comparing across studies one must account for the level of assessment.

According to the dual competition model (Pessoa, 2009, see also Eysenck, Derakshan, Santos, & Calvo, 2007), effects of emotion might not be exactly the same when the emotional information is relevant for the task and not serving as a distracter. Pessoa suggests that task relevant material will enhance EF in these situations, and only hamper EF when serving as a distracter. However, other research has shown that this is not necessarily the case. For instance, Lagatutta, Sayfan, and Mansour (2011) found that children as well as adults struggled when performing a modified day-night inhibition task, where the child and adult were instructed to say happy when viewing a sad facial expression and say sad when shown a happy facial expression. In another study, Rosenberg-Kima and Sadeh (2010) reported poorer inhibitory function as reflected in an increased number of errors and longer RT for negative facial expressions. It is still unclear whether Pessoa's predictions about the role of the emotional stimulus in the task are crucial, or in what way it might be crucial, for performance.

From another point of view, recent research has also proposed a differentiation between stimuli depicting for instance survival relevant information compared to social cues (Larson & Steuer, 2009; Sakaki, Niki, &Mather, 2011). Stimuli that bear significance on a biological and survival level (e.g., stimuli involving guns, stimuli pertaining to reproduction) will trigger different responses than social-emotional cues such as facial expressions do

(Sakaki et al., 2011). Social stimuli that are low on threat and more socially relevant than survival relevant are more ambiguous and therefore require top-down processes to evaluate the stimulus before acting on it (Pessoa, 2008, 2009; Sakaki et al., 2011). Results from Paper I, Study 2 suggests that sad facial expressions in particular are taxing top-down processes. This effect might be explained through the assumption that social-emotional stimuli require an initial evaluation and then subsequently to perform the cognitive task in which the stimuli are embedded. This proposition is quite recently put forth and therefore in need of more empirical research to be verified.

In all it seems important to further disentangle the effects of emotional stimuli both as a function of stimulus type and reactivity measured on several levels.

Associations with age

Understanding different age effects across studies. Results revealed in Paper I, Study 2 indicate that cognitive processing develops, but that this development still at the age of 12, is modified by emotion. Thus, as proposed by Casey et al. (2008) the effect of negative emotion on working memory may be accounted for by an unsynchronized early development of affective neural networks that interact with later developing networks associated with higher-order cognition such as working memory. According to Casey et al. (2008), this developmental dissociation persists well into adolescence, so the developmental pattern seen in Paper I, Study 2 should persist beyond the age-groups included in the present thesis.

Surprisingly, age was not associated with the DF effect, neither for neutral or negative pictures. If the same developmental trajectory was to be expected in both Paper I and Paper II one would assume an instruction X emotion X age modification of the DF effect in Paper II, indicating that negative pictures were exempt from intentional forgetting regardless of age. However, there are many possible reasons for why Paper I and II cannot be compared and why different main conclusions regarding age emerged.

It is suggested that the reasons why working memory abilities increase during childhood is in part due to the increased ability to efficiently process information in working memory (Fry & Hale, 2000; Gathercole et al., 2004). Paper I put high demands on the child to efficiently update working memory and decide whether two similar facial expressions were presented in a row. The task employed in Paper II had more lenient time constraints, and on the actual recognition test participants had no time limit to decide even if the re-presentation of the picture was limited to 2000 ms. Consensus prevails on the fact that reaction time (RT) increases significantly during childhood (e.g., Hale, 1990; Kail & Park, 1992), thus, the age difference between 9-10- and 11-12-year-olds on the Emo-n-back could be due to age differences in processing speed. When briefly assessing this possibility by conducting RT analysis on Emo-n-back data, no significant main or interaction effects of age were revealed. This might indicate that the effects revealed in Paper I are due to the effect of working memory capacity. Although RT is one aspect of working memory capacity (Fry & Hale, 2000), it seems as if it is not the primary contribution to better performance on the Emo-n-back for children included in Paper I. The age differences revealed in Paper I could therefore maybe be explained by an increased capacity in holding and updating information in working memory as orchestrated by the central executive. The central executive is found to be highly sensitive to developmental and individual differences (Conklin et al., 2007; Gathercole et al., 2004).

Another explanation for the lack of age differences in the picture item DF (Paper II) could be due to the fact that color photographs are more vividly represented in memory (Dewhurst & Conway, 1994; Whitehouse, Maybery, & Durkin, 2006). The simple, item-by-item rehearsal as opposed to cumulative rehearsal (Lehmann & Hasselhorn, 2007) might be sufficient to commit to-be-remembered pictures to memory. Item DF for easily processed stimuli (i.e., color photographs) might be more reliant upon an already established rehearsal strategy in school-aged children, not capturing the developmental changes taking place in encoding strategies across the age range included in the present study. Hitch and Halliday (1983, in Fry & Hale, 2000) showed that pre-school aged children were superior in visual processing compared to phonological processing, this might also make young school-aged children more efficient in selectively rehearsing visual stimuli compared to verbal. In sum, both the strategy children use to rehearse pictorial information and the experience children have in processing this mode of stimuli may have rendered the item DF task feasible for the age groups included in Paper II. In other words, the item DF task employed in Paper II might neither have captured a qualitative shift in working memory (i.e., rehearsal strategy), nor a quantitative shift in processing capacity due to the quite lenient time frame used in the experiment.

Depending on the task at hand, children will be able to excel as a function of age aided by the increasing ability to update working memory (Paper I), whereas when working memory is unchallenged age effects will not ensue (Paper II). Thus, the present findings may have revealed developmental trajectories of different working memory dependent processes.

Why different age groups? Paper I and Paper II included somewhat different age groups. In Paper I 8-year-olds were not included. Preliminary analyses indicated that 8-year-old children responded with significantly higher arousal and interpreted the intensity of the emotional facial expressions differently than the older children. This difference in emotional processing precludes the comparison across age on the Emo-n-back as the effects revealed for 8-year-olds would either be due to the processing of facial expressions or working memory. Developmental differences in processing speed could also be a considerable confounder if 8-year-olds were included in Paper I, Study 2. The development of processing speed is characterized by a non-linear function. During the first years of life, children undergo a very steep increase in processing speed. Although this development continues past the pre-school years, it will start to level of and not increase as dramatically with increasing age (Fry & Hale, 1996). Thus, age is important to consider both in relation to emotional processing and response time, both factors being important for the interpretation of Emo-n-back performance.

To be able to include children of a wider age range than presently done in Paper I there are a few possible future options. One can slightly increase the available response time during the task and look at age differences as a function of both age and processing speed (cf. Rosenberg-Kima & Sadeh, 2010). However, if emotional stimuli are included in EF tasks, one needs to reassure that children ascribe similar valence and arousal to the stimuli used across age, or control for these age differences in other ways (e.g., continuous covariate). An alternative option is to expand the age range including both younger and older children than done in the present dissertation. This solution could allow for comparisons within different age intervals and through this approach investigate what seems to drive the development of executing cognitive control while processing information of different valences. In relation to Paper II, including both older and younger children than presently done, could also have revealed at what age item DF for pictures starts to develop. If the age of onset for intentional forgetting for picture stimuli is earlier than what has been reported for words and line drawings, this could challenge present assumptions on when intentional forgetting starts to develop.

Individual differences in emotion-executive functioning interactions

Findings from Paper I, Study 2, related to social-emotional problem behaviors may be interpreted by using Phillips et al.'s (2003, 2008) models. According to both the original and revised model, impaired EF is considered to be at the core of emotion-regulation difficulties in adults. In Paper I, Study 2, we tested Phillips and colleagues'(2003, 2008) proposition in children. Findings revealed that children with more emotional behavior problems, as rated by their parents, encountered greater challenges when asked to process emotional information in working memory, compared to children with less problems of this kind. Generally, from a preventative perspective it seems important to be aware of the potential difficulties some children face with exerting cognitive control in situations where emotions are displayed and conveyed. Literature investigating the top-down regulation of emotional input in depressed and anxious children has revealed specific impairments in their ability to perform working memory tasks while being distracted by facial expressions (Ladouceur et al., 2009). Combined with results from Paper I, it might be suggested that impairments in integrating working memory and emotional information are evident before psychopathology has developed, but in a more unspecified way than Ladouceur and colleagues (2009) report.

From a social development perspective, the findings in Paper I might be interpreted in light of the affective social competence (ASC) model (Halberstadt et al., 2001). According to the ASC, the dynamics of understanding emotional expressions, acting appropriately towards them, and experiencing emotional problems are intertwined (Halberstadt et al., 2001). In the present study the associations proposed by the ASC model are tested cross-sectionally and it is therefore impossible to say anything about the direction of the effect. That is, whether poor emotion-EF integration leads to greater behavioral problems, or vice versa, that behavioral problems may lead to problems in effortfully executing goal-directed behavior while faced with emotional information. Trentacosta and Fine's (2010) interpretation of the ASC model propose that adequate and successful development of emotional knowledge will result in a good resolution of the different components of the ASC model. Hence, development of emotion knowledge will precede behavioral problems and social difficulties. According to this interpretation, children included in Paper I who have higher scores on the internalizing and total problems scale could be on a path towards developing less adaptive abilities in integrating emotion and EF, possibly leading to poorer social and emotional functioning in the future.

Recently it has been proposed a new approach in research on EF that should focus on the way in which EF is important for social and emotional development (e.g., Best et al., 2009; Riggs et al., 2006). In two recent reviews researchers have underscored the importance of assessing the association between EF and emotion in general, and also specifically in longitudinal studies (Best et al., 2009), and in intervention research (Riggs et al., 2006). By investigating specific mechanisms assumed to underlie adaptive behavior, for instance EF, the proposed associations between cognition and emotion as outlined in the ASC model could be addressed.

Maltreatment and executive functioning

Two possible mechanisms through which associations between maltreatment and EF could be interpreted were outlined in the introduction – either through psychiatric problems or directly from maltreatment–related stress. Results from Paper III suggest that maltreatment and maltreatment related stress might play an important role in explaining impaired EF in this group of children. As the first study to use Miyake's model (2000) as a conceptual framework to investigate maltreated children's EF, it was evident that maltreated children showed specific impairments in EF, which might be associated with stress dysregulation. Paper III revealed that children exposed to maltreatment did show problems with spatial working memory (SWM) in particular. SWM seems to be affected possibly due to the fact that SWM relies on right PFC structures that are already taxed by arousal induced activation (e.g., Davidson, 1994; Shackman et al., 2006).

Although maltreated children had higher symptom scores on all psychopathology measures included in Paper III, none of the measured symptoms were significantly associated with EF. Since we did not include a diagnostic interview, but rather asked the parent to complete self-report forms on the child's psychological functioning, the symptoms revealed might not have been an accurate representation of these children's well-being. Studies investigating the use of parents as informants have shown that there are systematic effects of the quality of the parent-child relationship, as well as the parents' own psychological well-being, on ratings of children's externalizing and internalizing behavior scores (Treutler & Epkins, 2003). Importantly, it is often thought that parents suffering from psychiatric problems themselves tend to rate their children as having more problems than other non-parental raters (e.g., teachers) do (Youngstrom, Izard, & Ackerman, 1999). It might well be that mothers of maltreated children experience psychological distress themselves and as such it should be expected that their children are rated more negatively compared to children of non-maltreated parents. According to this view, the lack of a significant correlation between psychopathology and EF reported in Paper III is based on a conservative approach. Alternatively, the parental reports are not necessarily too negative, but rather that the mother does not accurately see her child's positive and negative qualities. This possibility cannot be ruled out in Paper III, and future studies should address this empirical question by in addition retrieving measures on children's psychological functioning from other sources than the parent.

The effect of maltreatment on cognitive and psychological functioning—a possible explanation. The present thesis could not directly answer questions pertaining to biological markers of stress. However, Figure 7 depicts a model which is thought of as an illustration specifically connected to early life stress and is a combination of Lupien et al.'s (2009) life cycle of stress model and Phillips and colleagues' (2003) emotion-regulation model. As put forth by the life cycle model of stress (Lupien et al., 2009), abilities relying on PFC functioning are particularly sensitive to stressors in the environment during the age-range included in the present dissertation and beyond. Experiences of maltreatment, and in a broader sense early life stress, is found to affect neuroendocrine responses in children (i.e., HPA axis regulation; Loman & Gunnar, 2010) which in turn have a negative impact on right PFC and consequently right PFC dependent EF tasks (Davidson, 1994). In particular the right PFC has been thought of as involved in EF important for regulating behavior when emotionally aroused (Zelazo & Cunningham, 2007). In addition, EF is important for effective emotion-regulation, and deficits in EF are therefore associated with the development of psychopathology characterized by disturbed emotional reactivity (e.g., Phillips et al., 2003; Rueda et al., 2005). In sum, the two models taken together suggest that the psychopathology often associated with maltreatment (e.g., PTSD, anxiety, and depression) might be a result of poor neuropsychological functioning which again is a result of the prolonged negative arousal maltreated children have experienced. To date, the developmental literature has not sufficiently addressed the implications stress and EF might have for the understanding of maltreatment related sequelae (but see Loman & Gunnar, 2010, for a recent focus on this). The outlined model might be one way of testing possible associations in future research.

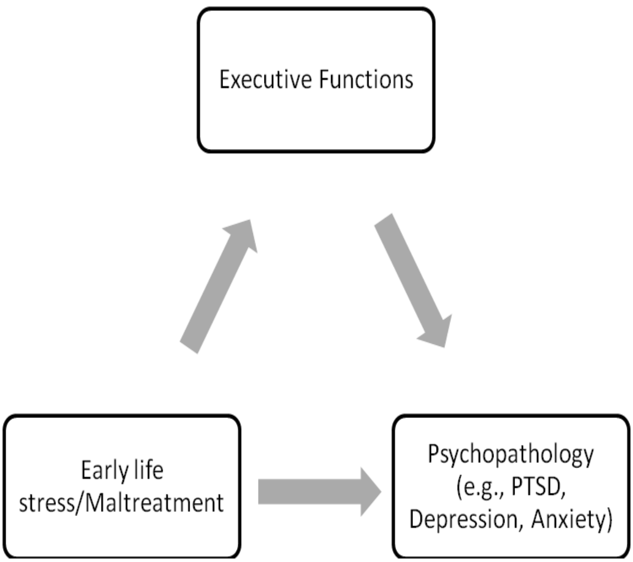

Figure 7. Mediation model illustrating a potential relationship between early life stress (maltreatment), executive functions, and psychopathology commonly reported in survivors of maltreatment.

Methodological considerations

Although great care has been taken to use sound methods and statistics in order to address the main hypotheses in the present studies, some methodological limitations exist. Threats to reliability and validity of the findings in light of the study design will be evaluated in the following paragraphs.

