Relations between Cognitive Control and Emotion in Typically Developing Children

by

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B.A. (Hons), University of Saskatchewan, 2002
M.Sc., University of Victoria, 2005

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Abstract

Objective: The goal of this study was to investigate relations between aspects of cognitive control and emotion in typically developing children, 7 to 9 years of age. This was investigated by examining performance on n-back working memory tasks that varied according to the level of cognitive control and emotion (e.g., faces, reward value) processing required. Relations between n-back performance and parental questionnaires of behavior were also examined.

Participants & Methods: Participants included 77 typically developing children, 7 to 9 years of age. Each participant completed two novel n-back tasks. The first task involved working memory (0-back, 1-back, and 2-back levels) for emotional faces (neutral, happy, sad). The second task involved working memory (0-back, 1-back, and 2-back levels) for number stimuli with differing levels of reward (two tokens, six tokens). Matrix Reasoning was also completed as a screening measure of cognitive function. Parents completed a Child History questionnaire, the BRIEF, Conners 3 AI-Parent, and the Emotion Questionnaire.

Results: No significant main effect was found for emotive content of stimuli or reward value. A significant effect of n-back level was found, both in terms of per hit RT and accuracy rates for both Emotive and Reward n-back. Significant relations were found between age and Sad conditions on 1-back and 2-back of the Emotive n-back, as well as 2-back conditions in the Reward n-back. No relations were found between BRIEF scales and performance on either n-back task. Significant correlations were found between Emotionality and accuracy measures of the Reward n-back task.

Conclusions: This study made several important contributions to understanding emotion and cognitive control interplay. These contributions include introducing novel tasks for assessing this interplay, and providing insight on developmental relations and interaction between emotion and working memory and individual differences in emotionality in day to day life. Results are discussed with respect to theories of emotional and cognitive control interplay, temperament and individual differences, and the development of cognitive control. Directions for future research and implications are discussed.

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Introduction

Emotion and cognition are fundamental to human behaviour, yet have frequently been researched in the developmental and neuropsychological literature as distinct and isolated constructs (Ochsner & Phelps, 2007; Sokol & Müller, 2007). More recently however, increased emphasis has been placed on considering emotion and cognition as interacting and interdependent components of a larger, complex system (Gray, 2004; Lewis & Todd, 2007; Luciana, 2007; Luu, Collins, & Tucker, 2000; Ochsner & Phelps, 2007; Perez-Edgar & Fox, 2003; Sokol & Müller, 2007; Toates, 2004). This is important from a theoretical perspective, but also has clinical significance because the interplay between cognition and emotion has been viewed as a core component of internalizing and externalizing disorders in childhood (e.g., Hardin, Schroth, Pine, & Ernst, 2007; Hayden, Klein, Durbin, & Olino, 2006; Jazbec, McClure, Hardin, Pine, & Ernst, 2005; Ladouceur et al., 2006; Stieben et al., 2007; Wodka et al., 2007).

The general goal of this study was to investigate relations between aspects of cognitive control and emotion in typically developing children. These relations were investigated in children 7 to 9 years of age by examining performance on tasks that varied according to the level of cognitive control and emotion processing required. Relations between cognitive control and parental reports of social and emotional behaviour were also investigated.

This paper is divided into five main sections. The first section consists of a review of theories that have been proposed explaining how cognitive control and emotion interrelate. The second section considers brain regions involved in their interplay.

Specifically, structure, function, and development of the prefrontal cortex (PFC) are reviewed, as well as interactions between regions of the PFC and other brain regions.

The third section consists of a review of research that has examined the interplay of emotion and cognitive control. Consistent with the aims of this study, focus is on research conducted with children, although adult literature is also reviewed. It should be noted that due to the vast amount of literature relating to cognitive control and emotional processes, this review is selective in scope. For example, this paper does not focus on literature pertaining to cognitive aspects of emotional control, such as cognitive strategies used to manage emotionally arousing information (e.g., suppression or reappraisal; Garnefski, Rieffe, Jellesma, Terwoft, & Kraaij, 2007; Green & Malhi, 2006) and emotion cognition (i.e., those processes involved in use of emotions in social transactions), such as the development of emotion recognition, theory of mind, social skills, and variables contributing to emotion cognition, such as family factors (Ackerman, & Izard, 2004). Rather, this review focuses on relations between cognitive control and emotive stimuli, reward salience, and social and emotional behaviour. In the fourth section of this paper, goals, hypotheses, and methodology (including sample size, measures, and procedure) are presented. In the final section, results of statistical analyses and summary and implications are discussed.

Theories of Cognitive Control and Emotion Interplay

Cognitive control involves the coordination of subprocesses that facilitate the focus of attention on goal-relevant information, while inhibiting goal-irrelevant information (Eigsti et al., 2006; Ladouceur et al., 2006). Cognitive control has been operationalized as working memory and inhibition (Wolfe & Bell, 2007), and is sometimes used interchangeably with ‘executive functions’ (Mitchell & Phillips, 2007). This process functions to select contextually relevant information and organize and optimize processing resources, which is important for goal directed behaviour (Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). A consistent theme in theories of cognitive control processes is their role in transcending a default mode of function and exerting higher-order control of behaviour (e.g., Barkley, 1997; Diamond, 2002; Grafman, 2002; Norman & Shallice, 1986; Roberts & Pennington, 1996; Shallice, 2002).

The relations between cognition and emotion have received surprisingly little attention. As a result, only a small number of theories have been formulated that address the interrelation between cognition and emotion. One idea that has been proposed is that emotion interacts with cognitive control in a global or diffuse manner (Gray, 2001). An example is capacity theories, which suggest that there are a finite amount of processing resources, and demands of tasks requiring emotion and cognitive control strain resources, resulting in decreased performance (e.g., as reviewed by Chajut & Algom, 2003; Mitchell & Phillips, 2007). Other theories suggest that emotion and cognitive control interact in a selective manner. These theories are interesting, because they suggest that although cognitive control and emotion are specialized and distinct, they have a high level of coordination and work together in a complementary manner (Gray, 2004).

Some researchers have proposed competition and reciprocal functioning between cognitive control and emotion systems. For example, Metcalfe and Mischel (1999) made a distinction between a cool, cognitive 'know' system that is flexible, integrated, slow, strategic, longer developing, and acts as the center of self-regulation. The hot system, in contrast, was conceptualized as an emotional, 'go' system that is impulsive, reflexive, early developing, and stimulus controlled. In various situations, one of these systems is viewed as gaining dominance over the other. For example, yielding to temptation in a delay of gratification task is reflective of dominance of the hot system, whereas implementation of control strategies is reflective of the dominance of the cool system (Metcalfe & Mischel, 1999). Similarly, Drevets and Raichle's (1998) review of brain regions involved in the performance of cognitive and emotion tasks suggests that neural activity in some brain regions crucial for supporting higher cognitive functions (e.g. specific areas of the PFC) increases during the performance of cognitive control tasks, but decreases during experimentally induced mood states. Conversely, activation in areas that process emotion (e.g., amygdala and regions of the PFC) increase during emotion tasks but decrease during cognitive control tasks, which is suggestive of reciprocal emotion-cognition processing in the brain.

Several authors (Gray, 2001, 2004; Tomarken & Keener, 1998; Tucker & Williamson, 1984) have proposed that emotion and cognitive control work cooperatively. According to these accounts, emotion biases cognitive control by influencing modes of information processing. Emotion is theorized to temporarily facilitate abilities in a rapid, flexible, and reversible manner in response to contextual cues (Gray, 2004). Gray (2004) proposed that one of the primary and most critical features of the cognitive control system is its engagement in adaptive, goal-directed behaviour, and its flexibility and ability to respond in divergent ways, depending on the complex interplay of internal processes and external demands. Gray (2004) suggested that because a flexible cognitive control system encounters a number of control conflicts in everyday life (e.g., short term vs. long term reward, allocating attention to details vs. gist, fast vs. slow processing, self-interest vs. altruism etc.), the influence of emotion may be necessary to bias decision-making and resolve dilemmas.

Bechara and colleagues (e.g., Bechara, 2004; Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Tranel, & Damasio, 2000) have also proposed a similar role for emotion in selectively biasing cognitive control. According to the 'somatic marker hypothesis', visceral states elicited by emotionally significant stimuli are critical in decision making. Regions of the PFC (particularly, ventromedial PFC) are involved in associating emotionally significant stimuli and visceral states elicited by the stimuli. Bechara and colleagues' studies on galvanic skin responses during a 'gambling task' involving decision-making under conditions of risk and reward, suggest that in control participants an aversive outcome of a choice is ‘tagged’ with somatic response that signals the aversion. However, in participants with ventromedial PFC damage, the association between somatic response and aversive contingency is lacking, resulting in poor decision making.

A theme in the idea of emotions selectively biasing cognitive control is the distinction between approach and withdrawal (e.g., Carver, Sutton, & Scheier, 2000; Gray, 1990; Tomarken & Keener, 1998). The basic distinction between approach and withdrawal behaviour has a long history in psychological theories of behaviour (e.g., see Carver et al., 2000 for a discussion), but has only relatively recently been applied to cognitive control. Tomarken and Keener’s (1998) theory proposes a link between PFC and approach and withdrawal tendencies, which they view as complex emotion systems subserved by multiple levels of brain functioning. The PFC facilitates goal-directed behaviour, but also has the capacity to shift sets in response to feedback (e.g., changing environmental conditions), and inhibit competing response tendencies. In essence, Tomarken and Keener (1998) propose a balance between behavioural flexibility and temporal continuity of goal directed behaviour.

In their model, this balance is achieved by lateralization of processes within the PFC that facilitate maintenance and shifting of behaviour according to emotional factors, as well as inhibition of interfering sources of emotion. Left frontal activity is related to increased motivation, and responsivity to rewards and other positive stimuli. In contrast, right frontal activity is associated with withdrawal responses, such as avoidance of new or potentially threatening stimuli. It is interesting to note that conceptualizations of cognitive control have also incorporated maintenance (e.g., attention to goal directed behaviour) and flexibility (e.g., protection from interference) features (Eigsti et al., 2006; Ladouceur et al., 2006). The approach/withdrawal distinction, such as extended by Tomarken and Keener (1998), elaborates how cognitive control dimensions of maintenance and flexibility may be accentuated or diminished by the influence of emotion.

An extension of the basic approach/withdrawal distinction can be seen in research on temperament and personality (e.g., Bjornebekk, 2007; Carver et al., 2000; Carver & White, 1994; Henderson, & Wachs, 2007; Smits & Boeck, 2006). Gray (1990) proposed the existence of systems corresponding to these basic distinctions, termed the behavioural activation system (BAS) and the behavioural inhibition system (BIS). The BIS is involved in stopping behaviour that would lead to loss of reward or punishment. It is also involved in the experience of negative subjective feelings (e.g., fear, anxiety, sadness), and an increased BIS sensitivity is related to greater tendency to anxiety. The BIS comprises the septophippocampal system, monoaminergic afferents from the brainstem, and projections to the frontal lobe. It facilitates risk assessment and increases attention and arousal.

Conversely, the BAS is activated by reward or a drive to cease punishing stimuli. This system is associated with the subjective experience of positive feelings, and increased BAS sensitivity is reflected in a greater tendency to approach sources of reward and engage with stimuli in the environment. Dopaminergic pathways are thought to play a role in approach behaviours (Ashby, Isen, & Turken, 1999) and the BAS system.

Neuroanatomical Basis of Cognitive Control and Emotion Interplay

Cognitive control processes, and their interplay with emotion, have been associated with circuits involving the prefrontal cortex (PFC). The PFC is comprised of heteromodal and paralimbic functional regions that subserve "… the associative elaboration and encoding of sensory information, its linkage to motor strategies, and the interplay of experience with drive, emotion, and visceral states" (Mesulam, 2002, p. 11). PFC is instrumental in the highest control of behaviour, serving to process, elaborate, and integrate both internal and external information, acting as the center for emotional and cognitive control (Davidson & Irwin, 1999; Knight & Stuss, 2002).

Within the PFC, three subdivisions are typically identified (e.g., Ridderinkhof et al., 2004; Stuss & Levine, 2002), including dorsolateral prefrontal cortex (DLPFC), the orbitofrontal cortex (OFC), and the medial prefrontal cortex (particularly the anterior cingulate cortex, ACC). These regions are most accurately understood as functioning as part of broader networks, with multiple connections with other regions of the brain (Bradshaw, 2001).

DLPFC has been associated with abilities such as problem-solving, planning (Tranel, Anderson, & Benton, 1994), cognitive flexibility, and working memory (Fuster, 1999; Roberts & Pennington, 1996). DLPFC operates to integrate information about sensation, movement, and long-term memory from visual and parietal cortices, and set up action plans (Bradshaw, 2001). In contrast to the DLPFC, the OFC has strong ties with the limbic system. This system is considered to be highly reward-sensitive and involved in appraisal of the motivational significance of stimuli (Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Zelazo & Müller, 2002). Some examples of functions attributed to OFC include processing the reward value of both primary (e.g., food) and abstract (e.g., money) reinforcers, changes in reinforcement contingencies, and approach (reward-related) and avoidance (punishment-related) behaviour (Rolls, 2004). OFC integrates information from sensory association cortices, the limbic system, and subcortical regions involved in autonomic behaviour (Bradshaw, 2001).

Medial aspects of the PFC (such as the ACC) are also reciprocally connected with the limbic system. The ACC has functionally distinct regions (Bush, Luu & Posner, 2000), one which has mainly cognitive functions and is activated by tasks that involve aspects such as stimulus-response selection with competing information (e.g., Stroop, divided attention, working memory tasks). The second region is more involved in assessing emotional and motivational information and regulating affective responses. ACC is important in conflict resolution and error monitoring (Holroyd & Coles, 2002), and has been identified as a hub of emotional and cognitive processing (Lewis & Todd, 2007).

PFC has a protracted developmental trajectory, developing throughout childhood, adolescence, and early adulthood. These changes are seen structurally in myelination (Pfefferbaum et al., 1994; Yakovlev & Lecours, 1967 as cited by Happaney, Zelazo, & Stuss, 2004), connectivity (Huttenlocher & Dabholkar, 1997), as well as functionally, through electrical activity (Segalowitz & Davies, 2004; Thatcher, 1997). It should also be noted that PFC development occurs in the context of multiple changes in brain development. Although cerebral volume remains constant after 5 years of age, there is a decrease in gray matter after 12 years of age, an increase in white matter and gradual loss of synapses through young adulthood, and brain regions have different trajectories of maturation (Casey, Tottenham, Liston, & Durston, 2005; Durston et al., 2001).

Behaviourally, cognitive control processes have been the main focus of research on behavioural correlates of PFC development (e.g., Diamond, 2002). It has been suggested that Piaget's cognitive stages (sensorimotor, birth to 2 years; preoperational, 2 to 7 years; concrete operational, 7 to 9 years; and formal operational, early adolescence) also parallel periods of 'growth spurts' within the brain (Anderson, Levin, & Jacobs, 2002). Research has suggested major stages of development in the first and second year of life, particularly in inhibition and working memory (e.g., Diamond, 2002). The preschool period is another important stage, with inhibition, cognitive flexibility, working memory, and problem-solving showing development (e.g., Carlson, 2005; Zelazo & Müller, 2002).

Middle childhood has been identified as a significant period of development of cognitive control skills, with effect sizes ranging from medium to large in magnitude (Romine & Reynolds, 2005). Improvements have been shown on measures of working memory, inhibition (Archibald & Kerns, 2001; Tsujimoto, Kuwajima, & Sawaguchi, 2007), cognitive flexibility (Klimkeit, Mattingley, Sheppard, Farrow, & Bradshaw, 2004), problem-solving, and planning (Chelune & Baer, 1986; Romine & Reynolds, 2005; Welsh, Pennington, & Groisser, 1991). Further refinement and development of cognitive control occurs in adolescence (Stuss & Anderson, 2004; Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molen, 2006).

Although the PFC subserves both emotional and cognitive control processes, historically most research and theory on PFC function and development has focused on functions consistent with the DLPFC. These include functions such as planning, decision-making, and working memory. These have been conceptualized as 'cool' EF, in reference to their decontextualized and abstract nature (Zelazo & Müller, 2002). Relatively recently, however, there has been increased interest in considering functions associated with medial and orbitofrontal regions of the PFC (e.g., Happaney et al., 2004; Rolls, 2006; Stuss & Anderson, 2002), which have been hypothesized to process 'hot' EF to reflect their affective-motivational nature (Zelazo & Müller, 2002). There has also been more interest in how regions of PFC interact with other brain structures to produce complex psychological functions, such as cognitive control and emotion interplay (Davidson, 2002; Davidson & Irwin, 1999). This literature provides important insights regarding the nature of the interchange between emotion and cognitive control.

