The Relation between Executive Function and Treatment Outcome in Children with Aggressive Behaviour Problems: An EEG Study

by

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Department of Human Development and Applied Psychology
University of Toronto

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Abstract

This study examined whether cortical changes underlying treatment for children with aggressive behaviour problems are related to changes in executive function (EF) performance. Fifty-five 8- to 12-year-old clinically-referred children were tested before and after a 14-week treatment intervention. Performance on four EF tasks varying in affective relevance was assessed at each session. EEG was also used to record peak amplitudes for the “inhibitory” N2, an event-related potential, while the children completed an emotion-induction Go/Nogo task. Results showed that changes in N2 amplitudes significantly predicted changes in performance only for the Iowa Gambling Task (IGT) – an affectively relevant task. Subsequent analysis revealed that only children who improved with treatment displayed significant decreases in N2 amplitudes and significant improvement in IGT performance from pre- to post-treatment. These findings suggest that cortical changes underlying successful treatment for children’s aggressive behaviour problems tap improvement in executive functions recruited for emotionally demanding events.
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Chapter 1
Introduction

1 Introduction

1.1 Overview

A defining feature of human development is the individual’s increasing capacity to self-regulate; as individuals develop they become better able to manage and control both their affect and cognition. In fact, inadequate self-regulation is often viewed as a prominent feature of psychopathology. Aggressive behaviour problems, anxiety disorders, and attention-deficit hyperactivity disorder (ADHD), for example, have all been linked to problems inherent in self-regulation. Accordingly, research examining the underlying mechanisms of self-regulation in the context of child psychopathology and treatment is of utmost importance in order to gain insight into the factors that contribute to successful biological and social development and to advance effective treatment interventions.

A suite of capacities essential for effective self-regulation is commonly referred to as executive function (EF). EF is a widely used term that generally refers to processes employed to monitor and control thought and action. Indeed, many EF tasks tap processes of self-regulation such as response control, inhibition, and self-monitoring. Several of these tasks have now been implemented in the testing of children (see Zelazo & Muller, 2002, and below for a review). In order to effectively model developing psychopathology, and to thus better understand the factors that contribute to successful treatment, it seems particularly important to investigate the role of EF. Among children who evidence psychopathology, those with aggressive behaviour problems are a particularly important population with which to study the developmental aspects of self-
regulation. Such children are clearly impaired in their self-regulatory capacities as evidenced by their impulsive, hostile behaviour. Furthermore, problems with aggressive behaviour tend to manifest in middle childhood through to adolescence, when significant developmental change in executive function is occurring. Finally, evidence-based treatments are known to decrease aggressive behaviour problems (Dishion & Andrews, 1995; Dishion, Bullock, & Granić, 2002; Henggeler, Shoenwald, Borduin, Rowland, & Chummingham, 1998; Kazdin, 2002; Snyder & Ingram, 2000). Given that treatment for aggressive behaviour problems can be successful, potential changes in EF capacities that result from treatment can be related to pre-treatment conditions, thus helping clarify differences between poor self-regulation and effective self-regulation.

An interesting aspect to consider when attempting to articulate the role of EF in self-regulation is the distinction between “cool” EF involved in mainly cognitive activities and “hot” EF involved in emotion regulation (Zelazo and Cunningham, 2007; Zelazo and Muller, 2002). Insofar as psychopathology elicits emotional distress in a given individual, improved emotion regulation is likely to play a role in successful intervention. This notion is strengthened when we consider children with aggressive behaviour problems, as many of their issues arise when they are faced with emotional challenges that they cannot regulate. For example, such children become easily frustrated on the sports field, resulting in disputes and fights with other players. Similarly, when children progress from elementary school to high school, there is increasing competition for status and attention, causing certain children to exert their dominance through maladaptive aggressive behaviour. The role of inefficient emotion regulation in aggressive behaviour problems calls for the study of hot EF capacities when social functioning is improved through successful therapeutic intervention.
Recently, at least two studies have directly tested for, and found, cortical changes that correspond with successful treatment for children’s aggressive behaviour problems (Lewis, Granic, Lamm, Zelazo, Stieben, Todd, et al. 2008; Woltering et al., in preparation). These changes were interpreted as indexing improvements in self-regulation. However, whether or not these cortical changes are related to improvements in specific EF capacities remains unclear. The present study was designed to specifically address this question, with the goal of gaining a better understanding of the treatment of childhood psychopathology by investigating changes in hot and cool EF during a period of therapeutic intervention.