Reliability of findings. Both the group of typically developing children and the much smaller group of children who reported to have endured maltreatment are probably not representative of the general population of children between the ages of 8-12 years. Our participants were not selected randomly, but children's parents chose to actively consent to participate in the study. Maltreated children and their families were all receiving help at the time of participation, either through the CPS or the domestic violence shelter through which they were recruited. Thus, maltreated children who live in families that are not under supervision from professionals might show different (maybe poorer) patterns of functioning than reported in Paper III. Also, children who have been removed from their biological parents and living with foster parents may demonstrate different patterns of functioning than revealed in the present dissertation. However, the largest group of children seen by the CPS receive services while still living with their biological parents (Statistics Norway, 2011), and thereby the present sample represents the group of children most commonly encountered by the CPS and other health professionals. The group of maltreated children was small and therefore the risk for committing a type I error increases. The rejection of the present findings, however, might result in a type II error. When considering the two possible outcomes it seems justified to run the risk of committing a type I error, as the negative consequences of ignoring the present findings will not outweigh the potential benefits of strengthening working memory in maltreated children.

Typically developing children were children of parents who considered it valuable to participate in research, and as such these families might be different from the ones refraining from participation. However, we made sure to contact a large variety of schools representing different socioeconomic neighborhoods, and thereby reaching families with a wide variety of backgrounds. Nevertheless, it is important to consider these sampling limitations when interpreting the present findings.

Computing Cronbach's α commonly constitute measurement of reliability for questionnaires. In the present dissertation (Paper I, study 2 and Paper III), questionnaires assessing symptoms of psychopathology were used as covariates, and Cronbach's α was retrieved from the original standardization manuals (e.g., Achenbach & Rescorla, 2001; Briere et al., 2001). Ideally, one would run exploratory factor analysis in the present sample to verify the established values. However, the present study did not have enough power to run a principal component analysis precluding the calculation of reliability in the present sample. In the literature on factor analysis it is commonly suggested that principal component analysis is based on at least an item/person ratio of 5 (ideally 10), or alternatively 300 participants (Field, 2009; Tabachnick & Fidell, 2007; but see, MacCallum, Widaman, Zhang, & Hong, 1999, for a different approach and claculation). For the CBCL one would need a minimum of 300 participants, and similarly in relation to the TSCYC. Thus, it is a limitation to the interpretation of the findings related to individual differences in psychopathology that cannot be ruled out.

Study Design. Study design has a particular impact on the validity of the reported findings and conclusions reached. The two major limitations in the present thesis' study design are that all data presented are cross-sectional and that the study comparing maltreated versus non-maltreated children is quasi-experimental in nature. These two methodological factors may result in threats to both internal validity and the validity of statistical conclusions.

Cross-sectional data. Cross-sectional data precludes causal inferences related to developmental patterns and relations with individual differences. This shortcoming in design threatens the *internal validity* of the study findings in that it is impossible to confidently dissociate which of the factors came first in time (Shadish, Cook, & Campbell, 2002). For instance in Paper I, it is not possible to know whether problems with emotional EF are the cause of behavior problems, or whether children's behavior problems result in difficulties with updating working memory when presented with social-emotional stimuli. Moreover, the present design will not eliminate the possibility that there is something else that explains both individual variability in both EF and behavioral problems. The only possible solution in order to address some of the threats to validity is to conduct longitudinal studies investigating changes within and across subjects over time. However, such designs run the risk of other threats to internal validity such as attrition, the likelihood of a systematic drop-out pattern, and also the effect of using the same test over several sessions potentially resulting in measuring learning rather actual development in the domain studied.

Quasi-experiment. The quasi-experimental design used in Paper III is not ideal. One of the weaknesses of the design is that there is no pre-test on the cognitive functioning of the maltreated group of children. That is, the maltreated children have not been tested prior to maltreatment to control for any confounding variables that may explain the proposed relationship between adverse life experiences and SWM. More specifically, we will not know if there are other factors that are the actual reasons for the differences reported between the two groups included in Paper III. This limitation precludes causal inference, and as referred to above, affects internal validity. This is of course unfortunate, but there are many reasons for why a pre-test is not obtainable in the maltreated child sample. For obvious reasons, one can not know for sure the exact population of children that will experience maltreatment in the future, and thus secure pre-abuse tests on EF.

Furthermore, in Paper III there is no random assignment of children into different groups. As the groups are already predetermined (maltreated vs. non-maltreated) randomization is redundant. However, since this is not a treatment study, we do not wish to see effects of a controlled manipulation, but rather investigate existing variance in EF between samples of children with different life experiences.

Sampling issues might threaten *statistical conclusion validity* by affecting the statistical power. According to Shadish et al. (2002) statistical power is one of the main threats to valid statistical conclusions in psychological research. Given difficulties in sampling maltreated children due to for instance difficulties in reaching families through the CPS and domestic violence shelters, the sample size is small and therefore minimizing statistical power. Nevertheless, the study includes several covariates that increase power by eliminating unknown variables that can affect performance on the outcome variables (Shadish et al., 2002). Matching of participants is one way to circumvent the threat to statistical validity. The matching method minimizes some of the disadvantages of no-pretest design. However, caveats are also attached to the matching method. One of these is selection bias (Shadish et al., 2002). Selection bias can result in regression towards the mean if one selects on the basis of extreme scores. This can distort the statistical findings and potentially result in revealing significant differences between the groups when this is not true (i.e., type I error), or the opposite, accept null findings when differences indeed exist (i.e., type II error). To avoid threats to statistical conclusion validity associated with matching, Shadish and colleagues (2002) suggest an approach where the groups are as similar as possible before matching. These similarities should be based on factors that are easily and accurately measured, such as age and gender. In order to try to limit the threats to statistical conclusion validity in Paper III, children in the maltreatment group and controls were all carefully matched on age, gender, and general cognitive functioning as expressed by IQ.

Implications

Findings from Paper I indicate that there are effects of emotional information on working memory and that this effect depends of the emotion displayed. Emotion-regulation is tied to working memory functioning (Schmeichel et al., 2008) and by definition, emotion-regulation entails emotional processing and the ability to exert control and distract oneself from negative moods (Zelazo & Cunningham, 2007). For clinicians, the interplay between emotion and EF is important to be aware of. Furthermore, the discrepancy between emotional reactivity and EF maturity (see Casey et al., 2008) is paramount to consider when clinicians evaluate children's psychological well-being. Since childhood and the transition to adolescence bear significant importance, particular care should be taken to consider many areas of a child's functioning. Although clinically, EF should not be the sole area of focus, it might prove fruitful to assess and try to strengthen EF abilities in children who struggle with social and emotional problems. Findings from Paper I can also inform teachers on the difficulties children might have to act flexibly and goal directed while deciphering emotional cues in the environment. The school environment is more or less structured, and thereby suited to practice EF enhancing tasks. If teachers are made aware of the importance of for instance working memory in order to regulate own feelings, and how one can enhance this ability, children with particular difficulties at school may receive interventions which aid healthy development at a crucial time point in life.

Including more naturalistic stimuli in an item DF tasks for children might be one avenue through which to understand delayed and incomplete witness memory accounts (Gordon & Connolly, 2010). Moreover, the moderating effect of negative information on DF is of special interest to the forensic domain. Results in Paper II demonstrate that DF for negative pictures is equally affected by instructions to forget at encoding, as are neutral pictures (in particular when using measures of discrimination accuracy). Thus, in forensic contexts this information is important to keep in mind, and it is casting doubt on the likelihood that emotional information is repressed or forgotten to a greater extent than neutral information. Nevertheless, it is important to note also from an applied perspective that negative stimuli seem to be false alarmed to a greater extent than neutral stimuli. Implications of the effect of emotion on the ability to discriminate old from new information in memory sheds important light on the possible detrimental consequences of introducing children to unverified information from a negative event, and in particular when children are asked to respond yes or no to such information.

One possible explanation for why maltreated children experience learning problems, resulting in poorer academic achievements compared to their peers (Huang & Mossige, 2011; Landsford et al., 2002; Shonk & Cicchetti, 2001) could be poorer SWM abilities revealed in Paper III. Similarly, emotion regulation abilities are thought to heavily rely on working memory (Schmeichel et al., 2008; Van Dillen & Koole, 2007), and the emotional problems reported in many children who have suffered from maltreatment experiences might originate from the deficits uncovered in the present study. Early and specifically tailored interventions might be suited for improving SWM abilities in children who have endured maltreatment. Therefore, identifying specific patterns of neuropsychological functioning can help practitioners intervene at an early stage and target training programs.

Future perspectives

Future studies should investigate the emotion-EF interaction in children longitudinally, and extend findings from the present research to other types of EF. Given the hypothesis put forward by Casey et al. (2008) it seems important to investigate what drives development in the ability to act goal directed in emotional situations or while processing emotional information. Questions that future studies should attempt to address and answer is whether emotional reactivity drives the development of more sophisticated EF as the ability to regulate affective reactions pushes the EF development ahead? Or alternatively, that emotional reactivity hampers EF development as the effects of higher emotional demands leave fewer resources for the adaptive and optimal development of EF? To date, most research on the effect of emotion on EF has studied children who have already developed mild to severe psychopathology. However, findings in Paper I suggest that typically developing children with normally ranging externalizing and/or internalizing patterns of behavior struggle to complete a working memory task with emotional facial expressions. Future studies should therefore map such vulnerability factors and follow up longitudinally to investigate if such variability translates into more established differences in psychological functioning later into adolescence.

Paper II suggests that the development of memory strategies may explain how intentional forgetting develops. Compared to previous item DF research on children, findings in Paper II suggest that memory strategies may vary as a function of stimulus modality. However, in Paper II, no direct measures of rehearsal strategies were employed. Future studies should aim at exploring rehearsal strategies as they pertain to different stimulus modalities so as to better understand how children encode and memorize lexical, pictorial, auditory information, and self-experienced events. Moreover, some existing literature suggest that EF are at the core of intentional forgetting (Aslan, Zellner, & Bäumel, 2010; Hauswald et al., 2010; Woody-Dorning & Miller, 2001), and new studies should be designed to assess the exact role of EF in memory and forgetting.

Future studies should empirically test the proposed model (Figure 7) of the association between early life stress, EF and psychopathology conjointly. At present these three components have not been integrated in one study, thus it is a future task to enhance our understanding of the mechanisms underlying maltreated children’s maladjustment in many areas of life.

In the future, larger samples should be included to further investigate the implications of findings revealed in Paper III for maltreated children's general functioning. Including larger samples may also allow for the differentiation between different types of maltreatment and thereby to investigate maltreatment specific patterns of neurocognitive functioning and development. Moreover, attenuation of neuropsychological problems through training should be thoroughly explored in groups of maltreated children so as to minimize negative long-term sequelae associated with child maltreatment.

Conclusions

To conclude, the present thesis has highlighted associations between emotion, EF and individual differences related to both age (Papers I and II) and psychological adjustment (Papers I and III). In all, the present thesis show that emotion impacts EF, and that negative information in particular impairs working memory and inhibition. Furthermore, variability in social and emotional functioning was associated with an impairing effect of emotional information on working memory. Moreover, maltreatment was adversely associated with spatial working memory. This last finding in combination with main conclusions from Papers I and II suggests that both short-term and long-term effects of negative emotional input may hamper important and adaptive abilities in children—namely executive functions.

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Papers I-III

The Effect of Emotional Facial Expressions on Children's Working Memory:

Associations with Age and Behavior

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Abstract

Studies on adults have revealed a disadvantageous effect of negative emotional stimuli on executive functions (EF), and it is suggested that this effect is amplified in children. The present study's aim was to assess how emotional facial expressions affected working memory across age, using a working memory task with emotional facial expressions as stimuli. Additionally, we explored how degree of internalizing and externalizing symptoms in typically developing children were related to performance on the same task. However, before employing the working memory task with emotional facial expressions as stimuli, an independent sample of 9-12-year-olds was asked to recognize the facial expressions intended to serve as stimuli on the working memory task, and to rate the facial expressions on intensity and arousal to obtain a base line for how children during this age recognize and react to facial expressions. The first study revealed that children rated the facial expressions with similar intensity and arousal across age. When employing the working memory task with facial expressions, results revealed that negatively valenced expressions impaired working memory more than neutral and positively valenced expressions. The ability to successfully complete the working memory task increased between 9-12 years of age. Children's internalizing symptoms and total problems were associated with poorer performance on the working memory task with facial expressions. Results on the effect of emotion on working memory are discussed in light of recent models on how emotional information might interact and interfere with cognitive processes such as working memory.

Keywords: executive functions, working memory, emotional facial expressions, development, social and emotional behavior problems

The Effect of Emotional Facial Expressions on Children's Working Memory: Associations with Age and Behavior

Executive functions (EF) may be defined as the skills crucial for purposeful, goal-directed activity (Anderson, 1998). Miyake and colleagues (2000) have proposed a model of EF comprising three, interrelated but also meaningfully dissociable components. The three EF components are; inhibition, set shifting, and working memory updating (Miyake et al., 2000). EF are associated with several abilities important in everyday life, such as socio-emotional adjustment (Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006), academic achievements (Gathercole & Pickering, 2000), and theory of mind (Melinder, Endestad, & Magnussen, 2006). In adults, working memory capacity has been considered crucial in the ability to distract one-self from negative moods (Van Dillen & Koole, 2007), and thereby aid emotion-regulation (Schmeichel,Volokhov, & Demaree, 2008). As a consequence, it has been suggested that using emotional stimuli in EF tasks might be a fruitful way to study the ability to act goal directed and flexibly in emotional situations (Banich et al., 2009; Elliott, Zahn, Deakin, & Anderson, 2011). Studies addressing the effect of emotion on working memory report impairments in working memory when processing negative information in particular (e.g., Kensinger & Corkin, 2003; Ladouceur et al., 2005, 2009; Landrø et al., 2009). Nevertheless, the development of the capacity to process emotional information in for instance working memory still remains unresolved (Blair & Dennis, 2010). Such knowledge may be relevant for our understanding of children's social and emotional adjustment (Zelazo & Cunningham, 2007).

According to Pessoa's (2008, 2009) dual competition model, EF and processing of emotional information are thought to share some of the same neural structures (e.g., Anterior cingulate cortex (ACC)), and thereby compete for the same neural resources. Depending on degree of emotional arousal, EF may be bolstered or impaired when applied in emotionally salient situations, or while processing emotional information (Pessoa, 2009). Processing of negative arousing stimuli may result in poorer EF whereas positive information may lead to enhanced EF (Pessoa, 2008). From a developmental perspective, Casey, Getz, and Galvan (2008) hypothesize that capacities that are associated with well-adjusted regulation of behavior, i.e., EF, are poorer at a time when emotional reactivity and reward oriented behavior is relatively high (Blair, 2002; Casey et al., 2008; Zelazo, Qu, & Kasek, 2010). According to the Casey et al. (2008) hypothesis, during development, children will become increasingly better at performing EF tasks with emotional content as EF becomes more mature and better at overriding emotional and motivational distracters. The proposed dissociation between levels of maturation of emotional processing and EF is present during school years and into adolescence, rendering even adolescents poorer in acting goal directed when at the same time processing emotional information (Casey et al., 2008). From an individual difference perspective, Phillips, Drevets, Rauch, and Lane (2003) have proposed two neural systems that are important for emotional behavior, in which one of the two systems also is important for EF. This model suggests that EF is a crucial tool for dealing with emotion. Deficits in regions predominately affecting EF might from an early age be associated with risk for developing affective disorders (Phillips et al., 2003).