Research on the neuroanatomical basis of emotion (e.g., Davidson & Irwin, 1999; Green & Malhi, 2006; LeDoux, 1995) support the notion that emotion and cognitive control are highly coordinated, and that this coordination occurs both at relatively low levels of processing (e.g., subcortical to cortical, 'bottom up') which provides arousal support, as well as high levels of processing (e.g., cortical to subcortical, 'top down') which exerts a modulatory effect on lower structures. An evolutionary perspective on neural structures involved in emotion has been proposed (McLean, 1990 as cited by Green & Malhi, 2006), which highlights the concept of multiple, reciprocal levels of processing (Lewis & Todd, 2007).

According to this perspective, the brain has evolved through elaboration of circuits surrounding the brainstem core. The brainstem and hypothalamus regulate autonomic and motor systems, which are primary functions involved in emotion generation. Continued evolution is signified by the limbic system (including the hypothalamus, septum, amygdala, hippocampus, and stria terminalis), which facilitates increasingly more flexible responses, sensitivity to cues, and learning. The amygdala has been identified as playing an important role in emotion perception and production of emotional response (Davidson & Irwin, 1999), including functions such as threat detection and fear (LeDoux, 1995), and directing responses to sources of potential threat (Davidson, 2002). The most evolutionary complex system is the paralimbic regions (e.g. cingulate, parrahippocampal, hippocampal, temporal pole, insula, OFC), which enable the most complex emotional functions.

Neural networks involved in reward processing also suggest a high degree of coordination between emotion and cognitive control at all levels of processing. Coricelli, Dolan, and Sirigu (2007) make a distinction between first and second level reward processing within the brain. First level processing is related to dopaminergic pathways. These are diffuse projections from midbrain neurons (ventral tegmentum and substantia nigra) to the basal ganglia and OFC. These facilitate the differentiation between rewarding and non-rewarding stimuli in the environment and discrepancies between expected and actual outcomes in reward value.

In contrast to first level reward processing in the brain, second level processing is associated with OFC, ACC, and the amygdala, and is involved in distinguishing between different rewards (alternatives), and involved in associating factors (e.g., relative preferences, affective value) with these alternatives. These systems of processing are interdependent. First level reward processing identifies relative reward values (and biases behaviour in an approach or avoid direction). The second level integrates this information with cognitive and emotional representations of reward (which could be manifest as subjective preferences), to provide a top down modulation in accordance with these representations. The amygdala-OFC system is more flexible and associated with complex behaviour than the dopamine-basal ganglia system.

Thus, the interplay of emotion and cognitive control is supported by interaction between PFC, limbic, and brainstem regions that integrate cognitive, autonomic, and emotional processes (Blair, 2006; Lewis & Stieben, 2004; Toates, 2004). Emotional and cognitive interplay is a product of both ‘top down’ (PFC downward) and ‘bottom up’ (subcortical structures upward) influence, as well as activity laterally, between regions at the same level. Using the example of regulation, Lewis and Todd (2007) suggest that the most accurate way of considering the operation of a complex function in the brain is as coordination among a number of different systems. This occurs across multiple levels of the neuroaxis, eliminates the need for a 'center' of control and allows for reciprocity as opposed to unidirectional control.

This view of interplay of emotion and cognitive control is also compatible with developmental concepts of brain development (such as the 'interactive specialization' perspective; Oliver, Johnson, Karmiloff-Smith, & Pennington, 2000), which propose brain development occurs as a result of a process of bi-directional and dynamic interactions among brain regions and the external environment. Oliver et al. (2000) adopt a neuroconstructivist approach to understanding brain development, whereby brain-behaviour relations are characterized by progressive emergence of functions across development and multiple influences on development (both intrinsic and extrinsic).

In summary, a review of theories and neuroanatomical bases of emotion and cognitive control interplay suggests a number of important points. First, although very few theories exist, most emphasize that emotion biases cognitive control to facilitate adaptive behaviour. Second, neural substrates of this interaction suggest that there are multiple brain regions involved, processing occurs reciprocally ('bottom up' and 'top down') across multiple levels, and that complex interplay occurs in regions of the PFC. Research examining cognitive control and emotion interplay will be reviewed in the following section.

Review of Research on Cognitive Control and Emotion Interplay

A review of research suggests that relatively few studies have closely examined the interplay between cognitive control and emotion in typically developing children. When considered together, the literature that exists suggests these relations are complex and relate to a number of factors, including the valence of emotion (e.g., Mitchell & Phillips, 2007; Qu & Zelazo, 2007), task demands (e.g., Carlson, Davis, & Leach, 2005; Prencipe & Zelazo, 2005; Qu & Zelazo, 2007; Zelazo & Müller, 2002), and individual differences in social and emotional behaviour (Santesso, Segalowitz, & Schmidt, 2006; Wolfe & Bell, 2007).

A review of literature investigating the interaction between emotion and cognitive control in children emotion has been operationalized in a number of ways, including: emotion as stimuli content (e.g., expressioned faces vs. non-emotive stimuli); manipulation of reward salience; and parental report of social and emotional behaviour. Studies using these approaches will be reviewed in the following section.

Emotion as stimuli content.

The effect of emotion on cognitive control has been measured through tasks requiring conflict resolution and selective attention using emotive stimuli. The most frequently used measure of this type is the Emotional Stroop, which indexes cognitive control processing (e.g., interference or facilitation) of stimuli with varying emotive content in a Stroop format. The objective is to identify the color of a word as quickly as possible, irrespective of the meaning of the word itself. In the standard Stroop the word is color related, but in the Emotional Stroop the word is neutral or emotional.

The Emotional Stroop has been administered to individuals from a wide range of clinical populations, including anxiety and depression (e.g., see Williams, Mathews, & MacLeod, 1996 for a review). The interest in this line of research likely follows from the widely held view that biased cognitive processing is fundamental to these clinical disorders (e.g., Schniering & Rapee, 2004). Interference is a robust finding, which has been conventionally attributed to selective attention, with others suggesting that the interference effect may be related to slowing due to the processing of emotional stimuli (Algom, Chajut, & Lev, 2004). A facilitation effect, rather than the typically documented interference effect, has also been noted on Emotional Stroop (e.g., faster response times to emotive stimuli; Perez-Edgar & Fox, 2003). Individual response tendencies in terms of facilitation or interference to emotive stimuli have been linked to social and emotional functioning in day to day life (Perez-Edgar & Fox, 2003).

Studies of the neural bases of Emotional Stroop have implicated the amygdala (Isenberg et al., 1999 as cited by Compton et al., 2003), and ventral regions of the ACC (Whalen et al. 1998), and DLPFC (Compton et al., 2003). These results have been interpreted to suggest that regions are activated by this task that monitor emotional information, maintain attention, and inhibit irrelevant information (Compton et al., 2003). There is a relatively large body of literature examining attentional bias for emotional information in children with clinical disorders, including anxiety and depression, for example (e.g., Moradi, Taghavi, Neshat-Doost, Yule, & Dalgleish, 1999; Taghavi, Dalgleish, Moradi, Neshat-Doorst, & Yule, 2003; Williams et al., 1996). Literature has provided support for interference effects due to personally relevant information (e.g., Martin & Cole, 2000), although the reasons for this have been debated (see Williams et al., 1996 for a discussion).

Few studies have used measures of dimensions of cognitive control other than selective attention. Ladouceur et al. (2006) investigated whether processing emotionally salient information influenced performance on a Go/No Go task of inhibitory control. Participants were 8 to 16 years of age and included a group diagnosed with an anxiety disorder, a group diagnosed with depression, and a typically developing group. The authors administered an emotional Go/No Go that included facial expressions of different valence, varying the level of cognitive control required (by altering the proportion of 'go' trials) across conditions. Results supported some interaction between group and valence of stimuli, as the depressed group had faster reaction times to sad faces.

Little research on cognitive control using emotional stimuli as content has been conducted in typically developing children. Qu and Zelazo (2007) recently conducted a study of the effect of emotional stimuli on 3- to 4-year old children's rule use, as measured by the Dimensional Change Card Sort (DCCS). The first condition was a standard version of DCCS (e.g., sort blue and red boats and rabbits by shape and then by color). The second condition was identical, but used emotional gendered faces rather than boats and rabbits (e.g., sort happy and sad faces by emotion then by gender). Performance was significantly better for the Emotional Faces compared to the standard version, with more correct in the Emotional Faces version and higher facilitation scores (the number of correct post-switch trials in the standard version subtracted from the number of correct post-switch trials in the Emotion version). A second experiment was conducted to examine which aspects of faces were salient in facilitating performance on the DCCS (e.g., valence of expression, age, gender). Results indicated the facilitation effect was attributable to the inclusion of happy faces as stimuli.

Perez-Edgar and Fox (2007) investigated cognitive processing of emotional material in children 7 years of age. The authors administered an auditory selective attention task that involved words that varied in emotional valence (positive or negative) and social (social or non-social) content. All children showed slower responses to stimuli that were social or negative in content.

Manipulation of reward salience.

There exist few studies that have assessed the relations between reward salience and cognitive control in children. Some studies have focused on differences between clinical groups and typically developing children and adolescents, such as depression, anxiety (e.g., Hardin et al., 2007; Jazbec et al., 2005), and ADHD (Michel, Kerns, & Mateer, 2005; Wodka et al., 2007). In general, accuracy has been shown to improve with the addition of incentives for all participants (e.g., Hardin et al., 2007; Jazbec et al., 2005; Michel et al., 2005) with other indicators of performance efficiency (e.g., modulation of incorrect responses) suggesting better performance in typically developing adolescents (Jazbec et al., 2005; Wodka et al., 2007).

Even fewer studies have examined relations between reward salience and cognitive control in typically developing children. Carlson et al. (2005) devised a task termed ‘Less is More’, in which a child is presented with two piles of candy (one large and one small). The child must point to the pile s/he does not want. Four year olds were able to point to the small pile (to obtain the large pile), but 3 year olds were not able to inhibit their tendency to point to the large pile. Carlson et al. then substituted abstract symbols for candy, and 3 year olds were better able to inhibit responses to pointing to the large reward.

In a similar task, Prencipe and Zelazo (2005) presented children with a choice between a smaller immediate reward and a larger, delayed reward. Conditions included choosing for self, and choosing for the experimenter. On this task, three year olds were more likely to choose the delayed reward for the experimenter, but the immediate reward for themselves.

Müller, Zelazo, Hood, Leone, and Rohrer (2004) administered a rule use and interference control task to typically developing 3 year olds. In this task (entitled the Smarties task), Smarties were placed on a card with a mismatching color, and to respond correctly, children had to provide the experimenter with a card the same color as the card the Smartie was placed on (rather than providing the experimenter with a card the color of the Smartie). Thus, children had to ignore the most salient aspect (Smartie color) and respond according to the less salient aspect (card color). To manipulate the affective salience of the stimuli, Müller et al. (2004) substituted colored beads for Smarties. Children were administered several conditions of this task, including the standard conflict condition and the beads task, as described. Results suggested children performed slightly, but not significantly, better in the beads condition compared to the standard condition. The authors suggested the lack of facilitated performance in the beads condition may be due to several factors, including beads may have been too affectively salient to alter performance, or that the complexity of rule structure in the task may have been more significant than the affective factors involved.

Social and emotional behaviour.

Research has suggested that day to day social and emotional behaviour may be another important way in which emotion is related to cognitive control (e.g., Mauer & Borkenau, 2007; Wolfe & Bell, 2007). One example is temperament, defined as moderately stable (Henderson & Wachs, 2007) biologically based individual differences in emotional reactivity and self-regulation beginning in infancy (Rothbart & Bates, 1998).

Dimensions of temperament most associated with cognitive control are those describing attention and self-regulation (i.e., attention shifting, inhibitory control, soothability, etc.). For example, working memory and inhibition have been positively associated with self-regulation as measured by parental report and laboratory observation (e.g., Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2003). Santesso et al. (2006) found that low socialization (high scores on psychoticism and low scores on a Lie scale) were associated with reliable differences in the ERN (an index of ACC function). Perez-Edgar and Fox (2007) found interactions between infant temperament and performance on a selective attention task completed when children were 7 years old, including that children who had been rated high in soothability and attentional control showed slower responses to social negative words.

Purposes and Hypotheses

Previous research on cognitive control and emotion in children has provided some information as to how emotion and cognitive control interrelate, and paradigms that may be useful for providing measurements of these constructs. However, this research is relatively limited, and there are many reasons why further study would be beneficial:

1. Given the limited number of studies examining the interplay of cognitive control and emotion, particularly in children, there is limited ability to draw conclusions about the nature of this interplay and the generalizability of findings.

2. The relative significance of emotion vs. cognitive control has not been examined. Therefore, it is unknown to what degree cognitive control tasks may constrain the facilitative/prohibitive effects of emotion, and conversely to what degree emotional

processing exerts a facilitative/prohibitive on aspects of cognitive control.

3. Most research has focused on group differences in clinical vs. typically developing populations, with relatively small samples, spanning a wide range of ages. There are few studies that assess developmental trends in cognitive control and emotion interplay.

4. To the author's knowledge, no studies conducted in child populations have used several methodologies within the same group of children. If cognitive control and emotion are coordinated systems, then examination of their interaction in a range of paradigms in a within-subjects design is critical to better elucidating the nature of their interplay.

In light of these limitations, the purpose of the current study was to further examine the interplay between cognitive control and emotion in typically developing children, 7 to 9 years of age. This age group was of particular interest because previous literature suggests that this is a period of significant development of cognitive control processes (e.g., Brocki & Bohlin, 2004; Romine & Reynolds, 2005). Older children show a slower trajectory of cognitive control development (with performance on some tasks reaching adult levels during adolescence).

Younger children (i.e., preschoolers) also show rapid development of cognitive control processes. Tasks assessing cognitive control and emotional interplay involve multiple operations. One of the challenges assessing cognitive control in preschoolers is modifying the task demands to ensure the constructs of interest are accurately measured and performance does not reflect extraneous factors, such as difficulty understanding or complying with task demands (Garon, Bryson, & Smith, 2008). When considered together, these factors suggest that children 7 to 9 years of age are the most suitable population to investigate the questions of interest in this study.

Two major questions were asked. First, how do emotion and cognitive control interrelate? Second, how does this relation develop? Although many functions have been conceptualized as involved in cognitive control (Eslinger, 1996), working memory has featured prominently (e.g., Diamond, 2002; Roberts & Pennington, 1996).

Working memory has been defined in various ways, including as the process by which information is maintained on-line for brief periods of time, or as the process of maintaining information in an active state for goal-directed behaviour (Banich, Mackiewicz, Depue, Whitmer, Miller, & Heller, 2009). Working memory has been associated with a number of complex cognitive abilities, including reading comprehension and mathematical problem-solving (Lee, Ng, & Ng, 2009; Sesma, Mahone, Levine, Eason, & Cutting, 2009), and is strongly related to fluid intelligence (Conway, Cowan, Bunting, Minkoff, & Therriault, 2002; Engle, Tuholski, Laughlin, & Conway, 1999). Working memory performance has also been found to be impaired in a number of child clinical populations [e.g., brain injury (Conklin, Salorio, & Slomine, 2008), AD/HD (McInerney & Kerns, 2003), fetal alcohol syndrome (Rasmussen, 2005)].

Due to working memory's theoretical and practical significance, in this study cognitive control was assessed by varying the demands on working memory. As previously noted there are multiple ways of attempting to operationalize the construct of emotion (i.e., emotion as stimuli content, manipulation of reward salience, and parental report of social and emotional behaviour). Each of these operationalizations was implemented in this study.

To investigate the interaction between cognitive control and emotion, two versions of a working memory ‘n-back’ paradigm were used that varied along two major dimensions: the level of working memory required, and the degree of emotive content (as manipulated by the inclusion of emotive/non-emotive content and varying levels of reward). Each version of this task assesses the interplay between cognitive control and emotion in different ways, but both reflect how emotion influences cognitive control in response to context (e.g., by varying features of the stimuli or reward), and both are hypothesized as involving brain circuitry involved in emotion and cognitive control interplay. By holding the working memory demands constant, the differential effect of reward value and emotive content on performance can be examined. In addition, the relations between performance on the n-back tasks and parental reports of social and emotional behaviour can be examined, as previous literature has yielded results suggesting that cognitive control and emotion interplay are related to day to day social and emotional behaviour.