1.2 EF and development

Executive function is a widely used term in contemporary psychology and neuroscience. However, it remains an ill-defined term, as pinpointing the exact components of EF is an arduous task. This difficulty stems from the fact that the EF construct attempts to integrate all of the cognitive processes that an individual uses in order to attain his or her goals. Nevertheless, psychologists have proposed various core components in an attempt to best capture executive function. Lezak (1995) identifies executive function as having four components: volition, planning, purposive action, and self-monitoring and regulation of performance. Carlson (2005) reviews a range of literature that includes the following processes under the EF construct: inhibitory control, planning, attentional flexibility, error correction and detection, and resistance to interference. Miyake et al (2000) have examined the connection between three often postulated executive functions – mental set shifting, information updating and monitoring, and inhibition of prepotent responses – and found that these three executive functions, although moderately correlated with each other, are clearly separable. Despite the lack of conceptual unanimity, it is still possible to use elements of the EF construct to investigate and better
understand both the development and treatment of psychopathology. This is especially relevant for externalizing psychopathology, which is often characterized by deficits in inhibition (Albrecht, Banaschewski, Brandeis, Heinrich, & Rothenberger, 2005; Barkley, 1997, 2001), a common EF component across the literature.

Executive function follows a protracted developmental course. Research suggests that its development parallels the development of the prefrontal cortex (PFC; Zelazo, Carlson, & Kesek, 2008). Zelazo and Muller (2002) have reviewed a wealth of literature indicating that EF begins early, around the end of the first year of life. Significant changes occur between the ages of 2 and 5 years, and by 12 years of age, adult levels of performance are attained on several standard EF tasks. EF does continue to develop as performance on certain tasks continues to improve into adulthood.

Although this developmental time course has been charted, much of the research undertaken examines EF in purely “cool” contexts, devoid of emotional significance (Prencipe, Kesek, Cohen, Lamm, Lewis, & Zelazo, in press). This seems at odds with everyday life, where most decisions are made on the basis of some motivationally or emotionally relevant information or in emotionally charged circumstances. In order to better understand self-regulation, Zelazo and Muller (2002) and Zelazo and Cunningham (2007) have approached EF by placing it along a continuum: tasks that are motivationally and emotionally salient are positioned at one end, and those tasks that are more cognitive and abstract are positioned at the other end. The former tasks have been labeled “hot” tasks, whereas the latter tasks have been labeled “cool” tasks. The researchers also suggest a neuroanatomical basis for this distinction, suggesting that the orbitofrontal cortex (OFC) is responsible for hot EF capacities and the dorsolateral prefrontal cortex (dLPFC) is responsible for cool EF capacities. Due to the affectively charged nature of hot
tasks, proficiency with such tasks may correspond with effective emotion regulation. Although there is yet to be a single accepted definition of emotion regulation, it can be understood as cognitive operations that modify the appraisals, feelings, and/or behaviours that accompany emotions (Gross, 2002; Lewis, Todd & Honsberger, 2007; Lewis, Todd, & Xu, 2010). Hence, such operations should be included among the processes that characterize hot EF. Clinically significant externalizing and internalizing disorders have been construed as disorders of emotion regulation (e.g., Bradley, 2000; Calkins, 1994; Calkins, Howse, & Philippot, 2004). Therefore, these specific disorders may implicate inadequate hot EF capacities. As such, to better understand the development of childhood psychopathology, research examining hot EF is imperative. In particular, the incidence and treatment of aggressive behaviour disorders in childhood provide a valuable opportunity to examine the role of hot EF in emotion regulation issues pertinent to child behaviour problems.