Recent literature on children’s attention to facial expressions has revealed an adult like faster detection rate for threatening (i.e., fear, anger), and negative (i.e., sadness) facial expressions compared to happy facial expressions (LoBue, 2009; Leppänen, 2011). However, children’s working memory capacity tend to be poorer than adults’ (Gathercole, Pickering, Ambridge, & Wearing, 2004; Luciana, Conklin, Hooper, & Yarger, 2005), possibly resulting in difficulties for children to adaptively regulate emotional input. In healthy adults only subtle indications of impaired working memory for emotional stimuli is reported (Kensinger & Corkin, 2003). It took longer for adults to correctly respond to an n-back task when processing fearful faces compared to neutral ones (Kensinger & Corkin, 2003). The discrepancy between emotional reactivity that is more adult like, and children's immature EF, may affect the ability to disengage from negative emotional information (cf. Blair, 2002; Casey et al., 2008). This proposition may be tested by asking children to deliberately process facial expressions of different valences in working memory.

Studies with focus on mood disorders have revealed that there is a specific association between psychopathology and working memory for emotional facial expressions. In one study using an n-back task with various facial expressions, adult women with genetic markers associated with risk for developing depression (i.e., serotonin transporter (5-HTTLPR) short allele) took longer to respond correctly to sad facial expressions (Landrø et al., 2009). Children at risk for developing mood disorders such as anxiety and depression show biased processing of negative information (Joorman, Talbot, & Gotlib, 2007; Ladouceur et al., 2005, 2009). Results from these studies have revealed that both children and adults with symptoms of depression and/or anxiety show poorer EF when processing negative facial expressions (e.g., Joorman et al., 2007), or are distracted by negative stimuli (Ladouceur et al., 2005, 2009). Thus, it is suggested that risk factors associated with developing emotional problems and mood disorders may work through the ability to execute control over emotional input, and adaptively distract oneself from negative stimuli (Joorman et al., 2007; Landrø et al., 2009; Phillips et al., 2003; Van Dillen & Koole, 2007; Zelazo & Cunningham, 2007). However, emotional disorders develop gradually (Zahn-Waxler, Klimes-Dougan, & Slattery, 2000). Early precursors of the risk for developing emotional problems might be externalizing (e.g., oppositional behavior, overt aggression) and internalizing behaviors (e.g., anxious, withdrawn tendencies) in children (Roza, Hofstra, van der Ende, & Verhulst, 2003; Zahn-Waxler et al., 2000). If degree of externalizing and internalizing behaviors is associated with attenuated working memory for emotional stimuli, this can be one avenue through which to understand how some children may develop unfavorable social and emotional behaviors.

To address the effect of emotion on working memory, two separate studies were undertaken. First, as we operationalize emotion by use of pictures depicting people showing emotional facial expressions, Study 1 was designed to retrieve age appropriate norms of recognition, intensity and arousal for the stimuli used in the working memory task employed in Study 2. The aim of Study 2 was threefold. The first aim was to investigate how children's working memory is affected when processing emotional facial expressions. Secondly, age differences in executing the working memory task with facial expressions during the elementary school years were assessed. The third aim was to investigate if early signs of emotional and behavioral maladjustment were associated with performance on a working memory task with emotional stimuli.

Study 1

Emotional facial expressions

Facial expressions of others are frequently encountered emotional stimuli (Herba & Phillips, 2004). Labeling and correctly recognizing facial expressions seems to follow a gradual developmental trajectory (e.g., DeSonneville et al., 2002; Herba, Landau, Russell, Ecker, & Phillips, 2006; Herba & Phillips, 2004). Positive emotions are correctly labeled prior to negative emotions, and the speed and accuracy with which they are recognized increases with age (DeSonneville et al., 2002; Herba et al., 2006). More specifically, research findings indicate a major improvement in labeling emotional facial expressions between 7-10 years of age (DeSonneville et al., 2002).

The effect of gender on the recognition of facial expressions has only inconsistently been reported (McClure, 2000). When gender differences are found, they seem to be in favor of girls (McClure, 2000). Moreover, the transition to adolescence is a vulnerable phase both in relation to the recognition of faces in general, but also for facial expressions in particular due to for instance hormonal variations (Scherf, Behrmann, & Dahl, 2011). To control for a potential gender bias, gender is included in analyses in both Study 1 and 2.

In addition to replicating previous work on the development of recognition of facial expressions (e.g., Herba et al., 2006), we wanted to establish a base line for the intensity and arousal ascribed to the facial expressions and whether these measures would vary as a function of age.

Method

Participants

Seventy-two children, 19 (8 boys) 9-year-olds, 17 (9 boys) 10-year-olds, 20 (11boys) 11-year-olds and 16 (5 boys) 12-year-olds participated in the study. Children were recruited from schools in an urban area. Information and consent forms were distributed through schools that agreed to send the letters out with their students. Only children of families that returned a signed consent form were included in the study.

Stimulus material and rating scales

A subsample of pictures from The Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998) formerly used in the Emo-n-back (Landrø et al., 2009) was included in the present study. In total 120 pictures from the KDEF were used in the Emo-n-back depicting equal numbers (i.e., 30) of Neutral, Sad, Happy, and Fearful facial expressions (Figure 1). Each expression was photographed from the front and pictures were color photographs of amateur actors, half male and half female within each emotion. For the emotion rating children were given the option to choose the label best describing the facial expression as happy, fear, sad, neutral, or other. If the "Other" option was chosen, the child had to come up with another label considered more appropriate in their opinion. Additionally, on a separate page, children were asked to rate the intensity of the emotional expression on a 9-point Likert scale from 1 ("not at all") to 9 ("very much") related to the degree to which the picture expressed the emotion they chose. They were also provided with the Self-Assessment Manikin (SAM; Lang, 1980), a graphic illustration of a person experiencing inner feelings. Based on the SAM children had to indicate the degree of arousal experienced when viewing the emotional facial expressions. The SAM figure was placed on a 9-point Likert scale where 1 indicates feeling calm and 9 is feeling aroused.

Procedure

A child-modified procedure to that reported in the validation study of the KDEF (Goeleven, De Raedt, Leyman, & Verschuere, 2008) was employed. Children were presented with either 32 or 24 pictures of facial expressions included in the Emo-n-back and drawn from the KDEF, for 6000 ms on a 15" Dell laptop computer. The researcher administered the whole rating procedure; the child indicated their responses verbally or by pointing at the emotion options and rating scales. First, the child was explained the purpose of the study, followed by a practice task focusing on understanding the rating scales (two trials) and then in another two trials practicing the actual task with the 6 seconds time constraint. For the arousal rating, children were asked to respond to how they actually felt when viewing the facial expression. During the actual test, a warning slide was first shown with the instruction ''Pay attention, a new picture is coming up''. Immediately after this slide, a KDEF picture was shown for 6 seconds. The next slide was then presented with the instruction to rate the picture. This procedure was repeated for each picture. The child had unlimited time to rate the picture, and was tested individually.

Results

Preliminary analysis

To investigate the effect of gender, three one-way analyses of variance (ANOVA) were conducted. In all analyses gender was the independent variable, and the four facial expressions happy, neutral, fear and sad, were independent variables for hit rates, arousal, and intensity respectively. No gender differences were revealed for hit rate, valence, or arousal. Thus gender is not considered in any further analyses.

Hit Rate

Analysis investigating children's ability to correctly identify emotional facial expressions was based on the unbiased hit rate (H_u) as proposed by Wagner (1993) (see Table 1)[1]. H_u considers jointly the probability that a stimulus is correctly identified when it is presented and that the response is correctly used if used at all (Wagner, 1993). H_u, which is based on frequencies in the participant's confusion matrix, is expressed in proportion scores. The proportion scores have to be arcsine transformed before statistically analyzed, which means that 0 is the lowest possible score and 1.57 (i.e., the arcsine of 1) is the highest possible score. This analysis conformed to a 4(Emotion; Neutral vs. Sad vs. Happy vs. Fearful) X 4(Age; 9- vs. 10- vs. 11- vs. 12-year-olds) mixed within and between repeated measures ANOVAs with emotion as within-subjects factor and age as between-subjects factor. Analysis showed a main effect of emotion, $F(3,192)=54.4$, $p<.001$, $\eta_p^2=.46$. Post-hoc comparisons with Bonferroni corrections indicated that Happy facial expressions enjoyed a significantly higher hit rate than any of the other emotional expressions ($p<.001$). The remaining emotional expressions did not differ significantly from each other in percentage of hit rate (see Table 1). No significant main or interaction effects of age were revealed.

(Insert Table 1 about here.)

Arousal and intensity ratings

Two repeated measures ANOVAs were conducted for arousal and intensity respectively; arousal and intensity ratings (see Table 1) for each emotion category were varied within subjects, whereas age was inserted as a between-subjects factor. A main effect of emotion was revealed in relation to arousal, $F(3,66)=41.85$, $p<.001$, $\eta_p^2=.66$. Bonferroni comparisons showed a significantly lower arousal rating for neutral faces compared to all the other facial expressions included in the task ($p<.001$), none of the other emotions differed significantly from each other on arousal (see Table 1). No other significant main or interaction effects were revealed. Regarding intensity, a main effect of emotion was revealed, $F(3,66)=31.67$, $p<.001$, $\eta_p^2=.59$. Bonferroni corrected comparisons showed a significantly higher intensity rating for happy faces compared to all the other facial expressions included in the task ($p<.001$). None of the other emotions differed significantly from each other in emotional intensity. Similar to the arousal analysis, no other main or interaction effects were significant in the analysis of the intensity ratings.

Discussion

Children in the present study recognized the emotional facial expressions similarly across age,and only happy faces were significantly better recognized than the other emotional expressions in the task. The superior identification of happy faces fits nicely with the significantly higher intensity ascribed to happy facial displays. Happy facial expressions are in other words conveyed more strongly in the present picture set, rendering them easier to detect as happy facial expression, which in turn affects the recognition rate positively. Furthermore, only neutral facial expressions were considered lower in arousal than any of the other facial expressions (i.e., Happy, Sad, and Fearful).

The present results provide a base line for the intensity and arousal children ascribe the different emotional expressions, and demonstrate the absence of significant age differences on recognition, arousal, and intensity ratings. Thus, any effects revealed in Study 2 should therefore not be explained by age differences in the ability to recognize facial expressions per se or due to differences in arousal between age groups. Rather, if any differences are revealed between ages in Study 2, it should be ascribed to the ability to process emotional input in working memory.

Study 2

Study 2 was designed to test the effect of emotional facial expressions on working memory in school-aged children using the Emo-n-back task (Landrø et al., 2009). In addition we aimed at investigating how working memory for facial expressions would be associated with socio-emotional functioning in typically developing children.

Given the preferential detection of negative facial expressions reported in children (LoBue, 2009), and predictions made in Pessoa's (2008, 2009) model on the effect of emotion on EF, we anticipated that children would perform superior on the Emo-n-back task when responding to happy facial expressions, whereas working memory would be impaired for sad and fearful expressions. In particular, we hypothesized that fearful expressions would impair working memory the most, as this facial expression seems to grab attention faster than sad facial expressions do (LoBue, 2009). Neutral facial expressions would enjoy scores in between the positive and negative facial expressions, as this facial expression is considered significantly less arousing than the others, and not representing a negative or positive valence. Furthermore, we proposed that children would become better at executing the working memory task with increasing age even if emotional in nature, as better working memory will aid the top-down cognitive control to a greater extent in the oldest age group (Casey et al., 2008; Zelazo et al., 2010). Lastly, as the development of mood disorders have been found to be significantly associated with externalizing and internalizing symptoms in childhood (Roza et al., 2003), and mood-disorders are related to performance on EF tasks comprising emotional stimuli (e.g., Joorman et al., 2007; Ladouceur et al., 2005, 2009), we predicted that children's externalizing and internalizing behaviors would be negatively associated with performance on the Emo-n-back task.

Method

Participants

The present paper includes only children between the ages of 9-12 years. Eighty-three children were recruited from elementary schools in an urban area. Two 9-10-year-olds did not complete the Emo-n-back due to vision disabilities (*n*=1) or because the child aborted the task due to fatigue (*n*=1) respectively. These 2 children were therefore excluded from further analyses. The final sample consists of 81 children 9 – 12 (*M*=10.4, *SD* = 1.1) years of age; 40 (18 boys) 9-10-year-olds, and 41 (22 boys) 11- 12-year-olds.

The majority of the participants (*n*=74) were Caucasians, but children with Asian (*n*=7) background participated as well. Information and consent forms were distributed through schools that agreed to send the letters out with their students. Only families that returned a signed consent form were approached and included in the study.

Measures

Emo-n-back. The *Emo-n-back task* (Landrø et al., 2009) is a cognitive control, working memory task with emotional stimuli. The task was administered on a 15" screen Dell lap top computer. The task requires the participant to push the button 1 (one) every time two identical facial expressions are displayed successively. The four emotional facial expressions included in the task are neutral, sad, happy, and fear (see Figure 1). The Emo-n-back was programmed in E-prime, E-studio software package (Psychology Software Tools, Inc.). Pictures of different males and females were presented randomly, as was the emotion displayed. The test consists of 3 blocks with 120 trials in each block, each block containing 8 targets of each facial expression; a total of 24 hits per emotion were possible. The facial expressions were shown for 1500 ms each with 1500 ms interval of a fixation point between each picture stimuli. All facial expressions were obtained from the validated images in KDEF (Lundqvist et al., 1998), and were age normed as reported in Study 1. The images were set on a black background; borders and image resolution were adjusted. Prior to the actual task, a practice task was employed. During the practice task, written feedback on the computer screen was given for correct responses (“correct!”), false responses (“wrong!”) and when the participant missed a response (“you should have responded!”). The feedback was only given during the practice task, which was either terminated after reaching 80% correct responses or after 150 trials depending on which came first. In the actual task no feedback was given as to whether the response was correct or not. The main variables of interest were proportion of hits for each of the four different facial expressions, as well as proportion of false alarms.

(Insert Figure 1 about here.)

Child Behavior Checklist/6-18 (CBCL; Achenbach & Rescorla, 2001). The CBCL is administered to parents asking them to rate their children’s social, academic, and behavioral strengths and weaknesses. Out of several types of scales indicating the presence of psychiatric symptoms above or below a clinical cut off, the present study is based on t-scores from the three scales *internalizing*, *externalizing* and the combination measure *total problems*. A higher score on either scale is associated with more symptoms on problems associated with these categories. All three scales have reached good reliability (Cronbach’s α=.90-.97).