The n-back paradigm was chosen as a measure of cognitive control for several reasons. First, it is viewed as a valuable measure of working memory because it holds demands of the task constant, while allowing for variation in the amount of information to be retained (e.g., Braver et al., 1997; Levin et al., 2004). Second, the n-back paradigm has been used in studies with fMRI and appears to activate left DLPFC and inferior frontal regions (Levin et al., 2004), providing support for the contention that performance requires frontal regions believed to be critical for cognitive control. Third, variations of the n-back paradigm have been administered to middle childhood populations, including children with traumatic brain injury (Chapman et al., 2006; Levin et al., 2004), AD/HD

(Shallice, et al., 2002), FASD (Astley et al., 2009), and autism (Williams, Goldstein, Carpenter, & Minshew, 2003), as well as typically developing children (Vuontela, Steenari, Carlson, Koivisto, Fjallberg, & Aronen, 2003), suggesting suitability for use with children in this age group.

Two questionnaires were chosen to assess social and emotional behavior in day to day life. These were the Emotion Questionnaire (Rydell, Berlin, & Bohlin, 2003; Rydell, Thorell, & Bohlin, 2007) and scales from the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000).

The Emotion Questionnaire was chosen as a measure of social and emotional behaviour in everyday life for several reasons. First, it is one of the few questionnaires appropriate for use in this age group that assesses both emotional reactivity and regulation in multiple areas (e.g., anger, fear, sadness and positive emotions, Rydell et al., 2003; Rydell et al., 2007). This questionnaire includes items assessing emotionality, pertaining to frequency and intensity of reactions, and emotional regulation, pertaining to child's regulatory ability and the child's ability to regulate emotions with others' assistance (Rydell et al., 2003).

Second, Rydell et al. (2003) report reliability and validity information for the questionnaire, including adequate internal consistency estimates from .65 to .79 and test-retest reliability from .62 to .79. Construct validity was demonstrated by differential correlations between emotional reactivity and regulation and relevant scales from the Children's Behavior Questionnaire, a measure of temperament. Finally, this questionnaire is of reasonable length and therefore is expected to be fairly convenient for parents to complete (decreasing the likelihood of missing data).

The BRIEF is a widely used (e.g., McCandless & O'Laughlin, 2007; Sherman, Slick, & Eryl, 2006) parental report measure of executive function in day-to-day life. For this study, the scales of Emotional Control and Working Memory were used. This measure was chosen because it provides information on cognitive control functions and emotional regulation, and is a standardized instrument that has been normed based on approximately 1500 parents in the USA (Gioia et al., 2000). Reliability data indicate high internal consistency (alpha = .80 to .98) and test retest reliability (*r*s = .82).

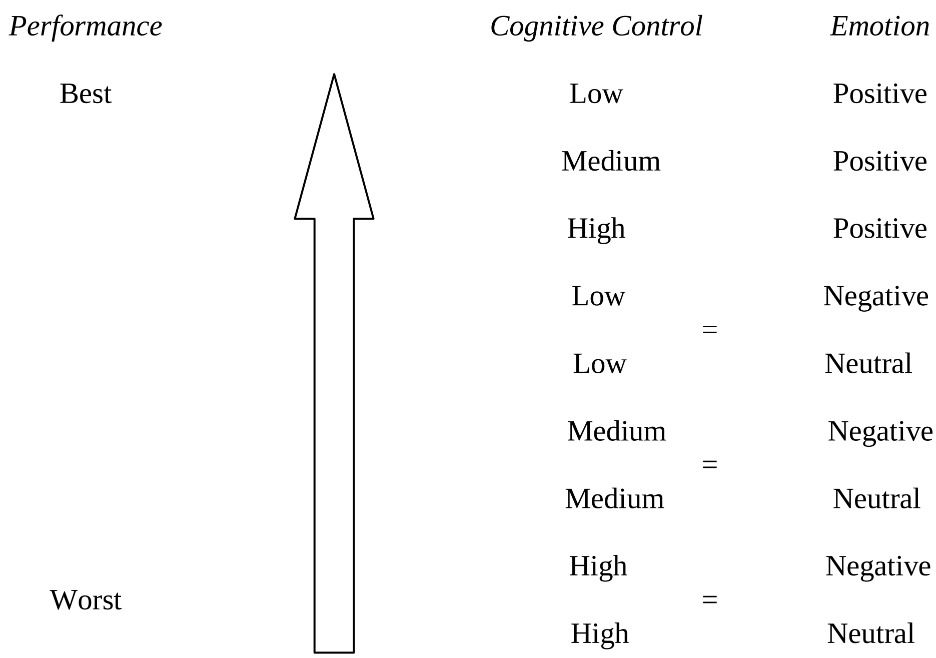
Although the research on cognitive control and emotion in childhood is relatively limited, the available literature was used to propose the following questions and hypotheses:

> <u>Question 1:</u> *What effect does altering emotive content of stimuli have on tasks demanding cognitive control? Does this effect vary, depending on level of cognitive control required?*

Based on previous literature (e.g., Qu & Zelazo, 2007), it was expected that increasing positive emotive content of stimuli would improve performance, and increasing negative emotive content of stimuli would not significantly affect performance. The relative significance of emotive content given varying degrees of cognitive control required is less clear, as this has not been previously investigated. It is not clear to what degree the demands of the cognitive control task would constrain the facilitative effect of positive emotion, or to what extent positive emotion is facilitative beyond the level of cognitive control required. If the effect of emotive content is most significant, the pattern of overall performance would be as depicted in Figure 1.

Figure 1

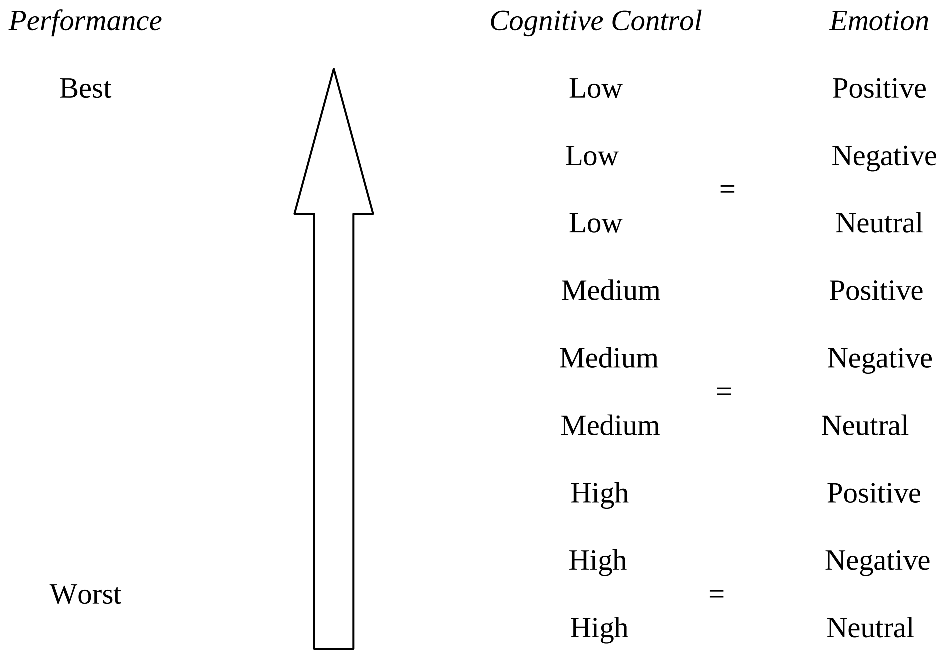
Hypothesized Pattern of Relations (Effect of Emotive Content Significant)



If the effect of cognitive control is most significant and limits the effect of positive emotion, the pattern of performance would be as depicted in Figure 2.

Figure 2

Hypothesized Pattern of Relations (Effect of Cognitive Control Significant)



<u>Question 2:</u> *What effect does altering reward value have on tasks demanding cognitive control? Does this effect vary, depending on level of cognitive control required?*

Based on previous literature, it was expected that increasing reward value would improve performance. The relative significance of reward incentive and degree of cognitive control required is less clear, as this has not been previously investigated. Similar to the addition of emotive content, it is not clear to what degree information processing demands of cognitive control tasks would constrain the facilitative effect of reward, or to what extent reward would be facilitative beyond the level of cognitive control required. If the effect of reward value is more significant, the pattern of performance would be as depicted in Figure 3.

Figure 3

Hypothesized Pattern of Relations (Effect of Reward Value Significant)

Performance	*Cognitive Control*	*Reward*
Best	Low	High
	Medium	High
	High	High
	Low	Low
	Medium	Low
Worst	High	Low

If the effect of cognitive control is more significant and constrains the effect of reward, the pattern of performance would be as depicted in Figure 4.

Figure 4

Hypothesized Pattern of Relations (Effect of Cognitive Control Significant)

Performance	*Cognitive Control*	*Reward*
Best	Low	High
	Low	Low
	Medium	High
	Medium	Low
	High	High
Worst	High	Low

<u>*Question 3:*</u> *How do parental reports of social and emotional behaviour and measures of cognitive control and emotion interplay relate?*

Based on previous literature (e.g., Davis et al., 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2003, 2007), it was expected that children who perform better on tasks assessing cognitive control and emotion will also be rated as less reactive and more regulated according to parent report.

<u>Question 4:</u> *How does performance on these tasks develop with age?*

There is an extensive literature indicating that cognitive control develops during childhood (e.g., Carlson, 2005; Diamond, 2002), and the ability to process emotion also develops across childhood (e.g., Kopp, 1982, 1989). However, less is known about the development of the interactions between cognitive control and emotion, and cognitive control and reward. Based on previous literature, it was reasonable to expect that age would be positively related to performance (accuracy and reaction time) in each condition of the n-back tasks.

Methods

Overview of Methods

One aspect of cognitive control, working memory, was measured through versions of the n-back paradigm. The level of working memory was varied, in a manner similar to previous literature with this age group (e.g., Beveridge, Jarrold, & Pettit, 2002; Brocki & Bohlin, 2004). By systematically varying the level of working memory (low, medium, high) and emotion (positive, negative, neutral) demands, nine conditions for the Emotive n-back were generated. By systematically varying the level of working memory demand (low, medium, high) and reward (low, high), six conditions of the Reward n-back tasks were generated. These conditions are briefly described here and more detail is provided in the ‘Measures’ section.

Working memory demands, which require the child to maintain and transform temporary information during mental operations, were manipulated by increasing the number of distractors between targets. For example, in the 0-back condition (low working memory demand), the child was required to respond when a target stimulus is displayed. In the 1-back condition (medium working memory demand), the child was required to recall the stimulus one previous to the target stimulus. In the 2-back condition (high working memory demand), the child was required to recall the stimulus two previous to the target stimulus.

Emotion in the two versions of the n-back task were operationalized as emotive content of stimuli and reward value, respectively. In one version of the n-back task, stimuli were either emotive (positive expressioned faces; negative expressioned faces) or non-emotive (neutral faces). In the other version of the n-back task, reward value was either high (six tokens) or low (two tokens).

Power Analysis

Results from studies assessing the relations between cognitive control and emotion were used to provide effect sizes for power analyses. The effect size magnitude of studies examining cognitive control and emotion interplay in children, or age differences in performance of cognitive control tasks in middle childhood, yields effect sizes ranging from medium large to large in magnitude (e.g., d=.65 to d=.91; Beveridge et al., 2002; Qu & Zelazo, 2007; Romine & Reynolds, 2005) according to Cohen's (1992) conventions.

The program GPOWER (Erdfelder, Faul, & Buchner, 1996; Faul, Erdfelder, Lang, & Buchner, 2007) was used to perform an *a priori* power analysis with the large effect sizes using a power level of .8 and an alpha level of .05. These analyses suggest a total sample size necessary to achieve sufficient power ranges from 32 to 36 children. A more conservative analysis, assuming an effect size from medium to large according to

Cohen's (1992) conventions of *d* = .65, yielded a total sample size of 60 children. This sample size is similar to, or exceeds, the size of samples in comparable literature (e.g., Beveridge et al, 2002) and was the goal sample size for the study.

Participants

Ninety nine children participated in this study (*M* = 8.26 years, *SD* = .89 years; 6.33 – 10.08 years, 56 boys, 44 girls). Participants comprising the sample in this study were recruited through schools and via advertisements in communities in Victoria. Letters were sent to school administrators and parents providing information describing objectives and methods of the study.

Children were excluded from final analysis if: they were not 7 to 9 years of age; they had been diagnosed with a psychiatric, psychological, neurodevelopmental, or learning disorder according to parental report; they failed to complete the tasks; they obtained a scaled score of less than 6 (9^{th} percentile) on the measure of non-verbal reasoning; or they obtained a clinically elevated score on the Conners' screening measure of attention (t-score >65; Conners, 2008). These exclusion criteria were employed because it was the intent of the study to draw a sample from the population of typically developing 7 to 9 year old children. Based on these criteria, 22 children from the original sample were eliminated. The specific proportions of the eliminated sample of children were as follows:

- Three children (~3% of sample) were eliminated due to failure to maintain attention throughout the tasks and consequently did not complete all the tasks.
- Two children (~2% of sample) were eliminated because they were significantly less than 7 years of age (ages 6.33 and 6.42 years).

- One child (~1% of sample) was eliminated due to the child stating that he forgot the instructions part-way through the task.
- Seven children (~7% of sample) were eliminated because parental ratings on the attention questionnaire were greater than a t-score of 65, suggesting a clinically significant difficulty with attention/concentration may exist.
- Nine children (~9% of sample) were eliminated because they had been diagnosed with an anxiety disorder or parent report indicated anxiety was a significant source of concern that impacted day-to-day life, were diagnosed with learning difficulties or received learning assistance at school, or were diagnosed with a neurodevelopmental disorder. For most of these participants (7 of 9), parental ratings also indicated a clinically significant degree of attention difficulties.

In order to preserve power, three children who had very recently turned 10 years old (ages 10, 10, and 10.08) and a child who was nearly 7 (6.92 years) were included in the final sample. The final sample therefore consisted of 77 children (M = 8.37 years, SD = .86 years; 6.92 – 10.08 years, 42 boys, 35 girls), exceeding the goal sample size of 60 participants. The sample was approximately equally divided among age groups (seven year olds, n = 28, M = 7.48 years, SD = .24 years, 6.92 - 7.83 years; eight year olds, n = 25 M = 8.4 years, SD = .26 years, 8 – 8.83 years; nine year olds, n = 24, M = 9.46 years, SD = .34 years, 9 - 10.08 years). The mean score on Matrix Reasoning task was a scaled score of 12.27 (SD = 2.72; 7 - 19). The mean parental rating on the Conners' was a t-score of 51.21 (SD = 6.74; 44 - 63).

Written consent was obtained from the participants and legal guardians of the participants, and verbal consent was also obtained from the children who participated in the study. Information provided in the consent form included purpose of study, the benefits of study, the procedures to be undertaken, and notification of the participants' right to withdraw at any time during the course of the study. This study was approved by the Human Research Ethics Board of the University of Victoria prior to data collection.

Measures

The measure of cognitive control used in this study was the n-back task. In order to obtain information regarding general intellectual function, the Matrix Reasoning (MR) subtest of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) was administered. In order to obtain information to satisfy exclusion/inclusion criteria, information pertaining to developmental history (Child History Questionnaire) and attention (Conners 3 AI-Parent) was also collected. The tasks and questionnaires used are discussed in more detail in the following sections.

Child History Questionnaire –developmental history.

The Child History Questionnaire is a medical/developmental history questionnaire in which parents are asked to provide information pertaining to the medical, developmental and educational history of the child. The questionnaire is provided in Appendix A.

Conners 3 AI-Parent - attention.

The Conners 3 AI-Parent is a standardized parental report intended for use with children and adolescents 6 to 17 years of age. There are 10 items on the Conners' 3 AI-Parent. This questionnaire was used as a screening measure of attention (Conners, 2008).

Matrix Reasoning Subtest (MR subtest) of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) – general intellectual ability.

The MR subtest of the WISC-IV is a standardized measure of non-verbal, fluid reasoning appropriate for use in children 6 to 16 years of age. The MR subtest requires the child to select an item that best completes a pattern shown on a grid, and requires approximately 15 minutes to complete. The MR subtest was used as a screening measure of non-verbal cognitive function.

Emotive N-back Task - cognitive control and emotive stimuli.

The n-back tasks used in this study were adapted from tasks used previously (e.g., Levin et al., 2004; Shallice et al., 2002) with this age group. There are three difficulty levels. At the first level (0-back), the child is to press a key when a target stimulus appears. In the 1-back condition, the child is to press a key when the stimulus currently presented is the same as one previous (e.g., Face A, Face A, press key). In the 2-back condition, the child is to press a key when the stimulus currently presented is the same as the stimulus presented two previous (e.g., Face B, Face C, Face B, press key). For each level, there are three conditions (positive emotive stimuli, negative emotive stimuli, neutral emotive stimuli). For the positive emotive stimuli conditions, only happy faces were shown. For the negative emotive stimuli conditions, only sad faces were shown. For the neutral emotive stimuli conditions, only neutral faces were shown.