Procedure

All children included in the present study completed the Emo-n-back task. Parents filled out the CBCL while the child performed the above-mentioned tasks in a separate room. Participation took place at the Department of Psychology, University of Oslo, where parent and child met the researcher once, and all children received a gift certificate. The study was carried out in accordance with the Helsinki Declaration and was approved by the regional ethic committee.

Analysis strategy

In order to operationalize working memory for emotional facial expressions, we transformed hits and false alarm rates on the Emo-n-back to d' scores using Wixted and Lee's (n.d.) procedure. According to the standard d' procedure, rates of zero and one were adjusted by the formula 1/(2N) where N is the total number of false alarms and hits (Wixted & Lee, n.d., http://psy2.ucsd.edu/~kang/sdt/sdt.htm). Thus, a positive d' score reflects that hits are endorsed more than false alarms. The opposite pattern is found (i.e., negative d' values) when children respond with more false alarms than hits. The response criterion set by the child was also calculated using *C.* A *C* value above 0 is considered conservative whereas a response criterion below 0 is regarded as liberal. This means that children who employ a conservative bias are more likely to miss than to falsely endorse items (i.e., false alarm). The opposite is true for liberal response biases, in order to avoid misses increased rates of false alarms will follow. For d' and *C* on the Emo-n-back two separate analyses were conducted using mixed within- and between groups repeated measures analysis of variance (ANOVA). When violations of the assumption of sphericity were present, multivariate tests, Wilk's lambda (λ), is reported. Post-hoc comparisons using Bonferroni corrections were employed. The association between the three CBCL symptom scales included in the study and performance on the Emo-n-back task was explored using analysis of covariance (ANCOVA) entering one CBCL variable at a time as a covariate. As no significant age differences were revealed in Study 1, age was collapsed into two groups, representing late childhood and early adolescence. All results reported are significant at p=.05 level or below.

Results

Preliminary analysis

Gender differences were explored using a one-way ANOVA. No significant gender differences emerged for either d' scores, or response bias expressed as C, thus gender is not considered in further analysis.

Effects of emotion and age on the Emo-n-back task

A 4(Emotion; neutral vs. sad vs. happy vs. scared) X 2(Age; 9-10- vs. 11-12-year-olds) mixed within and between repeated measures ANOVA was employed to investigate the effects of emotion on Emo-n-back performance as a function of age. Multivariate tests showed a main effect of emotion, λ=.16, $F(3,77)=136.0$, $p<.001$, $\eta_p^2=.84$. Bonferroni corrected post-hoc comparisons revealed a significant difference between emotions, (ps<.001). The order of discriminability from best to worse for all age groups was: happy, neutral, fearful and sad (see Figure 2). The emotion X age interaction did not turn out significant. However, there was a significant over all effect of age, $F(1,79)=6.2$, $p<.01$, $\eta_p^2=.07$. Post-hoc tests using Bonferroni corrections showed that the youngest children performed significantly poorer over all on the Emo-n-back compared to the older age group included (p=.02).

(Insert Figure 2 about here.)

Response bias (*C*) as a function of emotion, and age was also investigated using a 4(Emotion; neutral vs. sad vs. happy vs. scared) X 2(Age; 9-10- vs. 11-12-year-olds) mixed within and between repeated measures ANOVA. Analysis showed a main effect of emotion, λ=.37, $F(3, 77)$=43.7, p<.001, η_p^2=.63. Bonferroni corrected post-hoc comparisons revealed a significant difference between neutral and happy, and neutral and fearful expressions. In particular, response bias to neutral facial expressions was significantly more conservative than response bias for happy faces, and less conservative compared to fearful faces. Lastly, children applied a significantly stricter criterion in response to fearful facial expressions compared to all other facial expressions in the Emo-n-back (all *p*s<.05; see Figure 3). No main or interaction effects related to age were significant.

(Insert Figure 3 about here.)

Emo-n-back and individual differences on the CBCL

Controlling for age, several partial correlations were significant, indicating an association between individual differences on the CBCL (see Table 2) and performance on the Emo-n-back task. Higher scores on the externalizing symptom scale were negatively associated with working memory for sad facial expressions, *r*=-.199, *p*=.04. Children with more internalizing problems were less proficient in performing the Emo-n-back task for fear, *r*=-.237, *p*=.02, and happy facial expressions, *r*=-.249, *p*=.01. Scores on CBCL total problems scale was negatively associated with all but neutral d' scores on the Emo-n-back, indicating that more symptoms was associated with poorer performance on the Emo-n-back for the emotions happy, *r*=-.303, *p*<.01, sad, *r*=-.266, *p*=.01, and fear, *r*=-.262, *p*=.01.

(Insert Table 2 about here.)

To further investigate associations between Emo-n-back performance and individual differences, three mixed between and within repeated measures ANCOVAs were employed.

CBCL externalizing. Externalizing symptoms was not a significant covariate when entered into the ANCOVA.

CBCL internalizing. When entering the CBCL internalizing subscale as a continuous covariate, the above reported main conclusions were not altered. However, the covariate did turn out significant, $F(1,75)=4.1$, $p=.04$, $\eta_p^2=.05$. This underscores the correlations reported above, that internalizing problems are negatively associated with performance on the Emo-n-back.

CBCL total problems. When entering CBCL total problems symptoms scale, the main conclusions regarding effects of emotion on working memory and age remained significant. Moreover, CBCL total problems turned out as a significant covariate, $F(1,75)=6.8$, $p=.01$, $\eta_p^2=.08$, suggesting that children with more symptoms performed poorer on the Emo-n-back.

Discussion

In line with our predictions, children's working memory capacity varied as a function of the emotion depicted, but the effect of negative emotions was somewhat unexpected as sad facial expressions were associated with poorest working memory. Irrespective of age there was a significant decline in performance between each facial expression with happy faces enjoying the highest proportions of hits relative to false alarms, followed by neutral, fearful and sad facial expressions. The way neutral facial expressions were treated in working memory might be attributed to the significantly lower degree of arousal ascribed to this facial expression, falling in between the enhancing effect of positive emotion and the impairing effect of negative facial expressions. Children were most liberal (e.g., most likely to respond confirmatory) in relation to happy faces than to the other facial expressions, thus impulsive or a nondeliberate response pattern could not explain the effect of emotion revealed in the present study. Rather, the relatively more conservative response criterion set for negative facial expressions suggests that children engaged in elaborative processing and evaluations of fearful and sad facial expressions compared to expressions of happiness.

Furthermore, developmental improvements in Emo-n-back were also revealed, older children were better at performing the emotional n-back task compared to the 9-12-year-olds.

Lastly, internalizing symptoms were associated with poorer performance on all but sad facial expressions. The total problems scale consisting of measures associated with both internalizing, externalizing, and other emotional problems was associated with poorer working memory for happy, sad, and fearful facial expressions in the Emo-n-back even when age was accounted for. In large, internalizing symptoms seem to drive the associations found between total problems and Emo-n-back performance.

General Discussion

Effects of emotion on working memory

Related to the first aim of Study 2, results are in line with Pessoa's (2008, 2009) model suggesting that negative information impair EF. Regardless of emotional valence, Mathersul and colleagues (2009) found significant associations between EF and the recognition of facial expressions. Thus, it seems as if the joint involvement of EF in both the identification of facial expressions and performing a working memory task results in a competition for available neurocognitive resources. In addition, the effect of negative stimuli on EF such as working memory (cf. Pessoa, 2009) may render negative facial expressions specifically impairing on goal-directed and purposeful behavior.

When differentiating between negative facial expressions, we expected the poorest performance for fearful facial expressions because they seem to grab attention faster than sad facial expressions (LoBue, 2009). However, in the present study, sad facial expressions were associated with the poorest n-back performance. The effect of sad facial expressions on working memory capacity might be attributed to an enhanced activation in the amygdala found to be associated with processing sad facial expressions (Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2006; Winston, O'Doherty, & Dolan, 2003). The down regulation of the amygdala activation by the PFC might consume the capacity needed to correctly respond to sad facial expressions in a working memory task. Developmental patterns of amygdala activation might also explain why children in the present study were not as negatively affected by having to process fearful expressions in working memory compared to sad facial expression. Fearful facial expressions have been found to produce less amygdala activation in healthy children compared to adults (Thomas et al., 2001; but see Guyer et al., 2008), suggesting less need for children to down-regulate activation associated with fearful expressions while at the same time performing the n-back task. However, previous research on adolescents' neural responses to facial expressions (e.g., Thomas et al., 2001; Guyer et al., 2008) did not include sad facial expressions in their study, precluding a definite conclusion as to whether degree of amygdala activation could be the main reason for the effect of fear compared to sadness on children's working memory in the present study. Moreover, the present study did not include neuroscientific measures, which leaves the discussion about the neural underpinnings of the present results unresolved.

An alternative explanation that recently has been proposed is that non-threat related negative stimuli engage more elaborative neural and cognitive processes (e.g., cortical regions; Sakaki, Niki, & Mather, 2011). For instance, socially significant information such as sad facial expressions requires the individual to use cognitive processes to evaluate the stimulus and its context, which is considered a top-down dependent process (Sakaki et al., 2011). In line with this suggestion, the present findings might imply that children struggle with the top-down evaluation of negative social stimuli, while at the same time performing a demanding working memory task. Down-regulation in response to threatening facial expressions (i.e., fear), especially when the threat relevant stimulus is not rated as more arousing than sad facial expressions (Study 1), seems to interfere less with top-down processes involved in working memory. Hence, it might be the ability to simultaneously process the socially ambiguous stimulus of sadness while performing a working memory task that is the most challenging task for children which consequently affects working memory the most.

In sum, the present findings might indicate that the preferential attention to negative facial expressions revealed in previous research (LoBue, 2009), has an inverse effect on children's working memory. That is, what grabs attention quickly seems to be more difficult to disengage from in order to complete a working memory task successfully. Positive stimuli have been found to have an enhancing effect on cognition relative to negative stimuli (e.g., Pessoa, 2009; Qu & Zelazo, 2007), which is also the case in the present study.

Age differences in working memory for facial expressions

Although children's general recognition of facial expressions in Study 1 was not affected by age, processing emotional facial expressions in working memory did reveal age differences. Young children's working memory capacity was more limited than that of older children, which was reflected in attenuated working memory for facial expressions in the youngest age-group compared to the 11-12-year-olds. The developmental effect was present regardless of valence, possibly suggesting that negative valence pose additional challenges on working memory also into adolescence. Recent research has shown a more protracted development of so called hot (e.g., EF in situations of emotional significance) compared to cool EF (e.g., EF tasks with no emotional component) (Lagattuta, Sayfan, & Monsour, 2011; Prencipe et al., 2011). When having different facial expressions as targets for the working memory task, we were able to differentiate between the effects of different valences within this socially relevant stimulus category, and thereby investigate what develops in particular. Results showed that there was a general increase in working memory between 9-10- and 11-12-year-olds. However, consistent with Casey et al.'s (2008) hypothesis, which predicts that the dissociation between emotional processing and EF persist into adolescence, also the oldest children in the present study were struggling to accurately complete the working memory task when processing negative facial expressions compared to neutral and happy facial expressions.

Associations with emotional and behavioral problems

In line with Phillips and collaborators' (2003) model, the present findings suggest that typically developing children with higher, but non-clinical levels of emotional and behavioral problems, show additional deficits in working memory when faced with emotional stimuli. This highlights the importance of to a greater extent explore top-down processes such as working memory, and how working memory capacity interact with emotionally salient information as this approach might be one way to understand the development of more permanent psychological difficulties, as children grow older.

As mentioned in the introduction, research has shown that internalizing behavior predict the later development of mood disorders such as depression (Roza et al., 2003). Internalizing behavior was negatively associated with the ability to successfully update working memory for happy, neutral, and fearful faces, but not sad faces. However, contrary to the present findings, previous research on the interplay of emotion and cognition shows deficits in children at risk for developing depression to disengage from sad facial expressions compared to happy and fearful expressions (e.g., Joorman et al., 2007). However, internalizing symptoms have also been linked to the later development of anxiety disorders (Roza et al., 2003; Zahn-Waxler et al., 2000). Symptoms of anxiety are associated with a larger bias towards fearful expressions (Ladouceur et al., 2009). Anxiety related disorders have been found to develop at an earlier age than what is commonly reported as age of onset for depressive symptoms (Roza et al., 2003). If internalizing symptoms are in fact early precursors of the development of both anxiety and depression, fear bias might be stronger than bias to sadness in children with internalizing symptoms in the present sample due to the age range they are representing. Nevertheless, in the present study we found that having a higher degree of emotional behavior problems was associated with an amplified, negative effect of emotion on working memory. This association might suggest cognitive deficits associated with symptoms that are found to predict mood disorders (e.g., anxiety and depression) in children (Roza et al., 2003).

Caveats and future directions

Some researchers suggest different effects of threatening versus socially complex emotions on EF (Larson & Steuer, 2009; Pessoa, 2009; Sakaki et al., 2011). Future studies should more systematically try to dissociate emotional and social influences on working memory and other EF. Performing a similar cognitive task, but varying the stimuli used in the task to either represent threatening information (e.g., snakes, weapons) or social-emotional cues (e.g., facial expressions) is one way to address this. Dissociation between purely emotional and social-emotional cues may give insights to how people act in different situations, and to what degree goal-directed behavior is a function of the situational characteristics.

The present sample included children who were either in their late childhood (9-10-year-olds) or at the cusp of adolescence (11-12-year-olds). Future studies should include older children approaching the end of adolescence to study the effect of emotional stimuli on working memory. Extending the age range to include older children could allow for the identification of when adolescents become able to exert cognitive control over negative information at the same level as with neutral facial expressions. The identification of when children become able to better function in a deliberate manner also in social and emotional situations might give insights to adolescents' regulatory and goal-directed abilities in real life situations.

The present study could not detect whether children with more symptoms of internalizing and externalizing problems struggled with working memory or had higher degrees of arousal in response to the facial expressions. Both working memory, as well as emotional reactivity must be studied separately and together to further disentangle what drives the development of mood disorders.

Conclusion

In conclusion, the present findings advance the understanding of the interplay between emotion and working memory in typically developing children, and underscore the importance of jointly using emotional and cognitive tasks so as to better identify early vulnerabilities in children's emotional adjustment.