The task consisted of practice trials and test trials. Practice trials were of two forms. The first type were termed interactive, or ‘walk-through’ trials, where the stimuli were not presented in a timed fashion, but rather were presented when the experimenter pressed a button following the child’s verbal response. In this way, the experimenter was able to guide the child through the task demands and verify the child understood the task requirements. If the child did not understand, the interactive untimed practice trials were repeated.

The second type of practice trials ('feedback' practice trials) were identical to the subsequent test trials, but provided feedback on the child's performance (e.g., the words "right" or "wrong" appeared following a response to a target). For interactive trials, there was one target stimuli requiring a response (and 3 to 7 stimuli, depending on n-back level) and for practice trials for each condition, there were three target stimuli requiring a response. If the child missed one or more of the three target stimuli the practice trials were repeated.

The practice trials (3 to 7 walk-through; 10 feedback practice trials) were followed by 36 test trials for each condition (324 trials total), with a stimulus display time of 1.2 seconds and an inter-stimulus interval of .6 seconds, with 25% of trials (9/36 trials for each condition) being target stimuli. The number of trials was chosen to approximate the number used in previous studies using the n-back paradigm in middle childhood populations (e.g.,Vuontela et al., 2003), while also being of reasonable length to maximize the likelihood that children would be able to attend throughout all conditions of the study. Pilot testing was also completed with several children to ensure the task parameters were reasonable for use with this age group.

In the high emotive conditions, positively-valenced (e.g., happy) and negatively-valenced (e.g., sad) expressioned faces were used as stimuli. These expressions were chosen because positive stimuli appear to result in a different pattern of performance than negative stimuli (e.g., Fenske & Eastwood, 2003; Qu & Zelazo, 2007). In the neutral emotive conditions, neutral faces were used as stimuli. For each emotive condition, three levels of the n-back task (0-back, 1-back, and 2-back) were administered. It is important to note that the face stimuli in both emotive and the neutral conditions were from the same individuals. Thus, face recognition was required in each condition, and conditions differed only in the relative degree of emotive valence of the stimuli. The conditions are summarized in Table 1.

Table 1

Conditions in the Emotive N-back Task

	High Cognitive Control	Medium Cognitive Control	Low Cognitive Control
Positive Emotive Content	Happy faces 2-back	Happy faces 1-back	Happy faces 0-back
Negative Emotive Content	Sad faces 2-back	Sad faces 1-back	Sad faces 0-back
Neutral Emotive Content	Neutral faces 2-back	Neutral faces 1-back	Neutral faces 0-back

Facial stimuli were drawn from the NimStim set of facial expressions (e.g., Tottenham, Tanaka, Leon, McCarry, Nurse, Hare et al., 2008). This database was chosen for use in the current study because it contains a large number of facial stimuli (672 different expressions, consisting of 43 actors of various ethnicities, modeling 16 different facial poses). In addition, adequate validity (concordance between participants' labelling of emotional expression and intended expressions of the actors) and intra-subject test-retest reliability (extent to which participants' responses matched at two point in time, 20 minutes apart) information has been collected for stimuli in the NimStim set (Tottenham et al., 2008).

The particular expressions of relevance to the current study were: closed happy, closed sad, and neutral. Samples of these NimStim expressions are depicted in Appendix B. Validity and reliability data for these expressions was good to excellent [Landis & Koch, 1977; Tottenham et al., 2008; kappa .76 (.13) to .92 (.06); agreement between blocks one and two .91 to .94]. From the database of 43 actors enacting these expressions, 11 faces were chosen. One face was used as the target stimulus in the 0-back condition, and to prevent interference at higher n-back levels this face was not used in the 1-back or 2-back conditions [kappa .86 (.07), agreement between blocks .86]. The remaining 10 faces [kappa .76 (.21) to .91 (.02); agreement between blocks .83 to .9] were used as stimuli in the three n-back levels, and were approximately equally represented as targets in each condition.

The demographic features and proportion of these faces were: two black female faces, two black male faces, two asian female faces, two white female faces, and two white male faces. The selection of particular faces was based on psychometric properties, and a range of characteristics was also desired to maintain a reasonable level of difficulty in the task. For example, it was important that the task did not use only white female faces, as the salient features of the task design are to measure the effect of cognitive load and/or emotion, rather than to measure facial recognition abilities.

The dependent variables of interest for the Emotive n-back task were: hits (responding to a target stimulus), correct omissions (not responding to a non-target), commission errors (responding when a response is not required), omission errors (not responding when a response is required), and reaction time.

Reward N-back Task - cognitive control and reward.

The Reward n-back task was similar in structure to the Emotive n-back, with the same parameters, including 'walk-through' or interactive practice trials, feedback practice trials, number of test trials, percentage of target stimuli, stimulus presentation rate, and inter-stimulus interval. The difference was that numbers, as opposed to faces, were used as stimuli, and a reward element was included.

In the low reward conditions, the child was told before they began the condition that accurate performance would result in two tokens following this condition. In the high reward conditions, the child was told before they began that accurate performance would result in six tokens following the condition. The child was instructed that in order to obtain the full token value, they must achieve perfect performance, and a progress bar was depicted at the top of the screen. Once the bar "filled up", the child would receive the full token value. When the child received the tokens from each condition, the tokens could be exchanged later for a prize after the task was complete. In reality however (in order to ensure each participant had a positive experience with the research project) the progress bar filled up in a pseudo-random manner regardless of performance. In this way, unbeknown to the participants, a pseudo-feedback-reward link was established to maintain motivation throughout the task yet also ensure a positive testing experience for the young children who participated in this study. For each reward condition, three levels of the n-back task (0-back, 1-back, and 2-back) were administered. The conditions are summarized in Table 2.

Table 2

Conditions in the Reward N-back Task

	High Cognitive Control	Medium Cognitive Control	Low Cognitive Control
High Reward	6 tokens 2-back	6 tokens 1-back	6 tokens 0-back
Low Reward	2 tokens 2-back	2 tokens 1-back	2 tokens 0-back

The dependent variables of interest for the Reward n-back task were: hits (responding to a target stimulus), correct omissions (not responding to a non-target), commission errors (responding when a response is not required), omission errors (not responding when a response is required), and reaction time.

Behavior Rating Inventory of Executive Function (BRIEF) - social and emotional behaviour.

To explore relations between cognitive control and socioemotional behaviour in day to day life, scales from the BRIEF (Gioia et al., 2000) were administered. The BRIEF is a standardized parental report measure of regulation and cognitive control appropriate for use in children and adolescents 5 to 18 years of age. The BRIEF is comprised of 86 items that reflect broad indices of Behavioral Regulation (scales include: Inhibit, Shift, and Emotional Control) and Metacognition (scales include: Initiate, Working Memory, Plan/Organize, Organization of Materials, Monitor). Parents were asked to rate their child's behavior on items comprising the Emotional Control and the Working Memory scales, as these are the constructs of interest in this study. These scales from the BRIEF are comprised of 20 items and required approximately 5 minutes to complete.

Emotion Questionnaire - social and emotional behaviour.

To explore relations between cognitive control and emotional behaviour in day to day life, a parent report measure assessing emotional reactivity and regulation was administered. Rydell et al. (2003) devised a questionnaire that assesses emotional reactivity and regulation in four areas, including anger, fear, sadness, and positive emotions/exuberance. The scale is 40 items in length, with a Likert scale for each item ranging from 1 to 5. The dependent variables of interest include parent ratings for each of the four areas (anger, fear, sadness, and positive emotions). The specific questions comprising this questionnaire are listed in Appendix C.

Materials

In order to administer the tasks described above, a laptop computer, standardized materials for the questionnaires, tokens, and prizes were required.

Procedure

Data was collected individually either in a laboratory at the University of Victoria or in a computer laboratory at the child's school. All testing was completed individually. Completion of the two versions of the n-back task and the MR subtest required approximately 35 to 40 minutes, and all tasks were administered in one session with short breaks as needed.

Measures were administered in the following order: MR subtest, Emotive n-back, and Reward n-back. To account for potential order effects within the n-back tasks, the conditions were counterbalanced as indicated in Table 3.

Table 3

Counterbalance Order of Conditions in Emotive and Reward N-back

Emotive n-back			Reward n-back	
Order 1	Order 2	Order 3	Order 1	Order 2
0, NE	0, SA	0, HA	0, two tokens	0, six tokens
0, HA	0, NE	0, SA	0, six tokens	0, two tokens
0, SA	0, HA	0, NE	1, two tokens	1, six tokens
1, NE	1, SA	1, HA	1, six tokens	1, two tokens
1, HA	1, NE	1, SA	2, two tokens	2, six tokens
1, SA	1, HA	1, NE	2, six tokens	2, two tokens
2, NE	2, SA	2, HA		
2, HA	2, NE	2, SA		
2, SA	2, HA	2, NE		

Note. *0 = 0-back, 1 = 1-back, 2 = 2-back; NE = Neutral, HA = Happy, SA = Sad.*

Following completion of the tasks, the child was invited to choose a prize from a selection of small toys and was provided with a certificate. The parents completed the Child History, Conners 3 AI-Parent, BRIEF (select scales), and Emotion questionnaires, which were sent home with the child or completed on-site by the parent. The parents were provided with a thank you note and a small stipend in acknowledgment for their time in completing the questionnaires.

Results

Results from the measures implemented here will be discussed in the following manner. First, descriptive and within-task statistics from the Emotive n-back, Reward n-back, BRIEF scales, and Emotion Questionnaire will be presented. Second, comparisons between the Emotive and Reward n-back tasks will be presented. Third, results pertaining to the Emotive n-back, including the effect of condition, the effect of age, and relations between Emotive n-back performance and parental questionnaires will be discussed. Fourth, results pertaining to the Reward n-back, including the effect of condition, the effect of age, and relations between Reward n-back performance and parental questionnaires will be discussed.

Part 1: Descriptive Statistics and Within-Task Analyses for Emotive N-back, Reward N-back, BRIEF, and Emotion Questionnaire

Emotive N-back

The dependent variables of interest for each version of the n-back task were: hits (responding to a target stimulus), correct omissions (not responding to a non-target), commission errors (responding when a response is not required), omission errors (not responding when a response is required), and reaction time. A summary of data from the n-back task is presented in Table 4.

Table 4

Mean Hits, Commission Errors, Omission Errors, and Reaction Time for the Conditions of the Emotive N-back

Condition	*Hits* *M (SD)*	*CorOm* *M (SD)*	*Com* *M (SD)*	*Om* *M (SD)*	*PerHit RT* *M (SD)*
0-back					
Neutral	8.96	26.55	.44	.04	598.57
	(.19)	(.8)	(.8)	(.19)	(88.82)
Happy	8.92	26.49	.52	.08	605.38
	(.27)	(.81)	(.81)	(.27)	(92.48)
Sad	8.95	26.47	.56	.05	622.79
	(.22)	(1.08)	(1.09)	(.22)	(97.22)
1-back					
Neutral	8.86	26.55	.47	.14	674.11
	(.42)	(.94)	(.94)	(.42)	(100.5)
Happy	8.71	26.66	.34	.29	677.45
	(.76)	(.79)	(.79)	(.76)	(105.5)
Sad	8.74	26.52	.49	.26	672.09
	(.66)	(.87)	(.87)	(.66)	(101.45)
2-back					
Neutral	5.51	25.58	1.42	3.39	752.97
	(2.05)	(1.86)	(1.86)	(2.06)	(178.12)
Happy	5.25	25.3	1.7	3.75	745.39
	(2.17)	(2.04)	(2.04)	(2.17)	(196.22)
Sad	5.26	25.45	1.55	3.74	756.96
	(1.95)	(2.29)	(2.29)	(1.95)	(165.9)

Note. *Hits = responding to a target stimulus, CorOm = correct omissions (not responding to a non-target), Com = commission errors (responding when a response is not required), Om = omission errors (not responding when a response is required), and PerHitRt = mean reaction time for hits.*

Performance in the 0-back and 1-back conditions was near ceiling for hits. For example, in the 0-back conditions all children achieved a hit rate of 8/9 targets or 9/9 targets, with 92% to 96% of participants achieving a hit rate of 9/9 targets. Similarly, 92% to 97% of participants achieved a hit rate of 8/9 or 9/9 in the 1-back conditions. Hit rates for the 2-back condition were variable. Fourteen to 25% of participants achieved a hit rate between 1 and 3 out of 9, 43% to 52% received a hit rate between 4 and 6 out of 9, and 32% to 34% achieved a hit rate between 7 to 9 out of 9. Hits were significantly correlated with Matrix Reasoning, only at the level of 2-back [Neutral 2-back $r = .26$, $p < .05$; Happy 2-back $r = .3$, $p < .01$; Sad 2-back $r = .22$, $p < .05$; all other *r*s = -.13 to .08, *p*s > .05].

The pattern of errors appeared to change with the level of n-back, with more commission errors than omission errors at the level of 0-back [*t*s (76) from 4.10 to 4.33, *p*s<.001, for 0-back conditions], Neutral and Sad 1-back levels [*t*s (76) from 2.24 to 2.83, *p*s<.05], and significantly more omission errors at the 2-back level [*t*s (76) from 6.17 to 6.72, *p*s<.001]. The number of omission and commission errors did not significantly differ at the level of Happy 1-back [t (76) = .45, p = .65].

Reward N-back

The dependent variables of interest for the Reward n-back task were: hits (responding to a target stimulus), correct omissions (not responding to a non-target), commission errors (responding when a response is not required), omission errors (not responding when a response is required), and reaction time. A summary of data from the n-back task is presented in Table 5.

Table 5

Mean Hits, Commission Errors, Omission Errors, and Reaction Time for the Conditions of the Reward n-back

Condition	*Hits M(SD)*	*Cor Om M(SD)*	*Com M(SD)*	*Om M(SD)*	*PerHit RT M(SD)*
0-back					
2 tokens	8.96	26.75	.25	.04	539.54
	(.19)	(.49)	(.49)	(.2)	(83.28)
6 tokens	8.99	26.83	.17	.01	536.28
	(.11)	(.5)	(.5)	(.11)	(80.42)
1-back					
2 tokens	8.94	26.79	.21	.06	596.74
	(.30)	(.68)	(.68)	(.3)	(122.68)
6 tokens	8.91	26.86	.14	.09	594.51
	(.59)	(.39)	(.39)	(.59)	(113.28)
2-back					
2 tokens	6.77	26.10	.90	2.23	667.85
	(2.15)	(1.35)	(1.35)	(.90)	(156.89)
6 tokens	6.88	26.18	.82	2.12	707.49
	(1.97)	(1.34)	(1.33)	(1.97)	(183.36)

Note. *Hits = responding to a target stimulus, CorOm = correct omissions (not responding to a non-target), Com = commission errors (responding when a response is not required), Om = omission errors (not responding when a response is required), and PerHitRt = mean reaction time for hits.*

Performance in the 0-back and 1-back conditions was near ceiling for hits. For example, in the 0-back conditions all children achieved a hit rate of 8/9 targets or 9/9 targets, with 96% to 99% of participants achieving a hit rate of 9/9. In the 1-back conditions, 99% of participants achieved a hit rate of 8/9 or 9/9. Hit rates for the 2-back conditions were variable. Seven to 10% of participants achieved a hit rate between 2 and

3 out of 9, 26% to 31% received a hit rate between 4 and 6 out of 9, and 59% to 67% achieved a hit rate between 7 to 9 out of 9. Hits were significantly correlated with Matrix Reasoning, mainly at the level of 2-back [two tokens 2-back $r = .31$, $p < .01$; six tokens 2-back $r = .43$, $p < .01$; two tokens 1-back $r = -.27$, $p < .05$; all other *r*s = -.03 to .15, *p*s > .05].

The pattern of errors appeared to change with the level of n-back, with more commission errors than omission errors at the level of 0-back [*t*s (76) from 1.66 to 3.5, *p*s < .05], no significant difference at the level of 1-back [*t*s (76) from .63 to 1.66, *p*s > .05], and significantly more omission errors at the level of 2-back [*t*s (76) 5.17 to 5.4, *p*s < .001].

Parent Report Measures – BRIEF and Emotion Questionnaire

The dependent variables of interest in the BRIEF were scores from the Emotional Control and Working Memory scales. The dependent variables of interest in the Emotion Questionnaire were Anger, Fear, Sadness, and Positive Emotion/Exuberance, which were comprised of both emotionality and regulatory items. Each domain yielded an index of Emotionality and Regulation (e.g., Anger Emotionality, Anger Regulation, etc.). An overall score for Emotionality and Regulation was also obtained. Descriptive statistics for these questionnaires are presented in Table 6.