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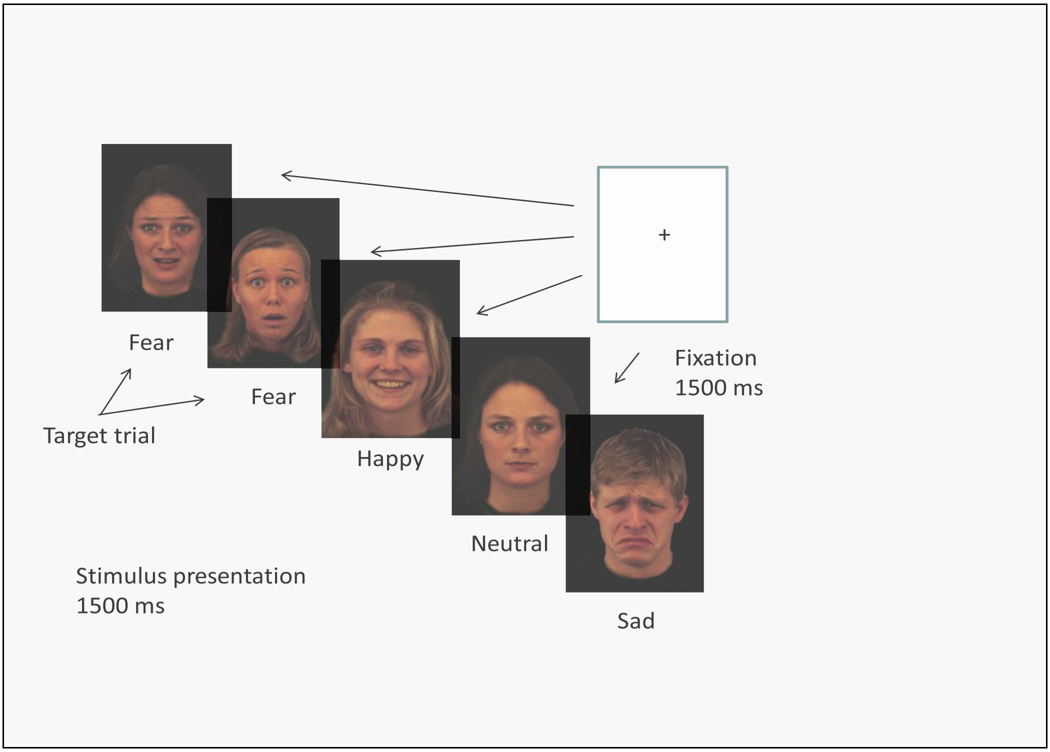

Figure 1. Illustration of the Emo-n-back stimuli and design. Children viewed each facial expression for 1500 ms and had the same amount of time to respond whether two facial expressions in a row depicted the same emotion (e.g., fear-fear).

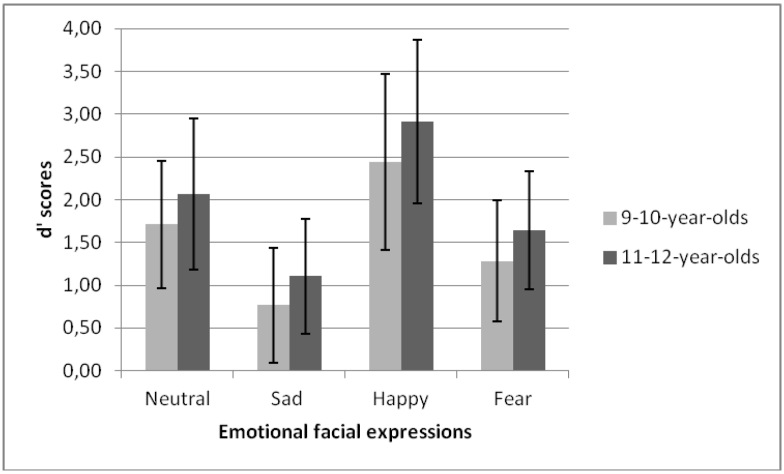

Figure 2. Mean d’ scores (standard deviation bars) on the Emo-n-back as a function of age and emotion. d’ neutral, sad, happy, and fear indicates the sensitivity with which the child discriminates between targets and non-targets on the Emo-n-back task. Higher d’ value indicates better performance.

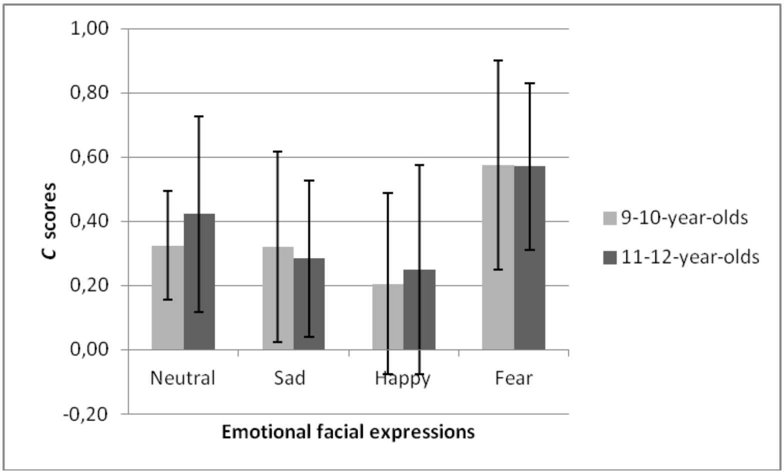

Figure 3. Mean *C* scores (standard deviation bars) on the Emo-n-back as a function of age and emotion. *C* neutral, sad, happy, and fear indicate the response criteria set by the child when performing the Emo-n-back. A score lower than 0 is liberal and a score higher than 0 is conservative.

Table 1.

Mean (standard deviation) for Unbiased Hit Rates, Arousal, and Intensity as a Function of Age and Emotional Facial Expression.

		Emotion			
		Neutral	**Sad**	**Happy**	**Fear**
Unbiased hits (%)					
	9-year-olds	76.6(24)	72.6(25)	98.0(5)	74.9(27)
	10-year-olds	80.7(17)	80.4(12)	98.5(4)	76.2(13)
	11-year-olds	83.6(17)	80.1(19)	97.6(5)	83.9(12)
	12-year-olds	85.2(20)	82.0(16)	98.4(6)	84.2(10)
Arousal					
	9-year-olds	3.47(1.6)	5.45(1.9)	4.81(2.0)	5.13(1.8)
	10-year-olds	3.52(1.7)	5.05(1.7)	5.14(2.1)	5.10(1.6)
	11-year-olds	2.25(1.1)	4.24(1.7)	4.15(2.0)	4.33(1.8)
	12-year-olds	2.85(1.4)	4.26(1.2)	4.78(2.1)	4.52(1.4)
Intensity					
	9-year-olds	6.44(1.3)	6.46(1.4)	7.21(1.1)	6.64(1.1)
	10-year-olds	6.72(1.0)	7.04(.83)	7.57(.76)	6.86(.98)
	11-year-olds	6.61(1.4)	7.18(1.1)	7.67(.82)	6.76(.86)
	12-year-olds	6.80(1.0)	6.65(1.1)	7.46(.82)	6.60(1.1)

Note. Unbiased hit rate (Wagner, 1993) are presented in percentages; Arousal scores range from 1-9, where 1 is calm and 9 is aroused; Intensity ratings indicate to what degree an emotion is expressed and varies between 1-9, where 1 is not at all and 9 is very much.

Table 2.

Means (standard deviations) on the CBCL Internalizing, Externalizing and Total Problems Scales as a Function of Age.

	9-10-year-olds	**11-12-year-olds**
CBCL internalizing	49.2(10.2)	46.4(10.6)
CBCL externalizing	45.2(8.5)	42.8(7.3)
CBCL total problems	45.3(9.0)	41.6(10.0)

Note. CBCL=Child Behavior Check List; internalizing, externalizing, and total problems symptoms continuous scales of standardized scores. Higher scores indicate more problems. Clinical cut off is a score of 63 or higher.

Footnote

[1] The reason for not using a d' measure instead is that Wagner (1993) propose limitations to d' in relation to forced choice paradigms in particular. According to Wagner (1993) signal detection theory assumes that the likelihood of choosing another option than the correct one is random, however, this is not likely to be the case in studies using non-verbal material such as facial expressions. H_u accounts for the joint probability of choosing the correct versus one of the incorrect options.

II

The Effect of Neutral and Negative Color Photographs on Children's Item Directed Forgetting.

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Abstract

Intentional forgetting is an active process relying on cognitive mechanisms (e.g., rehearsal strategies and inhibition) developing during the elementary school years. Color photographs might be rehearsed differently in memory than words, and therefore result in a different developmental pattern of intentional forgetting than previously acknowledged. Moreover, negative material is thought to be particularly reliant upon inhibitory mechanisms in order to not be encoded in memory. Thus, children's item DF might develop differently both in relation to color photographs in general and for negative pictorial stimuli in particular. The aim of the present study was to investigate item Directed Forgetting (DF) for color photographs of neutral and negative valence in sixty-five school-aged children (8-12 years of age). In the present study, a DF effect was revealed irrespective of age for neutral images as well as negative images. Results are discussed in relation to potential mechanisms underlying item DF for color photographs and how these affect development of intentional forgetting.

Keywords: item directed forgetting, color photographs, emotion, development.

The Effect of Neutral and Negative Color Photographs on Children's Item Directed Forgetting.

Intentional forgetting is considered an active process, which is thought to facilitate cognitive processes by allowing the individual to expel out-dated information from consciousness and therefore release cognitive capacity for new tasks (for a review, see Wilson & Kipp, 1998). The development of intentional forgetting is deemed highly adaptive and important for children's increasing processing capacity. To date only easily verbalized material is used as stimuli in studies on children's intentional forgetting. However, both stimulus modality and the emotions depicted in stimuli are aspects that in previous research are found to affect memory (e.g., Kensinger, 2009). For instance, complex color photographs are more strongly represented in memory than words, a phenomenon named the "picture superiority" effect (Shepard, 1967). Picture superiority is also supported in the developmental literature on picture processing and memory (Whitehouse, Maybery, & Durkin, 2006), and is evident in children as young as 7 years of age (Whitehouse et al., 2006). The picture superiority effect is likely due to a more distinct and elaborate encoding style for pictures (Dewhurst & Conway, 1994). Additionally, memory processes associated with negative stimuli are considered to be more rapid and automatic resulting in better memory for negative pictures compared to neutral (e.g., Kensinger & Corkin, 2004; Ochsner, 2000). It is likely that the memory processes described above may affect the development of intentional forgetting. The aim of the present study is therefore to explore how differently valenced picture stimuli are intentionally forgotten in school-aged children.

Directed forgetting

Directed forgetting (DF) is a widely described method by which intentional forgetting is studied (for reviews, see Basden & Basden, 1998; Bäuml, 2008). The two most commonly used DF versions are list DF (e.g., Bray, Justice, & Zahm, 1983; Harnishfeger & Pope, 1996) and item DF (e.g., Lehman, McKinley-Pace, Leonard, Thompson, & Johns, 2001; Lehman, Srokowski, Hall, Renkey, & Cruz, 2003). What distinguishes these two methods of DF is the timing of the cue to either forget or remember the item(s) presented. In the list-method, a series of words are presented consecutively before an instruction to either forget or remember the list is presented, followed by a second list of words with a new instruction to forget or remember. The item method is different in that cues to forget or remember are presented after each item presented in the test. Both in the list and item DF procedures a memory test is administered after studying the stimuli and receiving the memory instructions. What is commonly reported in both types of DF is better memory for to-be-remembered stimuli (i.e., R-stimuli) than to-be-forgotten stimuli (i.e., F-stimuli) (Bäuml, 2008).

A gradual development is reported in children's item DF (Lehman et al., 2001; Lehman, Morath, Franklin, & Elbaz, 1998). Young children tend to remember equal numbers of F- and R-stimuli in the item DF task, whereas older children (e.g., 11-year-olds) and adults remember proportionally more R-stimuli than F-stimuli in the DF task regardless of the total amount of stimuli remembered in the different age groups (Lehman, McKinley-Pace, Wilson, Slavsky, & Woodson, 1997). For instance, 1st, 2nd, and 3rd graders show DF effects in the item version, but to a smaller degree than older children and adults (Lehman & Bovasso, 1993; Posnansky, 1976). Two different explanations exist for the item DF effect; the selective rehearsal account (e.g., Lehman & Bovasso, 1993; Lehman et al., 2001) and the more recent inhibition at encoding explanation for semantically associated material in particular (Lehman et al., 2003).

According to the selective rehearsal account one withholds rehearsal of F-stimuli and encodes R-stimuli more elaborately (Lehman et al., 2001). Recent findings on children's strategy use during memory tasks in general can serve as one avenue to understand children's ability (or lack thereof) to intentionally forget. Rehearsal strategies in memory are present already in 2nd grade (Kron-Sperl, Schneider, & Hasselhorn, 2008), but the rehearsal strategy observed in young school-aged children is characterized by a less efficient approach, to rehearse one item at a time, and not cumulatively (Lehmann & Hasselhorn, 2007). The shift from using an item-by-item approach of rehearsal to be efficient in applying a cumulative rehearsal strategy is thought to take place between 9 – 10 years of age and is in part a result of children's improvement in meta-memory skills in general (Lehmann & Hasselhorn, 2007). This development in strategy use seems to underlie the development reported in children's item DF for words, as children during this period in life also show increasing and ultimately mature levels of item DF (e.g., Lehman et al., 2001; Lehman et al., 2003).

Little is known about children's nonverbal selective rehearsal and whether it differs from verbal. One recent study addressed nonverbal rehearsal using the item DF procedure with adults (Hourihan, Ozubko, & MacLeod, 2009). These researchers revealed that adults were able to rehearse without using verbal labels, although it was not possible to completely dissociate these two types of rehearsal (Hourihan et al., 2009). Another study using color photographs (Hauswald & Kissler, 2008) revealed that also pictorial information was subject to a DF effect, although this effect was smaller than for words. Thus, if selective rehearsal is sufficient in order to intentionally forget non-verbal figures (cf. Hourihan et al., 2009) and color photographs (cf. Hauswald & Kissler, 2008), children might be able to perform the item DF for images as children in the age groups included in the present study are found to successfully perform item DF for words and line drawings. If children are capable of intentionally forgetting color photographs it may indirectly inform us on whether item-by-item or cumulative rehearsal subserves children`s item DF for nonverbal information depending on the developmental trajectory revealed in the present study.

The inhibition at encoding explanation is only explored once in children using words as stimuli (Lehman et al., 2003). These researchers found that highly associated words were harder to forget when one of the words in the word-pair was cued remember and the other forget. This was interpreted as evidence for the use of inhibition at encoding in item DF, especially under conditions using highly associated words as stimuli. Lehman et al. (2003) interpreted this novel finding in light of the “inefficient inhibition hypothesis” (Bjorklund & Harnishfeger, 1990; Harnishfeger & Bjorklund, 1993). In this view, advances in memory development are explained by the increasing ability to inhibit the encoding of irrelevant information, which again releases more processing space to aid processing of task relevant information reducing interference from irrelevant information (Dempster, 1992). In relation to item DF, a more successful ability to inhibit the encoding of F-stimuli and selectively process the R-stimuli, will be associated with more adaptive and efficient memory functioning and an intended increase in the ability to intentionally forget.