Table 6

Descriptive Statistics for BRIEF and Emotion Questionnaire

Parent Questionnaire	*M (SD)*	Range
BRIEF		
Emotional Control	50.57 (9.51)	35-73
Working Memory	51.9 (9.42)	36-81
Emotion Questionnaire		
Emotionality Total	53.31 (9.11)	25-75
Anger Emotionality	13.83 (3.4)	5-23
Fear Emotionality	10.47 (3.55)	4-19
Positive Emotions Emotionality	18.58 (3.2)	12-25
Sadness Emotionality	10.43 (2.86)	4-18
Regulation Total	79.32 (13.43)	51-110
Anger Regulation	18.22 (3.67)	9-25
Fear Regulation	21.16 (4.44)	12-30
Positive Emotions Regulation	17.97 (3.41)	12-25
Sadness Regulation	21.97 (4.31)	12-30

Note. *BRIEF scales are represented in scaled scores, Emotion Questionnaire scales and indices are represented in raw scores.*

Part 2: Relations between Emotive N-back and Reward N-back

Relations between accuracy in Emotive N-back and Reward N-back are presented in Table 7. Most notable are strong correlations between 2-back conditions in both tasks, and variable relations between 0-back and 1-back conditions between the tasks. For example, two of the Emotive 0-back conditions (Neutral and Sad) correlate with most of the 0-back and 1-back Reward conditions, whereas very few correlations exist between 1-back Emotive conditions and 0-back and 1-back Reward conditions.

Table 7

Correlations Between Accuracy in Emotive N-back and Reward N-back

	2 tok_0	6 tok_0	2 tok_1	6 tok_1	2 tok_2	6 tok_2
NE_0	.4**	.36**	.24*	.05	.07	.21
HA_0	.2	.24*	.22	.07	.01	.2
SA_0	.36**	.45**	.31**	-.06	.13	.46**
NE_1	.02	.28*	.06	.16	.1	.02
HA_1	.04	.18	.08	.1	.19	.26*
SA_1	.12	.19	.37**	.01	.13	.35**
NE_2	.19	.14	.2	-.03	.44**	.48**
HA_2	.08	-.04	.02	-.18	.38**	.42**
SA_2	.01	.1	.13	.07	.44**	.42**

Note. *NE_0 = accuracy in neutral 0-back, HA_0 = accuracy in happy 0-back, SA_0 = accuracy in sad 0-back, NE_1 = accuracy in neutral 1-back, HA_1 = accuracy in happy 1-back, SA_1 = accuracy in sad 1-back, NE_2 = accuracy in neutral 2-back, HA_2 = accuracy in happy 2-back, SA_2 = accuracy in happy 2-back; 2 tok_0 = accuracy in 2 tokens 0-back, 6 tok_0 = accuracy in 6 tokens 0-back, 2 tok_1 = accuracy in 2 tokens 1-back, 6 tok_1 = accuracy in 6 tokens 1-back, 2 tok_2 = accuracy in 2 tokens 2-back, 6 tok_2 = accuracy in 6 tokens 2-back.* * $p < .05$, ** $p < .01$.

Relations between per hit RT in Emotive N-back and Reward N-back are presented in Table 8. Most notable are strong correlations between 0-back, 1-back, and 2-back rt measures between conditions in both tasks.

Table 8

Correlations Between Per Hit RT in Emotive N-back and Reward N-back

	2 tok_0	6 tok_0	2 tok_1	6 tok_1	2 tok_2	6 tok_2
NE_0	.47**	.5**	.33**	.44**	.1	.18
HA_0	.51**	.52**	.4**	.43**	.2	.24*
SA_0	.54**	.47**	.32**	.42**	.15	.23
NE_1	.46**	.48**	.39**	.52**	.26*	.32**
HA_1	.49**	.55**	.45**	.57**	.21	.15
SA_1	.53**	.51**	.41**	.54**	.31**	.3**
NE_2	.19	.22	.49**	.4**	.38**	.44**
HA_2	.25*	.32**	.4**	.37**	.42**	.58**
SA_2	.46**	.37**	.4**	.32**	.31**	.52**

Note. Note. *NE_0 = per hit RT in neutral 0-back, HA_0 = per hit RT in happy 0-back, SA_0 = per hit RT in sad 0-back, NE_1 = per hit RT in neutral 1-back, HA_1 = per hit RT in happy 1-back, SA_1 = per hit RT in sad 1-back, NE_2 = per hit RT in neutral 2-back, HA_2 = per hit RT in happy 2-back, SA_2 = per hit RT in happy 2-back; 2 tok_0 = per hit RT in 2 tokens 0-back, 6 tok_0 = per hit RT in 6 tokens 0-back, 2 tok_1 = per hit RT in 2 tokens 1-back, 6 tok_1 = per hit RT in 6 tokens 1-back, 2 tok_2 = per hit RT in 2 tokens 2-back, 6 tok_2 = per hit RT in 6 tokens 2-back.* $^{*}p < .05$, $^{**}p < .01$.

Part 3: Emotive N-back and Effect of Condition, Age, and Relations with Questionnaires

Effect of Condition

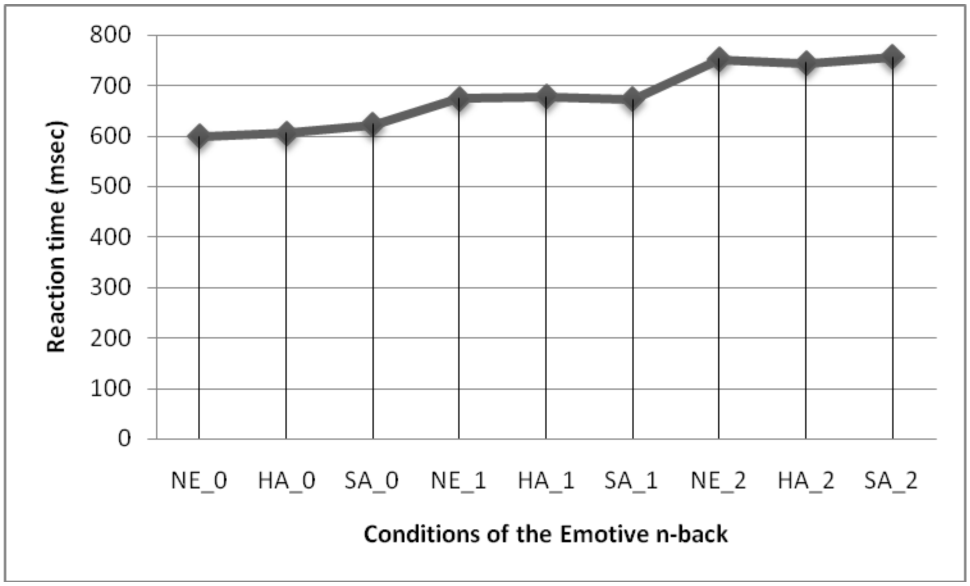
Due to the large number of variables generated from the Emotive n-back and a degree of redundancy in these measures, two main measures were used for further analyses. The first represented a measure of accuracy and consisted of commission errors subtracted from hits (Levin et al., 2004). This was chosen to represent accuracy because it represents targets correctly responded to, while also taking into account commission errors that may result from an overactive response style. The second measure was average RT per hit, which was obtained by dividing the hit RT rate by the number of hits for each participant. No effect was found for order [accuracy F (9, 67) = 1.57, p = .14; per hit RT F (9, 67) = 1.13, p = .36] or gender [accuracy F (9, 67) = 1.13, p = .36; per hit RT F (9, 67) = .57, p = .82].

A repeated measures ANOVA was performed with the within subjects factors of accuracy rates for emotion and n-back levels (three levels; positive emotive, negative emotive, and neutral; and three levels; 0-back, 1-back, and 2-back), and revealed a significant effect of n-back level [F (2, 75) = 280.86, p < .001, d = 3.72]. Pairwise comparisons indicated significant differences in n-back accuracy rates between 0-back and 2-back levels and 1-back and 2-back levels, with significantly lower accuracy rates in 2-back compared to 0-back, and 2-back compared to 1-back conditions (0-back M = 8.44; 1-back M = 8.34; 2-back M = 3.78). No significant effect was found for emotive level [F (2, 75) = 2.75 p = .15], although pairwise comparisons suggested a difference between emotive levels approached significance, with slightly higher accuracy scores obtained in neutral conditions compared to happy conditions, and neutral conditions compared to sad conditions [Neutral M = 7.00; Happy M = 6.77; Sad M = 6.78, Neutral vs. Happy p = .06; Neutral vs. Sad p = .08]. There was no significant interaction between n-back level and emotive level [F (4,73) = .93, p = .34].

A repeated measures ANOVA revealed a similar pattern for reaction time for hits, with a significant effect for n-back level [F (2, 75) = 56.27, p <.001, d = 1.71]. Pairwise comparisons revealed significant differences between each level of n-back (0-back M = 608.91; 1-back M = 674.55; 2-back M = 751.77), with significantly longer response times with increasing n-back level. No significant effect was found for emotive level [F (2,75) = .66, p = .42] and there was no significant interaction between n-back level and emotive level [F (4,73) = .63, p = .43]. The per hit RT rates for each condition are depicted in Figure 5.

Figure 5

Reaction Time for Conditions of the Emotive N-back



Effect of Age

Regressions of age unto the accuracy measures (hits minus commission errors) were performed for each n-back level. Age did not account for a significant proportion of variance in any of the 0-back conditions [Neutral 0-back F (1, 76) = .01, p = .98, Adjusted R^2 = -.01; Happy 0-back F (1, 76) = 1.3, p = .26, Adjusted R^2 = .01; Sad 0-back F (1, 76) = 1.6, p = .21, Adjusted R^2 = .01]. Age accounted for a significant amount of variance in the Sad 1-back condition [F (1, 76) = 4.24, p<.05, Adjusted R^2 = .04, f^2 = .05], and approached significance for the Neutral and Happy 1-back conditions [Neutral 1-back F (1, 76) = 3.69, p= .06, Adjusted R^2 = .03; Happy 1-back F (1, 76) = 3.05, p= .09, Adjusted R^2 = .03]. Age accounted for a significant amount of variance in the Sad 2-back condition [F (1,76) = 7.09, p<.01, Adjusted R^2 = .07, f^2 = .09], approached significance for the Neutral 2-back condition [F (1,76) = 3.56, p= .06, Adjusted R^2 = .03] and was not significant for the Happy 2-back condition [F (1,76) = .28, p= .6, Adjusted R^2 = -.01].

To examine developmental trends in per hit RT, regressions of age unto per hit RT measures were performed. Age accounted for a significant portion of variance for per hit RT for Happy 0-back and Sad 0-back conditions [F (1,76) = 7.48, p<.01, Adjusted R^2 = .08, f^2 = .1; F (1,76) = 10.94, p<.01, Adjusted R^2 = .12, f^2 = .15], and approached significance for the Neutral 0-back condition [F (1,76) = 3.61, p = .06, Adjusted R^2 = .03]. Age accounted for a significant amount of variance for all conditions of 1-back [Neutral 1 back F (1,76) = 6.04, p<.05, Adjusted R^2 = .06, f^2 = .08; Happy 1-back F (1,76) = 7.2, p<.01, Adjusted R^2 = .08, f^2 = .1; Sad 1-back F (1, 76) = 5.23, p<.05, Adjusted R^2 = .05, f^2 = .07]. Age did not account for a significant amount of variance for any condition of the 2-back [Neutral 2-back F (1, 76) = .39, p = .53, Adjusted R^2 = -.01; Happy 2-back F (1, 76) = 1.31, p = .29, Adjusted R^2 = .01; Sad 2-back F (1, 76) = 1.74, p = .19, Adjusted R^2 = .01].

Relations Between Questionnaires and Emotive N-back

Due to minimal variability in performance on 0-back and 1-back conditions, correlations were computed between 2-back conditions and parental questionnaires. No significant relations were found between Working Memory and Emotional Control scales on the BRIEF and measures of accuracy on the Emotive n-back task (*r*s -.14 to .15, all *p*s >.05), or between BRIEF scales and per hit RT (*r*s -.15 to .11, all *p*s >.05). The relation between per hit RT Neutral 2-back and Emotional Control on the BRIEF approached significance (r = -.22, p = .06).

Partial correlations were performed between indices of the Emotion Questionnaire (Emotionality Total, Regulation Total, and Emotionality and Regulation scales of Anger, Fear, Sadness, Positive Emotions) and accuracy measures from the 2-back conditions of the Emotive n-back (with age partialled out). Partial correlations were also performed between indices of the Emotion Questionnaire and per hit RT measures from the Emotive n-back (with age partialled out). These correlations are depicted in Table 9. Due to the multiple comparisons performed, a more stringent significance criteria of $p<.01$ was applied to analyses. At this threshold, no significant relations were found.

Table 9

Partial Correlations Between Indices of Emotion Questionnaire and Accuracy and per hit RT in Emotive N-back

	Em	Reg	Anger Em	Anger Reg	Fear Em	Fear Reg	Sad Em	Sad Reg	PE Em	PE Reg
NE_2 Acc	-.04	.05	.01	.02	-.04	.05	.16	.02	-.24*	.1
HA_2 Acc	.07	.08	.05	.07	.01	.04	.13	.07	.01	.08
SA_2 Acc	.02	.07	.07	.05	.02	.02	.01	.12	-.04	.05
NE_2 RT	-.13	-.01	-.12	.04	-.06	.04	-.13	.01	-.06	-.11
HA_2 RT	-.15	-.19	-.17	-.09	-.1	-.09	-.02	-.26*	-.14	-.2
SA_2 RT	-.16	.12	-.18	.19	-.14	.16	-.1	.07	-.02	-.03

Note. *NE_2 Acc = accuracy in neutral 2-back, HA_2 Acc = accuracy in happy 2-back, SA_2 Acc = accuracy in sad 2-back, NE_2 RT = per hit RT in neutral 2-back, HA_2 RT = per hit RT in happy 2-back, SA_2 RT = per hit RT in sad 2-back. Em = Emotionality, Reg = Regulation, PE = Positive Emotions.* * $p < .05$.

Part 4: Reward N-back and Effect of Condition, Age, and Relations with Questionnaires

Effect of Condition

As in the Emotive n-back, two main measures were used for further analyses. The first represented a measure of accuracy and consisted of commission errors subtracted from hits. This was chosen to represent accuracy because it represents targets correctly responded to, while also taking into account commission errors that may result from an overactive response style. The second measure was average RT per hit, which was obtained by dividing the hit RT rate by the number of hits for each participant. No effect was found for order [accuracy F (6, 70) = 2.19, p= .06; per hit RT F (6, 70) = 1.3, p= .27] or gender [accuracy F (6, 70) = .57, p= .76; per hit RT F (6, 70) = .81, p= .57].

A repeated measures ANOVA was performed with the within subjects factors of accuracy for reward and n-back levels (two levels; 2 tokens and 6 tokens; and three levels; 0-back, 1-back, and 2-back), revealing a significant effect of n-back level [F (2, 75) = 100.48, p<.001, d = 2.28]. Pairwise comparisons suggested significant differences in n-back accuracy between 0-back and 2-back levels and 1-back and 2-back levels, with significantly lower accuracy rates in 2-back compared to 0-back and 2-back compared to 1-back conditions (0-back M = 8.77; 1-back M = 8.75; 2-back M = 5.97). No significant effect was found for reward level [F (1, 76) = 1.55 p= .22] and there was no significant interaction between n-back level and emotive level [F (2,75) = .21, p= .65].

A repeated measures ANOVA revealed a similar pattern for reaction time for hits, with a significant effect for n-back level [F (2, 75) = 70.6, p<.001, d = 1.92]. Pairwise comparisons revealed significant differences between each level of n-back (0-back M =

537.91; 1-back *M* = 595.63; 2-back *M* = 687.67), with significantly longer reaction times with increasing n-back level. Reward level approached significance [F (1,76) = 2.83, p = .10], with longer per hit RT in six tokens versus two tokens conditions (two tokens *M* = 601.38, six tokens *M* = 612.76). An interaction between n-back level and reward level approached significance [F (2,75) = 2.36, p = .10], with longer reaction time in the 6 token condition than 2 token condition, only at the level of 2-back (two tokens 2-back *M* = 667.85, six tokens 2-back *M* = 707.49). The per hit RT rates for each condition are depicted in Figure 6.

Figure 6

Reaction Time for Conditions of the Reward N-back

Effect of Age

Regressions of age onto accuracy in Reward n-back levels were performed. Age did not account for a significant proportion of variance in the 0-back or 1-back conditions [two tokens 0-back F (1, 76) = 1.96, p = .17, Adjusted R^2 = .01; six tokens 0-back F (1, 76) = 2.24, p = .14, Adjusted R^2 = .02; two tokens 1-back F (1, 76) = 1.81, p = .18, Adjusted R^2 = .01; six tokens 1-back F (1, 76) = .17, p = .68, Adjusted R^2 = -.01]. Age accounted for a significant amount of variance in both 2-back conditions [two tokens 2-back, *F* (1,76) =8.70, *p* = .01, Adjusted R^2 = .09, f^2 = .12; six tokens 2-back, *F* (1.76) = 6.07, *p* = .02, Adjusted R^2 = .06, f^2 = .08].

To examine developmental trends in per hit RT, regressions of age unto per hit RT measures were performed. Age accounted for a significant amount of variance in six tokens 0-back condition [*F* (1, 76) = 5.4, *p* = .02, Adjusted R^2 = .06, f^2 = .07] and approached significance in two tokens 0-back condition [*F* (1, 76) = 3.77, *p* = .06, Adjusted R^2 = .04]. Age did not account for a significant amount of variance for two tokens 1-back per hit RT [*F* (1, 76) = 2.39, *p* = .13, Adjusted R^2 = .02], but approached significance for six tokens 1-back per hit RT [*F* (1, 76) = 2.89, *p* = .09, Adjusted R^2 = .02]. Age accounted for a significant amount of variance in six tokens 2-back per hit RT [*F* (1, 76) = 8.19, *p*<.01, Adjusted R^2 = .09, f^2 = .11], but not two tokens 2-back per hit RT [*F* (1, 76) = 1.65, *p* = .20, Adjusted R^2 = .01].

Relations Between Questionnaires and Reward N-back

Due to minimal variability in performance on 0-back and 1-back conditions, correlations were computed between 2-back conditions and parental questionnaires. No significant relations were found between Working Memory and Emotional Control scales on the BRIEF and measures of accuracy on levels of the Reward n-back task (*r*s -.15 to .1, all *p*s >.05). No significant relations were found between Working Memory and Emotional Control scales on the BRIEF and per hit RT rate of the Reward n-back (*r*s -.16 to .18, all *p*s >.05), with the exception of a relation between two tokens 2-back condition per hit RT and Emotional Control which approached significance (*r* = -.2, *p* = .09).

Partial correlations were performed between indices of the Emotion Questionnaire (Emotionality Total, Regulation Total, Anger, Fear, Sadness, Positive Emotions) and accuracy measures from the Reward n-back (with age partialled out), as depicted in Table 10. Due to the multiple comparisons performed, a more stringent significance criteria of *p*<.01 was applied to analyses. Significant relations were found between accuracy in the 2-back conditions and Anger Emotionality (two tokens 2-back, *r* = .32, *p*<.01; six tokens 2-back *r* = .3, *p*<.001) and Sad Emotionality (two tokens 2-back, *r* = .3, *p*<.01, six tokens 2-back *r* = .29, *p* = .01). As depicted in Table 10, partial correlations were also performed between indices of the Emotion Questionnaire and per hit RT measures from the Reward n-back (with age partialled out). No significant relations were found.

Table 10

Partial Correlations Between Indices of Emotion Questionnaire and Accuracy and per hit RT in Reward N-back

	Em	Reg	Anger Em	Anger Reg	Fear Em	Fear Reg	Sad Em	Sad Reg	PE Em	PE Reg
2tok_2 Acc	.26*	-.01	.32**	.01	.01	.02	.3**	-.03	.13	.01
6tok_2 Acc	.22	.18	.3**	.08	-.06	.19	.29**	.18	.11	.14
2tok_2 RT	-.21	.03	-.18	-.04	-.21	.01	-.17	.07	-.05	.03
6tok_2 RT	-.13	-.07	-.15	-.05	-.05	-.01	-.08	-.07	-.07	-.13

Note. *2tok_2 Acc = accuracy in two tokens 2-back, 6tok_2 Acc = accuracy in six tokens 2-back, 2tok_2 RT = per hit RT in two tokens 2-back, 6tok_2 RT = per hit RT in six tokens 2-back. Em = Emotionality, Reg = Regulation, PE = Positive Emotions. * p < .05, ** p< .01.*

Discussion

Summary of Objectives, Hypotheses, and Results

This dissertation investigated the interplay of working memory and emotion in typically developing 7 to 9 year old children. This was investigated by examining performance on n-back working memory tasks that varied according to the level of cognitive control and emotion (e.g., expressioned faces, reward value) processing required, and relations between n-back performance and parental questionnaires of behaviour.

No significant main effect was found for emotive content of stimuli or reward value. A significant effect of n-back level was found, both in terms of per hit RT and accuracy rates for both Emotive and Reward n-back. Significant relations were found between age and Sad conditions on 1-back and 2-back of the Emotive n-back, as well as 2-back conditions in the Reward n-back. No relations were found between BRIEF scales and performance on either n-back task. Significant correlations were found between Emotionality and accuracy measures of the Reward n-back task. Results will be discussed according to specific questions of the current study, as presented earlier in this paper.

Question 1 & 2: What effect does altering emotive content/reward value have on tasks demanding cognitive control? Does this effect vary, depending on level of cognitive control required?

Hypotheses and results.

Based on previous literature, it was expected that increasing positive emotive content of stimuli would improve performance, and increasing negative content would not significantly affect performance. It was expected that increasing reward value would improve performance. The relative significance of cognitive control and emotion/reward value was unclear, as this had not been previously investigated.

The results suggested varying the valence of emotive stimuli and reward value did not have a significant effect on performance, but increasing the executive demands of the n-back task did significantly affect performance. Specifically, reaction time increased with increasing n-back load, and accuracy was significantly lower in the 2-back condition compared to 0-back and 1-back conditions for both Emotive and Reward n-back tasks. It should be noted that an interaction between n-back level and reward level approached significance, with longer reaction times for the 6 token condition than 2 token condition, only at the level of 2-back.

Effect of n-back level and emotive/reward level.

An inverse relation between performance and n-back level is congruent with previous research using this task in childhood populations (e.g., Shallice et al., 2002; Vuontela et al., 2003; Williams et al., 2005). This study extends these findings with two novel n-back tasks incorporating both emotive and cognitive elements, in a middle childhood sample. A similar pattern of results was found both for both Reward n-back and Emotive n-back, despite different stimuli used (e.g., faces, numbers). The results of this study were based on performance of 77 children who were typically developing according to results of a developmental history questionnaire and attention screening measure completed by parents and a standardized measure of non-verbal cognitive function completed by child participants. Thus, this study provides normative data for these tasks, which can facilitate their use in other populations (e.g., other age groups, atypically developing populations).

Although higher working memory demands resulted in decreased performance (congruent with hypotheses), emotive facial stimuli (Emotive n-back) and reward value (Reward n-back) were not found to significantly influence performance. There are at least three reasons why these hypotheses may not have been supported.

The first possibility is methodological, in that emotive stimuli or reward value as implemented in this study may not have been sufficiently influential to affect working memory, and thus may not have impacted performance on tasks used in this study. Although emotive stimuli present in the environment (e.g., facial stimuli, reward), may be represented cognitively as images or symbols, the emotional meaning may not be selected or prioritized by the cognitive control system as important in guiding goal-directed behaviour.

Anecdotally, participants in this study appeared enthusiastic about receiving any sort of reward (either small or large), which may be the reason why a main effect of reward condition was not found. The n-back tasks used here were novel and therefore exploratory, and improvements may be made to render the influence of emotion more salient and increase the likelihood of emotion impacting performance. For example, future studies may consider enhancing reward salience by offering conditions of no reward, or punishment, versus high reward.

Secondly, the lack of effect for emotive stimuli and reward may relate to developmental or individual differences. For example, it may be that developmentally, 7 to 9 year olds are less affected by emotive content than other age groups, or that in middle childhood it is normative for emotive content to have little impact on cognitive control. This study was exploratory, and little previous research has been conducted on the interplay of cognitive control and emotion in children. An important direction for future research is thus to examine the n-back paradigms introduced in the current study across age groups and atypically developing populations to better understand normative performance on these tasks.

A third potential explanation for the lack of effect of emotion in this study is the nature of working memory, relative to other executive functions. Previous research on emotion and cognitive control interplay has found significant effects for emotional manipulations with other executive and cognitive control functions, such as inhibition, decision-making, rule use, and cognitive flexibility. It may be that emotion does not function to selectively bias working memory, but selectively biases other executive functions.

Cognitive control is comprised of both maintenance and flexibility elements (Eigsti et al., 2006; Ladouceur et al., 2006). Maintenance functions in a supportive capacity, to ‘stay on course’ and maintain a specific function or position. Flexibility, on the other hand, is an attribute that enables adjustment to changing conditions. Working memory, as a system of storage and manipulation of representations, may function primarily as the maintenance component of cognitive control. Other executive functions, such as inhibition, decision-making, and cognitive flexibility, may function primarily to adjust the cognitive control system to changing conditions.

Emotion is theorized to temporarily facilitate abilities in a rapid, flexible, and reversible manner in response to contextual cues (Gray, 2004), and perhaps emotion is most influential on cognitive control functions that involve conflictual processing (e.g., short term vs. long term reward, allocating attention to details vs. gist, fast vs. slow processing, self-interest vs. altruism etc.) as opposed to working memory, which may serve in a supportive capacity to store and organize representations. It may be beneficial for future studies to include a decision-making, or conflictual component with working memory tasks using emotive stimuli. This may serve to enhance the ambiguity of the task, which would theoretically place more demands on cognitive control and thus also call into action emotion as a tool to guide decisions between alternatives.

Question 3: *How do parental reports of social and emotional behaviour and measures of cognitive control and emotion interplay relate?*

Hypotheses and results.

Based on previous literature (e.g., Davis et al., 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2003, 2007), it was expected that children who perform better on tasks assessing cognitive control and emotion would also be rated as less reactive and more regulated according to parent report.

No relations were found between Emotive n-back accuracy or Emotive n-back per hit RT and BRIEF scales, and comparisons between Emotive n-back and indices of the Emotion Questionnaire were not significant. No relations were found between Reward n-back accuracy or reaction time and BRIEF scales, with the exception of a relation between two tokens 2-back condition per hit RT and Emotional Control which approached significance. Comparisons between Emotion Questionnaire and Reward n-back suggested significant relations between accuracy in the two tokens 2-back condition and Anger Emotionality and Sad Emotionality, and six tokens 2-back and Anger Emotionality, suggesting children who performed better were rated as more emotionally reactive by parents in everyday life. No significant relations were found between Emotive n-back and indices of the Emotion Questionnaire.

Relations between parent report measures of emotion and cognitive control and emotion interplay.

Significant relations between reward n-back accuracy and measures of emotionality are consistent with Gray’s (1990) conceptualization of the Behavioural Activation System (BAS), which suggests individuals with high BAS sensitivity experience heightened responsivity to rewards, and greater propensity to anger when this system is under-regulated. The relation between Emotionality, particularly Anger Emotionality, and Reward n-back performance may suggest that individuals with heightened BAS sensitivity are differentially motivated by rewards when compared with other children. For these children, the inclusion of reward stimuli may selectively facilitate executive performance.

This selective facilitation effect is consistent with previous literature suggesting that subtle alterations in the structure of executive function tasks can facilitate performance (e.g., Carroll, Apperly, & Riggs, 2007; Müller et al., 2004; Qu & Zelazo, 2007). The results of this study provide an extension of these findings in suggesting that this selective facilitation may be related not only to development, but also individual differences in temperament and affective disposition.

Previous research suggests that the interplay of motivational (emotional) and cognitive representations involves regions within the PFC and amygdala, and PFC provides modulation of performance in order to achieve these emotionally informed goals (Coricelli, Dolan, & Sirigu, 2007). The interplay between these levels could manifest as affective style, consistent individual differences in emotional reactivity that describe an individual`s response to emotional challenges, mood, and cognitive processes involving affect (Davidson, 2000).

Emotionality is defined as reactive components of temperament, including thresholds of reaction and intensity, and emotional regulation involves management of emotional arousal (Rydell et al., 2003). Although studies typically find relations between self-regulation and working memory and inhibition (Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2004), the emotive nature of the working memory tasks used in this study may have resulted in significant relations being found between reactivity and working memory, as opposed to regulation. The addition of emotive content to the working memory tasks may have altered task demands to involve more affective and motivational components conceptualized as hot regulatory processes (Metcalfe & Mischel, 1999; Zelazo & Müller, 2002), in comparison to cool regulatory processes involved in planning and problem-solving behaviour. In this way, the n-back tasks here may have evoked hot processes as opposed to cool processes, resulting in a different pattern of relations to temperament than typically found in the literature. However, it may be expected that if the tasks evoked the hot system, emotional content would have influenced performance on these tasks, which was not the case. Further research may be needed to identify the task parameters necessary to involve hot regulatory processes, and their specific relations with temperament.

No relations were found between BRIEF Working Memory and Emotional Control scales and n-back measures. Although conceptually related to the laboratory measures used here, it may be that BRIEF scales assess different processes than laboratory measures (Vriezen & Pigott, 2002). For example, the BRIEF is a parent report measure, and so may assess not only working memory but also compliance with parental instructions (e.g., `has trouble with chores or tasks that have more than one step`; `has trouble finishing things, e.g. chores and homework`), attention (e.g., `is easily distracted`), and other processes. In addition, performance-based and parent rating measures may not relate because parents may rely upon general impressions of behaviour, whereas performance-based measures are designed to assess specific, rather than general processes (Liebermann, Giesbrecht, & Müller, 2007). Additionally, the context in which capacities are assessed is different in performance-based vs. parental rating measures. For example, n-back task administration is one-on-one, with a relatively high level of support and motivation provided. This is in contrast to everyday situations demanding executive control, which may typically involve more self-direction and less structure in the environment (Conklin et al., 2008). It has been suggested that in order to capture the multi-faceted nature of executive functions and augment ecological validity, it is important to administer both parent and performance-based measures (Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007; Conklin et al., 2008). It may be beneficial for future studies to further investigate the pattern of relations between questionnaires assessing cognitive control in everyday life and laboratory measures of cognitive control, for example by assessing both parent and teacher report as well as a range of cognitive control measures (Conklin et al., 2008).

<u>Question 4:</u> *How does performance on these tasks develop with age?*

Hypotheses and results.

Based on previous literature, it was expected that age would be positively related to performance (accuracy and reaction time) in each condition of the n-back tasks. Age was found to relate to Sad 1-back and Sad 2-back measures of accuracy, suggesting that older children performed better on Sad 1-back and Sad 2-back conditions. Age related to reaction time in Happy and Sad 0-back conditions and 1-back conditions, suggesting older children took less time to respond to targets than younger children in these conditions.

Age accounted for a significant amount of variance in 2-back Reward n-back accuracy measures, with older children responding more accurately than younger children. Age accounted for a significant amount of variance in six tokens 0-back per hit RT and six tokens 2-back per hit RT, with older children responding faster than younger children.

Effect of age.

The positive relation between age and accuracy in the 2-back conditions on the Reward n-back task is consistent with previous studies of the development of cognitive control and executive functions. Previous studies have demonstrated improvements on measures of working memory, inhibition (Archibald & Kerns, 2001; Tsujimoto, Kuwajima, & Sawaguchi, 2007), cognitive flexibility (Klimkeit, Mattingley, Sheppard, Farrow, & Bradshaw, 2004), problem-solving, and planning (Chelune & Baer, 1986; Romine & Reynolds, 2005; Welsh, Pennington, & Groisser, 1991).

In terms of the Emotive n-back, relations with age were less straightforward, with relations found between age and accuracy of Sad 1-back and 2-back, and age and reaction time in happy and sad conditions of 0-back and 1-back. Although a main effect of emotion was not found for the emotive n-back in the overall sample, the differential relations between age and emotional valence suggest that emotional content of stimuli may interact with age. For example, in older children enhancing the sad content of a task may effectively bias cognitive control in an adaptive manner, for instance by increasing attention to the cognitive task in response to threatening (negatively emotive) stimuli. Previous literature suggests this may not be the case at different developmental stages. For example, Qu and Zelazo (2007) found a facilitative effect of happy faces in their study of preschoolers' rule use, in contrast to the facilitative effect of sad faces found in the sample of 7 to 9 year olds of the current study.

There is some evidence to suggest sad faces are different from other emotionally valent facial stimuli. For example, individuals with bilateral amygdala damage show specific impairment in rating sad faces compared to happy faces (Adolphs & Tranel, 2004) and processing of sad faces (relative to angry faces) in control participants has been related to activity in amygdala and temporal regions (Blair, Morris, Frith, Perrett, & Dolan, 1999). Emotional facial expressions are nonverbal emotional cues that provide information on an individual's internal emotional state (De Bonis, 1999 as cited by Berthoz, Blair, Le Clec'h, & Martinot, 2002), and sad faces are different from the other facial stimuli used in this study as they communicate socially aversive information (Blair, 1995).