Negative pictures in particular are subject to inhibition at encoding when F-cued, which is supported by the large frontal brain activation observed and reported in a recent study on item DF for neutral and negative color photographs (Nowicka, Marchewka, Jednoróg, Tacikowski, & Brechmann, 2011). According to Pessoa’s (2008, 2009) dual competition model, processing of emotional stimuli and cognitive control processes compete for the same limited neural resources. When emotional stimuli, in particular negative emotional stimuli, are presented in a cognitive task, negative information will negatively affect cognition (Pessoa, 2008, 2009). Thus, including differently valenced picture stimuli in the present study allows for a differentiation between the effects of neutral versus negative stimuli on effortful memory tasks such as intentional forgetting in children.

The present study

Color photographs as opposed to words are processed more elaborately and deeply (e.g., Dewhurst & Conway, 1994), suggesting that it should be harder to intentionally forget such information. Nevertheless, the selective rehearsal account has been identified as explaining also item DF for nonverbal stimuli (Hourihan et al., 2009). Therefore, in line with research on selective rehearsal development (Lehman & Hasselhorn, 2007) two possible outcomes could be expected in the present study; if selective rehearsal of pictures is mainly reliant upon cumulative rehearsal strategies, a significant age difference should be expected in the present experiment as cumulative rehearsal strategies are only reliably evident after 9 years of age (Lehmann & Hasselhorn, 2007). Alternatively, if an item-by-item rehearsal strategy is sufficient to achieve successful intentional forgetting, no age differences are expected.

Previous research has shown that it is harder to intentionally forget photographs of negative naturalistic scenes because the process of intentionally forgetting negative pictures in particular seems to rely on inhibition (Nowicka et al., 2011). School-aged children seem to struggle with inhibiting irrelevant information from being encoded (Dempster, 1992; Lehman et al., 2003). Thus, we predict that the ability to intentionally forget negative material will be absent in children as their inhibitory abilities are poorer than those of adults' (Wilson & Kipp, 1998).

Method

Participants

The present paper includes seventy-eight children recruited from elementary schools in a major Norwegian city. Thirteen children did not complete the DF task for various reasons (e.g., parents did not approve of their children being exposed to the pictures in the task (n=6), children themselves aborted the task before it was completed (n=2), technical issues with the computer program (n=4), severe vision disabilities (n=1)), and were therefore excluded from further analysis. The final sample consisted of sixty-five children between 8-12 years of age. Children were grouped into 2 age groups. 31 (16 girls) 8- 9-(M=8.5, SD=.57) and 34 (17 girls) 10-12-(M=11.1, SD=.88)-year-olds. The majority of the participants (n=57) represented the ethnic majority, but children with Asian (*n*=5) and other European (*n*=2) backgrounds participated as well. Information and consent forms were distributed through schools that agreed to send the letters out with their students. Families that returned a signed consent form were contacted and included in the study.

Stimuli

A set of 80 color photographs was used. Eighteen pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) were included and the remaining pictures were retrieved from the Developmental Affective Photo System (DAPS; Cordón, Melinder, Edelstein, & Goodman, 2011). Half of the pictures were neutral (e.g., landscapes, street life, and social situations) and the other half negative (e.g., wounded people, battle scenes, accidents). The 80 color photographs used consisted of 40 pairs of pictures matched on content and valence. One half of the pair was presented at study phase *and* recognition phase, where as the other picture in the pair was presented only at recognition and thereby serving as new distracters. Figure 1 depicts a sample of the pictures used in the experiment. Neutral and negative pictures differed significantly on valence $t(78)=-4.73$, $p<.001$.

Measures

Item Directed Forgetting (DF) task. The DF task conformed to the item version of the DF paradigm. The picture set at study phase consisted of 40 pictures, 20 to-be-forgotten pictures and another 20 to-be-remembered pictures. Twenty out of these 40 pictures were neutral and 20 were negative in content. Cues to remember and forget were randomly assigned to the pictures presented in the study phase so that half of the pictures were cued Forget (i.e., 20 pictures) and the other half cued Remember (i.e., 20 pictures). The 40 pictures at study phase were presented at a continuous sequence for 2000 ms each. After each picture, a signal to either forget (red circle) or remember (green circle) the picture just seen was presented for another 2000 ms. A fixation cross was presented after each forget/remember cue for another 1500 ms before the next picture was presented (see Figure 1 for an illustration of the design). All participants were instructed to try to memorize the pictures with a to-be-remembered cue (green circle) presented right after the picture, and try to forget pictures followed by a red circle (to-be-forgotten). A distracter task was then administered, lasting for about 20 minutes. Subsequently, the recognition test was administered, all 40 pictures from the study phase were presented as were 40 new matched pictures. The 80 pictures were presented in a random order for 500 ms each. Participants had to perform an old-new decision by pressing one (“1”) for old pictures and two (“2”) for new pictures on a computer keyboard. Participants were instructed to make an accurate and fast judgment as possible, but there was no time limit for the response. The DF test was programmed in E-prime, E-studio software package, version 2 (Psychology Software Tools, Inc.).

(Insert Figure 1 about here.)

Statistical analyses

Hits and false alarms were calculated for each of the four conditions respectively: neutral to-be-forgotten pictures, negative to-be-forgotten pictures, neutral to-be-remembered pictures, and negative to-be-remembered pictures. Mixed within- and between groups repeated measures analysis of variance (ANOVA) with memory instruction at encoding and picture valence varied within subjects, and age as a between subjects factor, was employed for hits and false alarms respectively. Additionally, two-high-threshold (P_r) discrimination accuracy measure was also calculated for the four dependent measures described above (Snodgrass & Corwin, 1988). This is a measure of the accuracy with which participants were able to distinguish old from new pictures at recognition, and was calculated based on hits and false alarms using Snodgrass and Corwin's (1988) formula, [P_r=H-FA][1]. Similarly, the response criterion, B_r [B_r=FA/1-Pr], was calculated to assess the response bias applied by children in the present experiment. A value above 0 indicates that children are more prone to respond "yes", whereas a value below 0 is equivalent to a higher tendency to say "no" to whether one has seen a stimulus before. Again, mixed within- and between groups repeated measures ANOVA is reported for the two latter response measures P_r and B_r. Results with a p=.10 or below will be reported and commented on.

Results

Preliminary results

There were no significant differences based on gender or ethnicity on either of the dependent DF measures. Thus, gender and ethnicity is not further considered in the analyses.

(Insert Table 1 about here.)

DF, emotion, and age

Recognition performance. Hits and false alarms were entered separately into the 2(Instruction; forget vs. remember) X 2(Emotion; neutral vs. negative) X 2(Age; 8 - 9 years vs. 10 -12 years) repeated measures ANOVA. For hits, a main effect of instruction was revealed, $F(1,63)=8.1$, $p<.01$, $\eta_p^2=.11$. Planned comparisons with Bonferroni correction, revealed that memory for R-pictures were enhanced compared to the recognition memory for F-pictures ($p<.01$). A significant main effect of emotion emerged, $F(1,63)=15.3$, $p<.01$, $\eta_p^2=.20$. Planned comparisons with Bonferroni correction revealed a significantly higher proportion of hits to negative pictures compared to neutral photographs ($p<.01$). Lastly, a trend of an instruction and emotion interaction was also evident, $F(1,63)=3.1$, $p=.08$, $\eta_p^2=.05$. Post-hoc t-tests revealed that only neutral pictures enjoyed a significant DF effect $t(1,64)$=-

[1] Note that calculations of hits and false alarms are corrected according to Snodgrass and Corwin's (1988) recommendation before used in the calculation of P_r and B_r.

3.1, p<.01, compared to negative pictures, $t(1,64)=-.76$, n.s.. No main or interaction effects of age emerged.

For false alarms, only a significant main effect of emotion was revealed, $F(1,63)=25.1$, p<.01, $\eta_p^2=.29$. Planned comparisons with Bonferroni correction, revealed a significantly higher proportion of false alarms to negative compared to neutral photographs (p<.01). No other main or interaction effects were significant.

Discrimination accuracy and response bias. Similar to the hits and false alarms analyses, P_r, was entered into a 2(Instruction; forget vs. remember) X 2(Emotion; neutral vs. negative) X 2(Age; 8 - 9 years vs. 10 -12 years) repeated measures ANOVA. Analysis revealed a main effect of instruction during study phase, $F(1,63)=6.2$, $p=.02$, $\eta_p^2=.09$. Planned comparisons with Bonferroni correction, revealed that memory accuracy for R-pictures were enhanced compared to memory accuracy for F-pictures (p<.01). The between-subjects factor age came out significant, $F(1,63)=4.0$, $p=.05$, $\eta_p^2=.06$, indicating that older children had a more accurate memory than the younger age group. No other significant main or interaction effects were revealed for discrimination accuracy.

Lastly, a repeated measure ANOVA similar to the one described above was employed, entering the response bias criterion (B_r) set by the child when responding at the recognition test as our dependent measure. Analysis revealed a main effect of emotion, $F(1,63)=46.5$, p<.01, $\eta_p^2=.42$, post-hoc planned comparisons with Bonferroni corrections revealed that children were more conservative when responding to neutral items compared to negative items (p<.01). No other main or interaction effects emerged.

Discussion

Remember cued pictures yielded higher hit rates compared to F-cued pictures, and children's DF did not increase as a function of age. For hit rates, a trend indicating an instruction and emotion interaction was revealed, this interaction suggested DF for neutral, but not negative color photographs. Negative pictures enjoyed a higher hit rate than neutral pictures. However, negative pictures were falsely endorsed as old to a higher degree than neutral pictures.

Analyses using calculations of discrimination accuracy as the dependent variable revealed a somewhat different pattern. In line with predictions, instructions to forget and remember at encoding significantly influenced children's accuracy at recognition. However, the previously reported interaction between instruction and emotion was completely absent. Additionally, 11-12-year-olds had a more accurate overall memory compared to the 8-10-year-olds, regardless of instruction or emotion. Analysis of response bias showed that negative pictures were more liberally endorsed as "old" compared to neutral pictures.

Age and DF

Regardless of the picture superiority effect (Whitehouse et al., 2006), we demonstrated that the DF effect was present also for children when using photographs. From the selective rehearsal account, one might have speculated that children would process the pictures deeply before receiving the instruction to forget or remember, and thereby eliminating the DF effect. However, this was not the case for children, and consistent with what has been reported for adults (Hauswald & Kissler, 2008).

The present lack of age differences in intentional forgetting might be understood through children's rehearsal strategies and how rehearsal strategies develop. Pictures are more vividly represented in memory (Dewhurst & Conway, 1994; Whitehouse et al., 2006) and simple item-by-item rehearsal as opposed to cumulative rehearsal (Lehmann & Hasselhorn, 2007) might be sufficient to commit to-be-remembered pictures to memory. As such, item DF for color photographs might be more reliant upon an already established rehearsal strategy in school-aged children, not capturing the developmental changes taking place in encoding strategies and intentional forgetting commonly reported in studies on children's DF for words (e.g., Lehman et al., 1997, 2001, 2003). The present findings suggest that quite early in life children become efficient at selectively rehearsing picture stimuli that are rich on information. Intuitively one would maybe expect that color photographs are harder to forget than words, as discussed in relation to the picture superiority effect. However, one might speculate that through experience, children are more used to filter pictorial information as relevant or irrelevant compared to their rehearsing experience with lexical information.

In sum, the implication of the present finding is a closer understanding of children's intentional forgetting of color photographs, and how this map onto memory strategy development as reported in other research (e.g., Lehmann & Hasselhorn, 2007). The absence of an age by DF interaction suggest that intentional forgetting of color photographs require a rehearsal strategy that has developed already by the age of eight, as the developmental trajectory is different in the present study compared to other item DF studies using words and easily verbalized line drawings as stimuli (Lehman et al., 2001, 2003).

DF and negative color photographs

A trend in the main analysis and significant post-hoc tests suggested that negative pictures seemed to impose additional demands on children's intentional forgetting by eliminating the DF effect for this group of pictures. For pictorial information a similar pattern is found in adults (Hauswald, Schulz, Iordanov, & Kissler, 2010). Thus, it might be that negative valence is associated with attenuated item DF effects. However, when using the more conservative discrimination accuracy measure a different picture was painted. This approach revealed equal rates of intentional forgetting of both neutral and negative color photographs. This finding suggests that children's level of inhibition during elementary school-years might be sufficient to inhibit the encoding of negative to–be-forgotten items. Inhibitory function vary as a function of task difficulty (Huizinga, Dolan, & van der Molen, 2006; Wilson & Kipp, 1998), and the present item DF task might have been at a level where children between 8-12 years were able to perform according to task requirements.

Emotion and memory

The enhanced recognition of negative picture stimuli compared to neutral is in line with previous research especially when using non-verbal stimuli (Talmi, Schimmack, Paterson, & Moscovitch, 2007). However, measures of discrimination accuracy revealed no significant difference in memory for negative compared to neutral pictures. Although previous research has shown an advantage in memory for negative stimuli (e.g., Kensinger & Corkin, 2004; Kensinger, Garoff-Eaton, & Schacter, 2006), other studies have reported a similar pattern of recognition memory as revealed in the present study (Windmann & Kutas, 2001).

A higher false alarm rate for negative pictures was also revealed. This finding adds to the recent literature reporting an impairing effect of negative valence on recognition memory in particular by increasing false memory (Hauswald et al., 2010; Howe, Candel, Otgaar, Malone, & Wimmer, 2010; Nowicka et al., 2011). Children's heightened false alarm rate for neutral information has been found to be associated with immature inhibitory functions (Ruffman, Rustin, Garham, & Parkin, 2001). In line with for instance Pessoa's (2008, 2009) model, children might struggle when integrating emotional information into cognitive tasks as the two processes compete for many of the same neural resources.

Another, but still related explanation to the higher proportion of false alarms in response to negative pictures, and the present absence of a superior memory for negative pictures, is the liberal bias often applied when responding to negative stimuli in a recognition task (Kapucu, Rotello, Ready, & Seidel, 2008). According to the bias explanation, it is not memory processes per se which account for the enhanced memory for negative information, but rather the greater likelihood of endorsing items as old relative to new in a recognition test

(Dougal & Rotello, 2007). The present results indicate that children had a less conservative bias in response to negative pictures compared to neutral ones. The consequence of such a response bias is the heightened likelihood for increasing both hits and false alarms. According to Windmann and Kutas (2001) the lenient criterion set when responding to negative information in a recognition memory task might serve as a reassurance not to miss relevant and threatening information. In addition, the liberal bias is associated with inhibitory functioning (Windmann & Kutas, 2001). In the present study, children were poorer at inhibiting their response to negative emotional information relative to neutral pictures, which is reflected in their liberal bias to negative pictures in particular.