It may be that younger children in this sample are more distracted by socially aversive information than older children, and consequently sad stimuli would interfere with working memory to a greater extent. The cognitive control system of older children may function more effectively to incorporate the influence of socially aversive information, perhaps by allocating attention to stimuli and incorporating the information into working memory. Further research is needed to determine the replicability of this finding in other middle childhood samples, as well as how emotional information influences cognitive control at different stages of development.

Limitations and Conclusions

This study made several important contributions to the literature, but also had limitations which should be addressed. First, recruitment in this study was necessarily selective. Participants were recruited from the community and private schools, some of which chose to participate and some of which did not. Thus, a sampling bias was introduced in this study, which may have had the effect of limiting generalizability of the results to the general population of 7 to 9 year olds. Second, the results suggested the majority of 0-back and 1-back conditions of the tasks were significantly correlated, and there was not a significant difference in accuracy between these two levels. Future studies may choose to eliminate either the 0-back or 1-back conditions, as inclusion of both may not be necessary and may unnecessarily lengthen the task. Third, the measures of day-to-day emotional and executive functioning were parent report measures, and as discussed, low concordance between parent report measures and laboratory measures has been demonstrated previously. It may be beneficial for future studies to include teacher report and laboratory measures to more fully explore relations that may exist between functioning in everyday life and cognitive control and emotion interplay.

When considered collectively, the results of this study provide insight into theories relating to cognitive control and emotion interplay. Based on capacity theories (e.g., as reviewed by Chajut & Algom, 2003; Mitchell & Phillips, 2007), it would be predicted that increasing emotive content and cognitive control would strain resources, resulting in decreased performance. However, in this study no significant differences were found between high emotive and low emotive conditions, indicating there was no significant decrease in performance incurred by combining cognitive and emotional demands.

The results provide some support for reciprocal functioning of cognitive control and emotion (e.g., dominance of either a cool, cognitive ‘know’ system or a hot, emotional ‘go’ system), in that no main effect of emotive or reward condition was found, suggesting dominance of a cognitive control system over an emotional system. However, performance was better in some circumstances involving emotion, which appeared to relate to development, suggesting relations are more complex than dominance of one system over another. The type of effects found in this study (e.g., age was related to performance only in Sad 2-back, performance was slightly better for six tokens 2-back than two tokens 2-back, reward 2-back was related to emotional reactivity) argue for a selective manner of interplay between emotion and cognitive control (Gray, 2001, 2004; Tomarken & Keener, 1998; Tucker & Williamson, 1984).

This study made several important contributions to the literature, particularly in introducing new methodologies of assessing emotion and cognitive control interplay, providing insight on developmental trends in this interplay during middle childhood, and how individual differences in emotionality may relate to cognitive control and emotion interplay. Future research is needed to better understand the complex interplay between emotion and cognitive control.

References

Ackerman, B.P., & Izard, C.E. (2004). Emotion cognition in children and adolescents: Introduction to the special issue. *Experimental Child Psychology, 89,* 271-275.

Adolphs, R., Tranel, D. (2004). Impaired judgments of sadness but not happiness following bilateral amygdala damage. *Journal of Cognitive Neuroscience, 16,* 453-462.

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the Emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. *Journal of Experimental Psychology, 133,* 323-338.

Anderson, V., Levin, H.S., & Jacobs, R. (2002). Executive functions after frontal lobe injury: A developmental perspective. In D.T. Stuss, & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 504-527). New York: Oxford University Press.

Archibald, S., & Kerns, K. (1999). Identification and description of new tests of executive functioning in children. *Child Neuropsychology, 5,* 115-129.

Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*, 529–550.

Astley, S.J., et al. (2009). Functional magnetic resonance imaging outcomes from a computational magnetic resonance study of children with fetal alcohol spectrum disorders. *Journal of Neurodevelopmental Disorders, 1,* 61-80.

Banich, M.T., Mackiewicz, K.L., Depue, B.E., Whitmer, A.J., Miller, G.A., & Heller, W. (2009). Cognitive control mechanisms, emotion and memory: a neural perspective with implications for psychopathology. *Neuroscience and Biobehavioral Reviews, 33,* 613-630.

Barkley, R. A. (1997). *ADHD and the nature of self-control.* New York: Guilford Press.

Bechara, A. (2004). The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition, 55,* 30-40.

Bechara, A., Damasio, H., & Damasio, A.R. (2000). Emotion, decision-making, and the orbitofrontal cortex. *Cerebral Cortex, 10,* 295-307.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 275,* 1293-1295.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making impairment of patients with bilateral lesions of the ventromedial prefrontal cortex. *Brain*, *123*, 2189-2202.

Berthoz, S., Blair, R.J.R., Le Clec'h, G., & Martinot, J.L. (2002). Emotions: From neuropsychology to functional imaging. *International Journal of Psychology, 37,* 192-203.

Beveridge, M., Jarrold, C., & Pettit, E. (2002). An experimental approach to executive fingerprinting in young children. *Infant and Child Development, 11,* 107-123.

Bjornebekk, G. (2007). Reinforcement sensitivity theory and major motivational and self-regulatory processes in children. *Personality and Individual Differences, 43,* 1980-1990.

Blair, C. (2006). How similar are fluid cognition and general intelligence? A developmental neuroscience perspective on fluid cognition as an aspect of human cognitive ability. *Behavioral and Brain Sciences*, *29,* 109-160.

Blair, R.J.R. (1995). A cognitive developmental approach to morality: Investigating the psychopath. *Cognition*, *57*, 1–29.

Blair, R.J., Morris, J.S., Frith, C.D., Perrett, D.I., & Dolan, R.J. (1999). Dissociable neural responses to facial expressions of sadness and anger. *Brain*, *122,* 883-893.

Bodnar, L.E., Prahme, M.C., Cutting, L.E., Denckla, M.B., & Mahone, E.M. (2007). Construct validity of parent ratings of inhibitory control. *Child Neuropsychology, 13,* 345-362.

Bradshaw, J.L. (2001). *Developmental disorders of the frontostriatal system: Neuropsychological, neuropsychiatric, and evolutionary perspectives.* Philadelphia, PA: Psychology Press.

Braver, T.S., Cohen, J.D., Nystrom, L.E., Jonides, J., Smith, E.E., & Noll, D.C. (1997). A parametric study of prefrontal cortex involvement in human memory. *Neuroimage*, *5,* 49-62.

Brocki, K.C., & Bohlin, G. (2004). Executive functions in children age 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology*, *26,* 571-593.

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

Carlson, S.M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28,* 595-616.

Carlson, S. M., Davis, A. C., & Leach, J. G. (2005). Less is more: Executive function and symbolic representation in preschool children. *Psychological Science, 16,* 609-616.

Carroll, D.J., Apperly, I.A., & Riggs, K.J. (2007). The executive demands of strategic reasoning are modified by the way in which children are prompted to think about the task: Evidence from 3- to 4-year-olds. *Cognitive Development, 22,* 142-148.

Carver, C.S., & White, T.L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67,* 319-333.

Carver, C.S., Sutton, S.K., & Scheier, M.F. (2000). Action, emotion and personality: Emerging conceptual interplay. *Personality and Social Psychology Bulletin, 26,* 741-751.

Casey, B.J., Tottenham, N., Liston, C., & Durston, S. (2005). Imaging the developing brain: What have we learned about cognitive development? *Trends in Cognitive Sciences, 9,* 104-110.

Chajut, E., & Algom, D. (2003). Selective attention improves under stress: Implications for theories of social cognition. *Journal of Personality and Social Psychology, 85,* 231-248.

Chapman, S.B., Gamino, J.F., Cook, L.G., Hanten, G, Li, Z., & Levin, H.S. (2006). Impaired discourse gist and working memory in children after a brain injury. *Brain and Language, 97,* 178-188.

Chelune, G. J., & Baer, R. A. (1986). Developmental norms for the Wisconsin Card Sorting Test. *Journal of Clinical and Experimental Neuropsychology, 8,* 219–228.

Chen, Y.-N., Mitra, S., & Schlaghecken, F. (2008). Sub-processes of working memory in the N-back task : An investigation using ERPS. *Clinical Neurophysiology, 119,* 1546-1559.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155-159.

Compton, R.J., Banich, M.T., Mohanty, A., Milham, M.P., Herrington, J., Miller, G.A. et al. (2003). Paying attention to emotion: An fMRI investigation of cognitive and emotional Stroop tasks. *Cognitive, Affective, & Behavioural Neuroscience, 3,* 81-96.

Conklin, H.M., Salorio, C.F., & Slomine, B.S. (2008). Working memory performance following paediatric traumatic brain injury. *Brain Injury, 22,* 847-857.

Conners, C.K. (2008). *Conners Third Edition (Conners 3) manual.* Minneapolis, MN: Pearson Assessment.

Conway, A.R.A., Cowan, N., Bunting, M.F., Minkoff, S.R.B., & Therriault, D.J. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30,* 163-184.

Coricelli, G., Dolan, R.J., & Sirigu, A. (2007). Brain, emotion, and decision making: The paradigmatic example of regret. *Trends in Cognitive Sciences, 11,* 258-265.

Davidson, M.C., Amso, D., Anderson, L.C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44,* 2037-2078.

Davidson, R. J. (2002) Anxiety and affective style: Role of prefrontal cortex and amygdala. *Biological Psychiatry 51,* 68–80.

Davidson, R.J. (2000). Affective style, psychopathology, and resilience: Brain mechanisms and plasticity. *American Psychologist*, 1196-1214.

Davidson, R.J., & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences*, *3*, 11-21.

Davis, E.P., Bruce, J., & Gunnar, M.R. (2002). The anterior attention network: Associations with temperament and neuroendocrine activity in 6-year-old children. *Developmental Psychobiology, 40,* 43-56.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 466-503). Toronto: Oxford University Press.

Drevets, W.C., & Raichle, M.E. (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: Implications for interactions between emotion and cognition. *Cognition and Emotion*, *12,* 353-385.

Durston, S., Pol, H.E.H., Casey, B.J., Giedd, J.N., Buitelaar, J.K., & van Engeland, H. (2001). Anatomical MRI of the developing human brain: What have we learned? *Journal of the American Academy of Child and Adolescent Psychiatry, 40,* 1012-1019.

Eigsti, I.-M., Zayas, V., Mischel, W., Shoda, Y., Ayduk, O., Dadlani, M.B. et al. (2006). Predicting cognitive control from preschool to late adolescence and young adulthood. *Psychological Science, 17,* 478-484.

Engle, R.W., Tuholski, S.W., Laughlin, J.E., & Conway, A.R.A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128*, 309-331.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, & Computers, 28*, 1-11.

Eslinger, P.J. (1996). Conceptualizing, describing, and measuring components of executive function: A summary. In G.R. Lyon & N.A. Krasnegor (Eds.), *Attention, memory, and executive function.* (pp. 367-395). Sydney: Brookes.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Fenske, M.J., & Eastwood, J.D. (2003). Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. *Emotion, 3*, 327-343.

Fuster, J. M. (1999). Cognitive functions of the frontal lobes. In B. L. Miller & J. L. Cummings (Eds.), *The human frontal lobes* (pp. 187-195). New York: Guilford Press.

Garnefski, N., Rieffe, C., Jellesma, F., Terwoft, M.M., & Kraaij, V. (2007). Cognitive emotion regulation strategies and emotional problems in 9-11-year-old children: The development of an instrument. *European Child and Adolescent Psychiatry, 16,* 1-9.

Garon, N., Bryson, S.E., & Smith, I.M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134*, 31-60.

Gerardi-Caulton, G. (2000). Sensitivity to spatial conflict and the development of self-regulation in children 24-36 months of age. *Developmental Science, 3*, 397-404.

Gioia, G.A., Isquith, P.K., Guy, S.C., & Kenworthy, L. (2000). Behavior Rating Inventory of Executive Function. *Child Neuropsychology, 6*, 235-238.

Grafman, J. (2002). The structured event complex and the human prefrontal cortex. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 292-310). New York: Oxford University Press.

Gray, J.A. (1990). Brain systems that mediate both emotion and cognition. *Cognition & Emotion*, *4*, 269-288.

Gray, J.R. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology*, *130*, 436-452.

Gray, J.R. (2004). Interplay of emotion and cognitive control. *Current Directions in Psychological Science, 13,* 46-48.

Green, M.J., & Malhi, G.S. (2006). Neural mechanisms of the cognitive control of emotion. *Acta Neuropsychiatrica, 18,* 144-153.

Happaney, K., Zelazo, P.D., & Stuss, D.T. (Eds.). (2004). Development of orbitofrontal function: Current themes and future directions [Special issue]. *Brain and Cognition, 55,* 1-10.

Hardin, M.G., Schroth, E., Pine, D.S., & Ernst, M. (2007). Incentive-related modulation of cognitive control in healthy, anxious, and depressed adolescents: Development and psychopathology related differences. *Journal of Child Psychology and Psychiatry, 48,* 446-454.

Hayden, E.P., Klein, D.N., Durbin, E., & Olino, T.M. (2006). Positive emotionality at age 3 predicts cognitive styles in 7-year-old children. *Development and Psychopathology, 18,* 409-423.

Henderson, H.A., & Wachs, T.D. (2007). Temperament theory and the study of cognition-emotion interactions across development. *Developmental Review, 27,* 396-427.

Holroyd, C.B., & Coles, M.G.H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review, 109,* 679-709.

Hongwanishkul, D., Happaney, K. R., Lee, W., & Zelazo, P. D. (2005). Hot and cool executive function: Age-related changes and individual differences. *Developmental Neuropsychology, 28,* 617-644.

Horstmann, G., Borgstedt, K., & Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. *Emotion, 6,* 28-39.

Huizinga, M., Dolan, C.V., & van der Molen, M.W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44,* 2017-2036.

Huttenlocher, P.R., & Dabholkar, A.S. (1997). Developmental anatomy of prefrontal cortex. In N.A. Krasnegor, G.R. Lyon, & P.S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp.69-84). Sydney: Brookes.

Jazbec, S., McClure, E., Hardin, M., Pine, D.S., & Ernst, M. (2005). Cognitive control under contingencies in anxious and depressed adolescents: An antisaccade task. *Biological Psychiatry, 58,* 632-639.

Klimkeit, E.I., Mattingley, J.B., Sheppard, D.M., Farrow, M., & Bradshaw, J.L. (2004). Examining the development of attention and executive functions in children with a novel paradigm. *Child Neuropsychology, 10*, 201-211.

Knight, R.T., & Stuss, D.T. (2002). Prefrontal cortex: The present and the future. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 573-598). New York: Oxford University Press.

Kopp, C.B. (1982). Antecedents of self-regulation: A developmental perspective. *Developmental Psychology, 18*, 199-214.

Kopp, C.B. (1989). Regulation of distress and negative emotions: A developmental view. *Developmental Psychology, 25,* 343-354.

Ladouceur, C.D., Dahl, R.E., Williamson, D.E., Birmaher, B., Axelson, D.A., Ryan, N.D. et al. (2006). Processing emotional facial expressions influences performance on a Go/NoGo task in pediatric anxiety and depression. *Journal of Child Psychology and Psychiatry, 47,* 1107-1115.

LeDoux, J. E. (1995) Emotion: Clues from the brain. *Annual Review of Psychology*, *46,* 209-235.

Lee, K., Ng, L.E., Ng, S.F. (2009). The contributions of *working memory* and executive functioning to problem representation and solution generation in algebraic word problems. *Journal of Educational Psychology*, *101,* 373-387.

Levin, H.S., Hanten, G., Zhang, L., Swank, P.R., Ewing-Cobb, L., Dennis, M. et al. (2004). Changes in working memory after traumatic brain injury in children. *Neuropsychology, 18*, 240-247.

Lewis, M.D., & Stieben, J. (2004). Emotion regulation in the brain: Conceptual issues and directions for developmental research. *Child Development*, *75,* 371-376.

Lewis, M.D., & Todd, R.M. (2007). The self-regulating brain: Cortical-subcortical feedback and the development of intelligent action. *Cognitive Development*, *22*, 406-430.

Liebermann, D., Giesbrecht, G.F., & Müller, U. (2007). Cognitive and emotional aspects of self-regulation in preschoolers. *Cognitive Development, 22*, 511-529.

Luciana, M. (2007). Special issue: Developmental cognitive neuroscience. *Developmental Review, 27*, 277-282.

Luu, P., Collins, P., & Tucker, D.M. (2000). Mood, personality, and self-monitoring: Negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology*, *129*, 43-60.

Martin, J. M., & Cole, D. A. (2000). Using the personal Stroop to detect children's awareness of social rejection by peers. *Cognition and Emotion, 14,* 241–260.

Mauer, N., & Borkenau, P. (2007). Temperament and early information processing: Temperament-related attentional bias in emotional Stroop tasks. *Personality and Individual Differences, 43,* 1063-1073.

McCandless, S., O'Laughlin, L. (2007). The clinical utility of the Behavior Rating Inventory of Executive Function in the diagnosis of ADHD. *Journal of Attention Disorders, 10,* 381-389.

McInerney, R.J., & Kerns, K.A. (2003). Time reproduction in children with ADHD: Motivation matters. *Child Neuropsychology, 9,* 91-108.

Metcalfe, J., & Mischel, W. (1999). A hot/cool system analysis of delay of gratification: Dynamics of willpower. *Psychological Review, 106,* 3-19.

Mesulam, M.-M. (2002). The human frontal lobes: Transcending the default mode through contingent encoding. In D.T. Stuss, & R.T. Knight (Eds.), *Principles of frontal lobe function*. (pp. 8-30). New York: Oxford University Press.

Michel, J.A., Kerns, K.A., & Mateer, C.A. (2005). The effect of reinforcement variables on inhibition in children with ADHD. *Child Neuropsychology, 11,* 295-302.

Mitchell, R.L.C., & Phillips, LH. (2007). The psychological, neurochemical, and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia, 45,* 617-629.

Moradi, A. R., Taghavi, M. R., Neshat-Doost, H. T., Yule, W., & Dalgleish, T. (1999). Performance of children and adolescents with PTSD on the Stroop colour-naming task. *Psychological Medicine, 29,* 415–419.

Müller, U., Zelazo, P.D., Hood, S., Leone, T., & Rohrer, L. (2004). Interference control in a new rule use ask: Age-related changes, labeling, and attention. *Child Development, 75,* 1594-1609.

Munro, G.E.S., Dywan, J., Harris, G.T., McKee, S., Unsal. A., & Segalowitz, S.J. (2007). ERN varies with degree of psychopathy in an emotion discrimination task. *Biological psychology, 76,* 31-42.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (Vol. 4). New York: Plenum.

Ochsner, K.N., & Phelps, E. (2007). Emerging perspectives on emotion-cognition interactions. *Trends in Cognitive Sciences, 11,* 317-318.

Oliver, A., Johnson, M.H., Karmiloff-Smith, A., & Pennington, B. (2000). Deviations in the emergence of representations: A neuroconstructivist framework for analyzing developmental disorders. *Developmental Science, 3,* 1-40.

Perez-Edgar, K., & Fox, N. (2003). Individual differences in children's performance during an emotional Stroop task: A behavioural and electrophysiological study. *Brain and Cognition, 52,* 33-51.

Perez-Edgar, K., & Fox, N. (2007). Temperamental contributions to children's performance in an emotion-word processing task: A behavioral and electrophysiological study. *Brain and Cognition, 65,* 22-35.

Pfefferbaum, A., Mathalon, D.H., Sullivan, E.V., Rawles, J.M., Zipursky, R.B., & Lim, K.O. (1994). A quantitative magnetic resonance imaging study of changes in brain morphology from infancy to late adulthood. *Archives of Neurology, 51,* 874-877.

Prencipe, A., & Zelazo, P. D. (2005). Development of affective decision-making for self and other: Evidence for the interplay of first- and third-person perspectives. *Psychological Science, 16,* 501-505.

Qu, L., & Zelazo, P.D. (2007). The facilitative effect of positive stimuli on 3-year-olds' flexible rule use. *Cognitive Development, 22,* 456-473.

Rasmussen, C. (2005). Executive functioning and working memory in fetal alcohol spectrum disorder. *Alcoholism: Clinical and Experimental Research, 29,* 1359-1367.

Ridderinkhof, K.R., van den Wildenberg, W.P.M., Segalowitz, S.J., & Carter, C.S. (2004). Neurocognitive mechanism of cognitive control : The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. *Brain and Cognition, 56,* 129-140.

Roberts, R.J., & Pennington, B.F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology, 12,* 105-126.

Rolls, E.T. (2004). The functions of the orbitofrontal cortex. *Brain and Cognition, 55,* 11-29.

Rolls, E.T. (2006). The neurophysiology and functions of the orbitofrontal cortex. In D.H. Zald, & S.L. Rauch (Eds.), *The orbitofrontal cortex* (pp. 95-124). New York: Oxford University Press.

Romine, C.B., & Reynolds, C.R. (2005). A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology, 12,* 190-201.

Rothbart, M.K., & Bates, J.C. (1998). Temperament. In W. Damon & N. Eisenberg. *Handbook of child psychology: Vol. 3 Social, emotional, and personality development.* (pp.105-176). New York: Wiley.

Rothbart, M.K., Ahadi, S.A., Hershey, K.L., & Fisher, P. (2001). Investigations of temperament at 3-7 years: The Children's Behavior Questionnaire. *Child Development, 72*, 1394-1408.

Rydell, A.-M., Berlin, L., & Bohlin, G. (2003). Emotionality, emotion regulation, and adaptation among 5- to 8- year old children. *Emotion, 3,* 30-47.

Rydell, A.-M., Thorell, L.B., & Bohlin, G. (2007). Emotion regulation in relation to social functioning: An investigation of child self-reports. *European Journal of Developmental Psychology.*

Santesso, D.L., Segalowitz, S.J., & Schmidt, L.A. (2006). Error-related electrocortical responses in 10-year-old children and young adults. *Developmental Science, 9,* 473-481.

Schniering, C.A., & Rapee, R.M. (2004). The relationship between automatic thoughts and negative emotions in children and adolescents: A test of the cognitive content-specificity hypothesis. *Journal of Abnormal Psychology, 113,* 464-470.

Segalowitz, S.J., & Davies, P.L. (2004). Charting the maturation of the frontal lobe: An electrophysiological strategy. *Brain and Cognition, 55,* 116-133.

Sesma, H.W., Mahone, E.M., Levine, T., Eason, S.H., Cutting, L.E. (2009). The contribution of executive skills to reading comprehension. *Child Neuropsychology, 15,* 232-246.

Shallice, T. (2002). Fractionation of the supervisory system. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 261-277). New York: Oxford University Press.

Shallice, T., Marzocchi, G.M., Coser, S., Del Savio, M., Meuter, R.F., & Rumiati, R.I. (2002). Executive function profile of children with and without Attention Deficit Hyperactivity Disorder. *Developmental Neuropsychology, 21*, 43-71.

Sherman, E.M.S., Slick, D.J., & Eryl, K.L. (2006). Executive dysfunction is a significant predictor of poor quality of life in children with epilepsy. *Epilepsia, 47,* 1936-1942.

Smits, D.J.M., & Boeck, P.D. (2006). From BIS/BAS to the Big Five. *European Journal of Personality, 20,* 255-270.

Sokol, B., & Müller, U. (2007). The development of self-regulation: Toward the interplay of cognition and emotion. *Cognitive Development, 22,* 401-405.

Stieben, J., Lewis, M.D., Granic, I., Zelazo, P.D., Segalowitz, S., & Pepler, D. (2007). Neurophysiological mechanisms of emotion regulation for subtypes of externalizing children. *Development and Psychopathology, 19,* 455-480.

Stuss, D.T., & Anderson, V. (2004). The frontal lobes and theory of mind: Developmental concepts from adult focal lesion research. *Brain and Cognition, 55,* 69-83.

Stuss, D.T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology, 53,* 401-433.

Taghavi, M.R., Dalgleish, T., Moradi, A.R., Neshat-Doorst, H.T., & Yule, W. (2003). Selective processing of negative emotional information in children and adolescents with Generalized Anxiety Disorder. *British Journal of Clinical Psychology, 42,* 221-230.

Thatcher, R.W. (1997). Human frontal lobe development: A theory of cyclical cortical reorganization. In N.A. Krasnegor, G.R. Lyon, & P.S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp.85-116). Sydney: Brookes.

Toates, F. (2004). Cognition, motivation, emotion, and action: A dynamic and vulnerable interdependence. *Applied Animal Behaviour Science, 86,* 173-204.

Tomarken, A.J., & Keener, A.D. (1998). Frontal brain asymmetry and depression: A self-regulatory perspective. *Cognition and Emotion, 12,* 387-420.

Tottenham, N., Tanaka, J.W., Leon, A.C., McCarry, T., Nurse, M., Hare, T., Marcus, D.J., Westerlund, A., Casey, B.J., & Nelson, C.A. (2008). The NimStim set of facial expressions: Judgments from typical research participants. Unpublished manuscript.

Tranel, D., Anderson, S. W., & Benton, A. (1994). Development of the concept of 'executive function' and its relation to the frontal lobes. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology, 9,* Elsevier Science B.V.

Tsujimoto, S., Kuwajima, M., & Sawaguchi, T. (2007). Developmental fractionation of working memory and response inhibition during childhood. *Experimental Psychology, 54,* 30-37.

Tucker, D.M., & Williamson, P.A. (1984). Asymmetric neural control systems in human self-regulation. *Psychological Review, 91,* 185-213.

Vriezen, E.R., & Pigott,, S.E. (2002). The relationship between parental report on the BRIEF and perofmance-based measures of executive function in children with moderate to severe traumatic brain injury. *Child Neuropsychology, 8,* 296-303.

Vuontela, V., Steenari, M.-R., Carlson, S., Koivisto, J., Fjallberg, M., & Aronen, E.T. (2003). Audiospatial and visuospatial working memory in 6-13 year old school children. *Learning and Memory, 10,* 74-81.

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991).A normative- developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology, 7,* 131–149.

Whalen, P. J., Bush, G., McNally, R. J., Wilhelm, S., McInerney, S.C., Jenike, M. A., & Rauch, S. L. (1998). The emotional counting Stroop paradigm: A functional magnetic resonance imaging probe of the anterior cingulate affective division. *Biological Psychiatry, 44,* 1219–1228.

Williams, D.L., Goldstein, G., Carpenter, P.A. & Minshew, N.J. (2005). Verbal and spatial working memory in autism. *Journal of Autism and Developmental Disorders, 25,* 747-756.

Williams, J.M.G., Mathews, A., & MacLeod, C. (1996). The emotional stroop task and psychopathology. *Psychological Bulletin, 120,* 3-24.

Wodka, E.L., Mahone, E.M., Blankner, J.G., Larson, J.C.G., Fotedar, S., Denckla, M.B., et al. (2007). Evidence that response inhibition is a primary deficit in ADHD. *Journal of Clinical and Experimental Neuropsychology, 29,* 345-356.

Wolfe, C.D., & Bell, M.A. (2003). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology, 44,* 68-83.

Wolfe, C.D., & Bell, M.A. (2007). The interplay of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. *Brain and Cognition, 65,* 3-13.

Zelazo, P.D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 445-469). Malden, MA: Blackwell Publishers.

Appendix A: Child History Questionnaire

This questionnaire is designed as a measure to obtain basic information about your child. Whatever information you may be able to offer will be invaluable in helping us to determine which applicants are most suitable for this study. We appreciate your participation in what we feel is an exciting and important study.

D.O.B.: ______________________ Age: ______
Gender: ☐ M ☐ F

<u>Pregnancy with this child:</u>
Were there any complications with your pregnancy with your child (e.g. anemia, high blood pressure, toxemia, diabetes, infections, hospitalizations, etc.)?

Were any medications or prescription drugs used during the pregnancy (if yes, please explain)?

Were any other substances (such as nicotine, alcohol, herbal remedies, drugs) used during the pregnancy (if yes, please indicate what and the amount of time during the pregnancy – for example, smoked cigarettes during first trimester)?

<u>Complications during birth:</u>

	YES
Induced	☐
C-section	☐
Forceps	☐
Fetal Distress	☐
Breech (feet first)	☐
Twins	☐

Other (e.g. breathing problems, cord around neck)

<u>Newborn:</u>
Following delivery, was the baby:

Blue at birth	☐
Requiring oxygen	☐
Having jaundice	☐
Requiring phototherapy	☐
Having seizures	☐

Other

Was medication used? ☐ yes, reason: ____
☐ no

Childhood:
Has your child experienced any of the following medical problems?

	YES
Problems or delays with early development	☐
Hearing or other sensory impairment	☐
Loss of consciousness	☐
Seizures	☐
Major falls	☐
Motor vehicle accident	☐
Stroke	☐
Major infection (e.g., meningitis, encephalitis)	☐
Head injury	☐
Other serious injuries or illnesses	☐
Major surgeries	☐
Psychiatric problems	☐
Learning problems	☐
Anxiety	☐
Depression	☐

If you answered *yes* to any of these, please provide more details:

Has your child been diagnosed with any other medical, developmental, or psychological disorder/difficulty? If *yes*, please provide details.

Is your child receiving any medication or other type of treatment for these difficulties (e.g., therapies, etc.)? Please provide details of any treatment.

Does your child regularly take any other medications? If so, please specify what medications they are prescribed.

Has your child ever been referred for a school based team or a psychoeductional assessment? If so, indicate when and provide details of results.

Does your child receive special education or remedial services or attend a special class or special school? If yes, please explain what kind of services, class, or school your child attends.

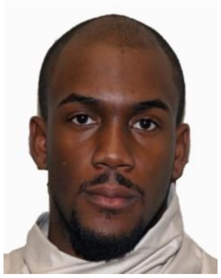
What is the primary language spoken in your child's household?

YES

English ☐
Chinese ☐
Punjabi ☐
German ☐
French ☐
Other language spoken in the household:

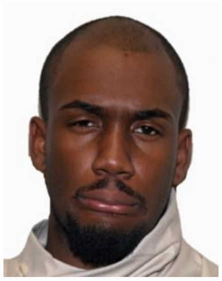
Does your child speak more than one language? If so, which languages are spoken?

Appendix B: Sample Faces in Emotive N-back task



Closed neutral

Closed happy



Closed sad

Appendix C: The Emotion Questionnaire

Anger

1. My child often becomes angry and falls in a bad mood. (EM)

2. When angry or in a bad mood, my child reacts strongly and intensely. (EM)

3. It is easy for others, for instance a parent, to calm him/her down. (ER)

4. He/she has difficulties calming down on his/ her own.-R (ER)

5. When my child is forbidden to do something he/she wants to do, he/she reacts strongly and intensely. (EM)

6. It is easy for others, for instance a parent, to calm him/her down. (ER)

7. He/she has difficulties calming down on his/ her own.-R (ER)

8. When my child gets in conflict with a peer, he/she reacts strongly and intensely. (EM)

9. It is easy for others, for instance a parent, to calm him/her down. (ER)

10. He/she has difficulties calming down on his/ her own.-R (ER)

Fear

11. My child often gets frightened and worried.(EM)

12. When frightened and worried, he/she reacts strongly and intensely. (EM)

13. It is easy for others, for instance a parent, to make him/her calm down. (ER)

14. He/she has difficulties making him/herself calm down.-R (ER)

15. If my child sees or hears something scary, he/she reacts strongly and intensely. (EM)

16. It is easy for others, for instance a parent, to make him/her calm down. (ER)

17. He/she has difficulties making him/herself calm down.-R (ER)

18. If my child becomes scared of the dark, he/she reacts strongly and intensely. (EM)

19. It is easy for others, for instance a parent, to make him/her calm down. (ER)

20. He/she has difficulties making him/herself calm down.-R (ER)

Positive Emotions and Exuberance

21. My child often gets happy, excited and in an exuberant mood. (EM)

22. When in an exuberant mood, my child reacts strongly. (EM)

23. It is easy for others, for instance a parent, to make her/him quiet down. (ER)

24. He/she has difficulties quieting down on his/ her own.-R (ER)

25. When my child wins a contest or a game, he/ she reacts strongly and intensely. (EM)

26. It is easy for others, for instance a parent, to make him/her quiet down. (ER)

27. He/she has difficulties quieting down on his/ her own.-R (ER)

28. When playing a game that he/she enjoys a lot, he/she reacts strongly and intensely. (EM)

29. It is easy for others, for instance a parent, to make him/her quiet down. (ER)

30. He/she has difficulties quieting down on his/ her own.-R (ER)

<u>Sadness</u>

31. My child often becomes sad. (EM)

32. When sad, my child reacts strongly and intensely (e.g., cries, screams). (EM)

33. It is easy for others, for instance a parent, to make him/her feel better (e.g., by comforting, distracting or talking things through). (ER)

34. He/she has difficulties finding something to make him/herself feel better.-R (ER)

35. He/she reacts strongly and intensely. (EM)

36. It is easy for others, for instance a parent, to make him/her feel better. (ER)

37. He/she has difficulties finding something to make him/herself feel better.-R (ER)

38. He/she reacts strongly and intensely. (EM)

39. It is easy for others, for instance a parent, to make him/her feel better. (ER)

40. He/she has difficulties finding something to make him/herself feel better.-R (ER)

EM=emotionality item; ER=emotion regulation item; R=item is reversed in scoring.