Conclusion and Future Research

The present study adds to the developmental DF literature by showing that item DF has an effect also for color photographs. The present findings suggest that children are capable of intentionally forgetting images, and that picture stimuli seem to be equally forgotten across age. Contrary to expectations, children did intentionally forget negative color photographs as well. Although the present study did reveal patterns of intentional forgetting for neutral and negative images respectively, it did not include any measures directly assessing children's strategy use in memory tasks with pictures. Inclusion of such a measure could inform us on the underpinnings of the development of selective rehearsal as it relates to item DF for color photographs. Future research should carefully design item DF experiments allowing for a closer investigation of strategy use and executive functions underpinning children's intentional forgetting for different types of pictorial stimuli

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Table 1.

Means (and Standard Deviations) of P_r, B_r, proportions of hits and proportions of false alarms on the item Directed Forgetting task.

	Age	
	8-9-year-olds	10-12-year-olds
P_r		
F negative	.58(.20)	.66(.21)
F neutral	.55(.20)	.61(.18)
R negative	.61(.20)	.67(.19)
R neutral	.61(.23)	.70(.18)
B_r		
F negative	.42(.21)	.42(.18)
F neutral	.29(.20)	.26(.21)
R negative	.41(.22)	.43(.17)
R neutral	.31(.17)	.31(.17)
Hits		
F negative	.78(.17)	.83(.15)
F neutral	.69(.21)	.71(.21)
R negative	.79(.16)	.85(.12)
R neutral	.75(.22)	.79(.19)
False Alarms		
F negative	.16(.14)	.12(.09)
F neutral	.10(.07)	.07(.04)
R negative	.14(.11)	.13(.10)
R neutral	.09(.08)	.08(.07)

Note. F negative, negatively valenced pictures cued forget; F neutral, neutral valenced pictures cued forget; R negative, negatively valenced pictures cued remember; R neutral, neutral valenced pictures cued remember; *Pr* is an index of discrimination accuracy, higher value indicates better ability to discriminate between "old" and "new" items in a recognition memory task; *Br* is an index of response criterion set by the respondent. A score above 0 is considered a conservative response bias and a score below 0 is considered liberal.

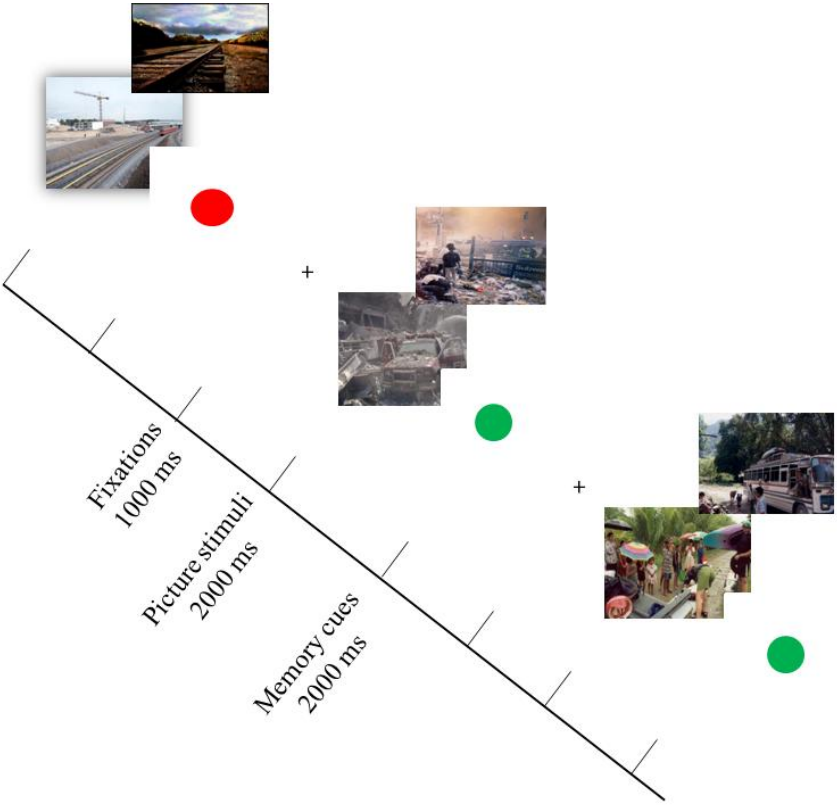

Figure 1. Study design and sample of stimuli used in the Directed Forgetting task. Red and green circles depict memory cues, forget and remember respectively. One of the two pictures in each pair depicted was only presented at recognition serving as a distracter.

III

Maltreatment is Associated with Specific Impairments in Executive Functions: Insights from Differential Testing

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Abstract

Child maltreatment is associated with a host of adverse consequences. However, few studies exist that map maltreated children's performance on neurocognitive tests particularly sensitive to brain and behavior associations. The aim of the present study was to investigate whether maltreated children (*n*=21) differed in their executive functioning compared to their non-maltreated peers (*n*=22). Tasks aimed at measuring set shifting, spatial working memory (SWM), and inhibition from the Cambridge Neuropsychological Automated Test Battery and the Delis-Kaplan Executive Function System were administered. Trauma-related symptomatology and general emotional and behavioral adjustment was assessed. Maltreated children performed significantly poorer compared to their non-maltreated peers on the SWM task, in particular SWM strategy. No differences were revealed between the two groups on measures of set shifting and inhibition. Symptoms of psychopathology were not significantly related to performance on the executive functions tests. The present results suggest an association between maltreatment-related stress and SWM strategy.

Keywords: child maltreatment, executive functions, stress, psychopathology

Maltreatment is Associated with Specific Impairments in Executive Functions: Insights from Differential Testing

Recent reviews have identified the importance of studying the brain-behavior association in maltreated children who live under stressful conditions (e.g., Knudsen, Heckman, Cameron, & Shonkhoff, 2006; Lupien, McEwen, Gunnar, & Heim, 2009; Shonkoff, 2011). Child maltreatment represents a long lasting stressful context characterized by acts of commission and omission from attachment figures. It includes physical and sexual abuse, as well as general and emotional neglect (Bottoms et al., 2008). Several domains of development are negatively affected by child maltreatment, ranging from disturbed brain functions to deficits in behavioral, cognitive, and emotional regulation (for recent reviews see, Mulvihill, 2005; Watts-English, Fortson, Gibler, Hooper, & De Bellis, 2006). The life cycle model of stress (Lupien et al., 2009) identifies children from the age of 8 and in to early adulthood at a developmental stage where the stress system is vulnerable. Moreover, the prefrontal cortex (PFC) is particularly prone to be affected by stressors in the environment during this age (Lupien et al., 2009). The PFC has a protracted development into young adulthood (Giedd et al., 1999), and is largely subserving executive functions (EF) (Sowell et al., 1999; Sowell, Trauner, Gamst, & Jernigan, 2002).

EF may be defined as the skills essential for purposeful, goal-directed activity (Anderson, 1998). Miyake et al. (2000) proposed a model of EF, comprising *shifting* between mental sets or tasks, *updating* and monitoring of information in working memory, and *inhibition* of dominant responses. These three sub-sets of EF are inter-related but also meaningfully dissociable abilities (Miyake et al., 2000). EF have been related to increments in academic achievements in general (e.g., Ardila & Rosselli, 1994; Bull & Scerif, 2001; Gathercole & Pickering, 2000), memory functioning (e.g., Davidson, Amso, Anderson, &

Diamond, 2006; Ruffman, Rustin, Garnham, & Parkin, 2001), as well as in regard to socio-emotional functioning (e.g., Calkins & Bell, 2010; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006).

EF has been examined in maltreated children (Beers & De Bellis, 2002; DeBellis, Hooper, Spratt, & Woolley, 2009; DePrince, Weinzierl, & Combs, 2009; Pears & Fisher, 2005). In a sample of individuals with maltreatment related posttraumatic stress disorder (PTSD), Beers and DeBellis' (2002) and DeBellis et al. (2009) found a negative association between maltreatment and abstract reasoning/EF and attention when using neuropsychological tests (NEPSY; Korkman, Kemp, & Kirk, 2001). Although a maltreatment-related PTSD diagnosis was associated with the most severe EF deficits, also maltreated children without PTSD performed poorer than non-maltreated controls. In a study of a community sample of school-aged children, DePrince and colleagues (2009) reported a significant association between familial-trauma exposure and poorer performance when assessing EF as a composite of different cognitive tests. Similar negative associations between EF and maltreatment experiences were reported in pre-schoolers who had been removed from their biological parents by the child protective services (CPS) and placed in foster care already by the age of three years, suggesting an early detrimental effect of maltreatment on EF (Pears & Fisher, 2005). In spite of the general tendency that maltreatment and poorer performance on EF tasks are highly associated, we do not know if there is a specific (executive) function that is mostly affected by maltreatment. The aim with the present study was thus to differentiate between the three main aspects of EF (e.g., set shifting, inhibition, and working memory; Miyake, et al., 2000).

A more differentiated approach to EF is important when examining individuals who have endured stressful life experiences. For instance, hypothalamic-pituitary-adrenal (HPA) axis reactivity, which is affected by stress (e.g., Lupien et al., 2010), has been found to be closely related to EF (Blair et al., 2005). The right PFC and EF associated with right hemispheric cortical areas are particularly vulnerable to psychological stressors in adults (Davidson & Irwin, 1999; Shackman et al., 2006), and the adverse effects of stress on the right PFC are documented in children as well (e.g., Davidson, 1994; Loman & Gunnar, 2010). One explanation to this stress-EF association is suggested by the dual processes perspectives on neurocognitive functioning (e.g., Klingberg, 1998; Bunge, Klingberg, Jacobsen, & Gabrieli, 2000). These models propose that affective stressors will consume mental capacity, as expressed by higher right PFC activation, in order to regulate arousal experienced by the individual. Consequently, due to a competition for neural resources between arousal regulation and cognition, EF tasks relying on right PFC functioning will be particularly affected (Shackman et al., 2006).

Research on maltreated children have also identified this group of children at a heightened risk for developing psychopathology, such as symptoms of depression, anxiety, and PTSD to name a few (MacMillan et al., 2001; Cicchetti & Toth, 1995). In addition, emotional-behavior problems such as externalizing and internalizing behaviors are highly associated with child maltreatment (Appleyard, Egeland, VanDulmen, & Sroufe, 2005). Children’s internalizing and externalizing behaviors have been linked to alterations in EF (Murray and Kochanska, 2002), fitting well with the assumption that impaired EF is associated with emotion-regulation problems (Phillips, Drevets, Rauch, & Lane, 2003; Rueda, Posner, & Rothbart, 2005). Thus, there may at least be two routes through which the effect of maltreatment might affect EF in maltreated children. Either through the direct effect of maltreatment related stress on PFC development and functioning (Davidson, 1999; Loman & Gunnar, 2010). Alternatively, the effect of maltreatment could indirectly affect the right PFC through the development of maltreatment related psychopathology such as anxiety, which is also associated with elevated activation in the right PFC and impairments in EF (Hane & Fox 2006; Penza, Heim, & Nemeroff, 2003; Shackman et al., 2006).

Assessing set shifting, working memory and inhibition separately may be one step towards a more differentiated understanding of underlying neurocognitive deficits related to specific difficulties maltreated children report. The present study was therefore designed to investigate the associations between child maltreatment and EF as it pertains to set shifting, working memory, and inhibition. If any differentiation should be revealed in the present study due to the above-mentioned stress-right PFC association, it would most likely to be reflected in poorer SWM functioning in the maltreated children compared to their peers. Likewise, we expected maltreated children to evince higher symptom scores on measures of psychopathology compared to the non-maltreated contrast group, and that behavioral problems would be associated with worse EF above and beyond what would be expected from maltreatment alone.

Method

Participants

Forty-four 8-12-year-olds were recruited to participate in the research project. Two children were excluded from the final sample due to an IQ score of 70 or below. Another two children were excluded from the main analysis and out of these two one child was excluded from the SWM analysis and another from the IED analysis due to technical difficulties with the computer program. The final sample therefore consisted of twenty-one (14 girls; M_{age}=9.5, *SD*=1.5) children who had experienced maltreatment (e.g., physically abused *and* witnessed violence (23.8%), witnessed domestic violence (61.9%), or neglected (14.3%)) and were recruited through the CPS and domestic violence shelters. Another 22 (15 girls; M_{age}=9.6, *SD*=1.5) children served as the contrast group (non-maltreated) and were recruited through schools in the same areas as children who had endured maltreatment. Parents of children in the non-maltreatment group were asked to report if their child had experienced any known maltreatment. Children in the maltreatment group were from diverse ethnic backgrounds, 11 were Europeans, whereas ten were of a Middle-Eastern and African descent. Children in the non-maltreatment group were mainly of a European descent (*n*=16), but a few had also Middle-Eastern (*n*=5) or Asian (*n*=1) backgrounds. Children in the two groups were matched on IQ in order to rule out the effect of IQ on EF task performance. Age was also a factor on which children were matched. All children participating in the study spoke Norwegian fluently. Families that returned a signed consent form were contacted and included in the study.

Neuropsychological tests

Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999). The WASI provides a brief estimate of intelligence that is normed for the ages 6 through 89 years. The WASI consists of four subtests; vocabulary, block design, similarities, and matrix reasoning. In the present study, only vocabulary and matrix reasoning was administered. The primary variable of interest was the combined standardized score of the two subtests vocabulary and matrix reasoning.

Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, 2006). CANTAB has reached high validity in measuring the different components of EF (Fray, Robbins, & Sahakian, 1996; Robbins et al., 1998; Sahakian & Owen, 1992), also in children (DeLuca et al., 2003; Luciana & Nelson, 2002). In particular CANTAB has been considered as particularly sensitive to brain-behavior associations (Luciana & Nelson, 2002). The tests used in the current paper are the Spatial Working Memory (SWM) test and the Intra/Extradimensional Set Shift (IED) task.

The *SWM test* measures updating and monitoring in working memory. The screen displays a number of boxes. The participant has to find blue, squared tokens in each box.

Gradually, the number of boxes increases from three to eight. Touching a box where the participant already has found a token is considered an error. The participant decides the order in which each box is visited. The variables of interest for the current paper were total errors and strategy. Total errors reflect the number of errors obtained on the SWM task (i.e., number of times revisiting boxes that already had had a hidden token behind it). Hence, low score on the SWM indicates good working memory (i.e., fewer errors). The SWM strategy variable indicates whether the participant uses an efficient strategy to remember where blue tokens were previously found. A high score on this variable represents poor use of an efficient strategy.

The *IED task* is designed to assess set shifting abilities. In the IED task the subject is presented with two simple, color-filled shapes. The subject must learn which of the two stimuli is correct by touching it, and continue to do this until the criterion is reached. During the task, a dimensional shift is imposed, that is, for the answer to be correct the participant has to be able to differentiate between the color-filled shapes and white lines drawn on or next to the shapes. Both general set shifting as indexed by the number of errors prior to the extradimensional shift (i.e., Pre-ED errors) and number of errors on the extradimensional shift (i.e., EDS errors) variables as well as stages reached (i.e., 1-9) are included in the present study. Higher scores on the error measures indicate poorer IED, whereas a higher score on the IED stages measure is indicative of better IED performance. Thus, the IED strategy measure was reversed for the purpose of analysis.

Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference Test (Delis, Kaplan, & Kramer, 2001). The D-KEFS color-word interference test is similar to the Stroop task, characterized by inhibiting prepotent responses to read color words, and instead name the color in which each word is printed. The D-KEFS color-word interference test consits of a set of four cards, beginning with the two screening cards to name colors and to read color names respectively. The actual test is first to inhibit the natural response to read words instead of naming colors, followed by the fourth and last task to switch between mental sets of either naming the colors in which words are printed or read the color words. Thus, switching between two different sets of rules. In the present study, mean scaled scores on number of errors on the 3rd condition, inhibiting automatic responses, the associated response time measure for this condition, and the contrast time score are used as an index of inhibition. The contrast score is a measure based on the discrepancy between the second condition word reading and the inhibition condition 3. It is considered a measure that accounts for the participants' general level of reading fluency, and as the condition that measures inhibition in particular (Delis et al., 2001). Raw scores were age normed before included in analyses.

Trauma symptomatology assessment

Trauma Symptom Checklist for Young Children (TSCYC; Briere et al., 2001). The TSCYC is a 90-item parent-report measure on children's trauma- and abuse-related symptomatology. Responses were given on a 4-point scale ranging from "never" to "almost all the time", and the respondent was asked to only consider the child's behavior during the last month. Eight clinical scales are derived from the checklist as well as two reporter validity scales. Of interest in the present study were standardized t-scores on clinical symptom scales associated with common psychological sequelae after child maltreatment, post-traumatic stress-total (PTS-TOT), Dissociation (DIS), Anxiety (ANX), Depression (DEP). A higher score on either scale is associated with more symptoms on problems associated with these categories. Clinical scales on the TSCYC have all reached good reliability (Cronbach's α=.87-.93).

Child Behavior Checklist/6-18 (CBCL; Achenbach & Rescorla, 2001). The CBCL is administered to parents asking them to rate their children's social, academic, behavioral strengths and weaknesses. Out of several types of scales indicating the presence of psychiatric symptoms above or below a clinical cut off, the present study is based on standardized t-scores from the three scales *internalizing* (i.e., anxious/depressed, withdrawn/depressed, somatic complaints), *externalizing* (i.e., rule-breaking behavior and aggressive behavior) and the combination measure *total problems* (i.e., internalizing symptoms, externalizing symptoms and other problems such as for instance wet self, overweight, sleep disturbance, whining). A higher score on either scale is associated with more symptoms on problems associated with these categories. All three scales have reached good reliability (Cronbach's α=.90-.97).

Procedure

Parent and child met the researcher once, and testing was carried out in a quiet room without the parent present during testing. The order of administration of the CANTAB measures and the D-KEFS color-word interference task was counter balanced. WASI was administered for matching purposes and completed prior to all other neuropsychological tests in the procedure. The TSCYC (Briere et al., 2001) and CBCL (Achenbach & Rescorla, 2001) measures were administered to the parent for screening purposes. The study was carried out in accordance with the Helsinki Declaration and was approved by the regional ethic committee (REK sør-øst).

Statistical Analysis

Chi-square analysis and one-way analysis of variance (ANOVA) were carried out to investigate differences between the two groups on demographic variables such as gender and ethnicity. Additionally, trauma related psychopathology was assessed and differences between the maltreated and non-maltreated children on these variables were investigated also using one-way ANOVA. To explore the association between neuropsychological functioning and trauma-related psychopathology, Pearson's correlations were employed. In the case of significant correlations the significant symptomatology measures were included in the main analysis as covariates. As reported above, each of the neurocognitive measures consisted of several variables measuring different aspects of working memory, set shifting and inhibition abilities respectively. To explore group differences on the main neurocognitive variables all variables were standardized using Z scores and subsequently sub variables addressing same executive function were combined into one mean Z score each. First, three univariate ANOVAs were carried out entering separately three mean scores; SWM, IED, and inhibition as dependent variables. Fixed factor comprised the group of maltreated and non-maltreated children respectively. If any significant differences between the groups emerged on any of the mean variables, separate univariate ANOVAs were carried out to investigate the specific associations between maltreatment status and the different neurocognitive sub-variables. Only results significant on a p=.05 or below will be reported and commented upon.

Results

Demographic, psychometric, and clinical characteristics

Chi-square analysis revealed no significant difference on ethnic origin between the two groups, and ethnicity was therefore not considered in any further analysis investigating group differences. To assess differences on symptoms of trauma-related psychopathology, a one-way ANOVA was carried out on all relevant variables from the TSCYC and CBCL. As reported by the parent, children in the maltreatment group had significantly more problems on all symptom scales included from both the TSCYC and CBCL, as compared to the contrast group (Fs(1,33-1,39)= 12.5-4.1, ps<.05) (see Table 1). Gender differences were also explored using a one-way ANOVA, however, no significant gender differences were revealed on either the neuropsychological measures or the trauma related psychopathology measures included in the present study. Thus, gender will be collapsed across all analysis. In addition, a one-way ANOVA was carried out to investigate any significant associations between group and general cognitive functioning (i.e., WASI). There was no significant difference in IQ scores between the maltreated (*M*=89.1, *SD*=10.9) and non-maltreated (*M*=95.7, *SD*=10.6) children. Lastly, to assess potential associations between psychiatric symptoms and the dependent measures on EF, correlations were performed between variables on the TSCYC, CBCL and EF measures. None of the symptom scales included in the present paper correlated significantly with any of the EF measures. Thus, symptom scales are not included in any further analysis.

(Insert Table 1 about here.)

Performance on EF tasks

SWM variables. Significant group differences were revealed on the SWM measure, $F(1,40)=4.20$, $p=.05$, $\omega^2=.07$, when the SWM mean score was entered as the dependent variable. Maltreated children performed significantly poorer on this measure compared to the non-maltreated children (see Table 1; $p=.05$, $r=.31$).

Furthermore, a significant main effect of group was revealed in relation to the SWM strategy adopted by the children, $F(1,40)=5.70$, $p=.02$, $\omega^2=.12$. Post-hoc comparisons revealed that maltreated children showed significantly poorer performance on the strategy use than their non-maltreated peers (see Table 1; $p=.02$, $r=.36$).

No significant group differences were revealed when employing a univariate ANOVA to assess group differences on the SWM error score.

IED variables. No significant group differences were revealed on either the IED mean score or any of the sub scales on which the mean IED score is based.

Inhibition variables. No main effects of group were found in relation to the mean score on the inhibition variable.

Discussion

Maltreated children showed impaired SWM, in particular SWM strategy, compared to the contrast group. However, differences in EF between the two groups were not global, as performance on the set shifting and inhibition measures did not significantly differ between maltreated and non-maltreated children. Former studies on maltreated children's neurocognitive functioning have reported associations between maltreatment and general cognitive deficits. Compared to previous studies, the present findings, paint a more nuanced picture of the association between maltreatment and EF. Although maltreated children had significantly higher scores on all measures of psychopathology included in the present study compared to their non-maltreated peers, psychopathology was not significantly associated with EF in the present study. Thus, the present results suggest a direct association between maltreatment and specific neurocognitive deficits.

The present maltreatment and SWM association could be explained through the abnormal neuroendocrine regulation associated with maltreatment, reflected through HPA axis dysregulation (e.g., Bremner, 2003; Bremner et al., 2003; Cicchetti & Walker, 2001). Other research examining EF on groups of individuals suffering from conditions that are associated with HPA axis dysregulation (e.g., self-injurous behavior, chronic fatigue syndrome) have also reported impaired SWM in these clinical populations (cf. Fikke, Melinder, & Landrø, 2011; Joyce, Blumenthal, & Wessley, 1996; Wolf, 2008). Thus, biological and neurological alterations due to stress seem to have subsequent impairing effects on cognition, particularly functions such as SWM, perhaps due to its heavy reliance on the right hemisphere cortical areas (Shackman et al., 2006).

At present it is premature to conclude about the neurobiological underpinnings of reduced SWM capacity in maltreated children. However, the present findings suggest that working memory tasks are particularly prone to be affected by maltreatment experiences. Importantly, in the present study, only working memory strategy was negatively associated with maltreatment. This finding indicates that children who had endured maltreatment were not having more errors in working memory, but using a poorer strategy to complete the task than the non-maltreated children. This finding implies that maltreated children need to use more cognitive efforts to complete working memory tasks at the same level as their non-maltreated peers. In addition, the strategy measure of the CANTAB SWM is more sensitive in detecting individual differences (Luciana, Conklin, Hooper, & Yarger, 2005). Moreover, empirical studies and theoretical work converge on the finding that stress has an impairing effect on working memory dependent processes in general (cf., DeBellis et al., 2009; Hasher & Zacks, 1979), and spatial working memory in particular (Shackman et al., 2006).

However, no significant differences were revealed between maltreated children and their non-maltreated peers on the inhibition and set shifting measures. This might be due to at least two factors. Two types of inhibition have been suggested in the literature, behavioral and cognitive inhibition (Harnishfeger, 1995, but see Aron, 2007). The color-word interference task used as an inhibition measure in the present study is considered as representing the latter category of inhibition, and it might well be that children who have endured maltreatment only show deficits in behavioral inhibition and not cognitive. As revealed in the present study, children with reported maltreatment experiences showed more behavior problems, such as externalizing and internalizing behaviors. Thus, this finding might suggest that using a different measure of inhibition, better capturing behavioral deficits of inhibition, than presently done could have revealed significant differences between groups in the present sample. Second, sample sizes are small. This study is a first attempt to understand specifically what maltreated children struggle with on a neurocognitive level by use of specific brain-behavior sensitive measures (cf. Luciana & Nelson, 2002). Power calculations suggest medium to high power to detect actual differences in the present sample, hence, the present effect sizes should not be ignored (Field, 2009). Larger samples could have revealed additional differences between the groups, and future studies should attempt to address this proposition by adding more participants.

The present study did not reveal a significant relationship between measures of psychopathology and EF. Previous research on maltreated samples has revealed that EF is associated with maltreatment related psychopathology (Beers & DeBellis, 2002; DeBellis et al., 2009). What differed the present sample from previous samples of maltreated children were that in the present study children were not recruited based on their psychological functioning, whereas in Beers and DeBellis (2002) and DeBellis and colleagues (2009) specifically included children suffering from maltreatment related PTSD. Thus, the sub-clinical nature of the present group of maltreated children might be one explanation to the lack of significant associations between psychopathology and EF. Another possible explanation for the lack of associations between psychopathology and EF is that parents in the present study provided the ratings of their children's behavior. Parents as informants might be less reliable than other raters (Treutler & Epkins, 2003; Yongstrom, Izard, & Ackerman, 1999). Nevertheless, the present study revealed that children's life experiences may shape their neurocognitive functioning irrespective of psychological problems.

Overall, differences in the present study compared to previous studies might be explained by how maltreatment was defined. Literature on the present topic has to date focused on pre-school aged children removed from their maltreating caregivers and placed in foster care (Pears & Fisher, 2005), used large community samples of children exposed to non-specified, familial trauma (De Prince et al., 2009), or focused mainly on children suffering from maltreatment related PTSD (Beers & DeBellis, 2002). The present sample of maltreated children were all living with their biological parents, they were specifically targeted through CPS and domestic violence shelters or reported that they received assistance through the CPS. As the majority of children referred to the CPS in Norway are living with their biological parents (Statistics Norway, 2011), it seems paramount to study this group of children and to better understand the behavioral correlates of living in families characterized by higher levels of stress.

From a clinical perspective it is important to note that maltreated children not always demonstrate behavior difficulties (e.g., internalizing or externalizing symptoms), or score at a clinical level on trauma checklists, but still struggle with neurocognitive functions subserving important abilities in children's everyday life. Thus, the present finding highlights the importance of being aware of underlying mechanisms of maladaptation in maltreated children. As a consequence, several avenues of assessment should be implemented when clinicians evaluate maltreated children's functioning. Moreover, EF in general and SWM functions in particular can be improved both on a neurological and behavioral level through intensive and structured training (e.g., Diamond, Barnett, Thomas, & Munro, 2007; Holmes, Gathercole, & Dunning, 2009; for a recent review see, Diamond & Lee, 2011). Therefore, identifying specific patterns of neurocognitive functioning can help practitioners intervene at an early stage and target training programs.

The present study employed Miyake et al.'s (2000) model to explore the association between specific EF and rearing conditions (i.e., maltreatment vs. non-maltreatment). However, we were not able to link EF to other domains of these children's life, such as for instance school performance or emotion regulation. Research on maltreated children should use larger samples to further investigate the implications of the present findings on maltreated children's general functioning. Additionally, future studies should aim at further unraveling the biological, neurological, as well as neuropsychological patterns associated with child maltreatment, conjointly. Moreover, attenuation of neuropsychological problems through training should be thoroughly explored in groups of maltreated children so as to minimize negative long-term sequelae associated with child maltreatment.

In conclusion, the present study revealed that maltreatment is not associated with a global deficit in EF, but rather specifically associated with SWM.

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Table 1

Means (standard deviations) on neuropsychological measures and symptom scales for maltreated and non-maltreated children.

	Maltreated (*n*=21)	**Non-maltreated (*n*=22)**
IED		
IED mean score	8.7 (3.7)	7.8 (3.8)
Pre-ED errors	8.6 (4.8)	7.8 (2.9)
EDS errors	15.5 (11.1)	14.1 (10.3)
Stages completed	7.6 (1.9)	8.4 (0.9)
SWM		
SWM mean score	38.2 (11.1)	31.0 (15.1)
Errors	40.2 (19.7)	31.9 (21.7)
Strategy	36.3 (3.6)	30.1 (11.1)
Inhibition		
Inhibition mean score	10.9 (2.3)	10.2 (1.4)
Time	10.6 (2.5)	9.9 (2.6)
Errors	10.9 (2.5)	10.5 (2.4)
Contrast	11.2 (3.2)	10.1 (2.1)
TSCYC		
PTSD	59.8 (20.0)	46.3 (6.0)
Dissociation	49.1 (8.1)	45.0 (2.9)
Anxiety	56.1 (20.2)	46.1 (7.6)
Depression	55.1 (16.4)	45.8 (5.7)
CBCL		
Internalizing	57.2 (12.2)	48.6 (8.8)
Externalizing	53.9 (10.8)	44.6 (6.3)
Total problems	55.7 (12.4)	44.9 (6.7)

Note. IED, Intra-Extradimensional Shift; Pre-ED errors, errors made prior to the extra-dimensional shift; EDS errors, errors made in the extra-dimensional stage; SWM, Spatial Working Memory; Contrast, scaled score of time spent on the inhibition condition when subtracting time spent on base line condition; TSCYC, Trauma Symptom Checklist for Young Children; CBCL, Child Behavior Checklist. Unless otherwise stated (i.e., Z), all scores are scaled scores.