Recently, work has begun to study hot EF processes in early childhood. In one study, Prencipe and Zelazo (2005) compared 3- and 4-year-old children on a delay of gratification task that required them to choose between receiving 1 treat (candy, sticker, or penny) immediately, or more (2, 4, 6) treats at the end of the game. Half of the children were asked to make the choice on behalf of the experimenter and half were asked to make the decision for themselves. When asked to make the choice for themselves, 3-year-olds were less likely to delay rewards than 4-year-olds. More interestingly, however, when acting on behalf of the experimenter, 3-year-olds performed similarly to 4-year-olds, suggesting that the younger children’s decision making was hampered by the personal relevance of the rewards. In another study performed by Carlson, Davis and Leach (2005), children were shown large and small piles of candies and told to point to the smaller pile in order to receive the larger, desired pile. Four-year-olds were able to successfully point to the smaller pile, whereas 3-year-olds consistently pointed to the larger pile.
However, 3-year-olds’ performance improved when the candies were replaced with symbols (e.g., a mouse and an elephant). Thus, when emotional salience (created by the desirable candies) was embedded in the task, children were unable to inhibit their propensity to point to the larger reward. Finally, in a third study, Kerr and Zelazo (2004) reported that 4-year-olds were significantly better than 3-year-olds at performing a childhood gambling task (adapted from the Iowa Gambling task [IGT]; Bechara, Damasio, Damasio, & Anderson, 1994) that required children to learn which of two decks of cards was more advantageous in the long run and to consistently choose from this deck. One deck had larger individual rewards (in the form of candies) but produced larger losses, with a low aggregate total. In contrast, the other deck featured smaller rewards and even smaller loses. Despite smaller marginal differences, this deck resulted in a higher total reward at the completion of the task. To successfully choose the more advantageous deck, children arguably had to inhibit their emotional response to larger individual rewards. Similar to the Carlson, Davis, and Leach (2006) study, then, the emotional salience of the gambling task, attributed to the more tempting deck of cards, again disrupted cognitive control in the younger children.

The interval from middle childhood to early adolescence is marked by a dramatic increase in individual autonomy and is a time during which increasing demands are placed on the individual’s self-regulatory capacities (Prencipe et al., in press). This is also a time when behaviour problems become increasingly apparent. Thus, children of this age range provide an ideal demographic from which to investigate EF and how different dimensions of this construct can inform the development of psychopathology. By studying this developmental period and by appealing to the hot and cool EF distinction, therefore, it may be possible to further elucidate factors underlying problems of self-regulation in children.
One such study performed by Hooper, Luciana, Conklin, and Yarker (2004) compared hot and cool EF in 145 children and adolescents ranging in age from 9 to 17 years using the Iowa Gambling Task (IGT) as the hot measure and Digit Span and Go/Nogo tasks as the cool measures. Performance on all measures showed improvements with age. However, performance on the IGT was not predicted by performance on the two cooler tasks, implying that hot EF may proceed on a distinct developmental track. Recently, Prencipe et al. (in press) have completed a provocative study extending this line of reasoning. They examined the development of EF in children between the ages of 8 and 15 years by measuring performance on four EF tasks – Stroop task, Digit Span task, IGT, and a Delay Discounting task. The former two tasks provide a measure of cool EF and the latter two tasks provide a measure of hot EF. Their results indicated that developmental changes associated with improvements on the cooler task were more robust and occurred earlier in age, whereas improvements on the hot EF tasks occurred only in the oldest age group (14 to 15 years). These findings can be interpreted to suggest that during middle childhood to early adolescence EF develops to a point that allows children to cope in cool contexts that do not call for emotion regulation strategies. Alternatively, in affective or hot contexts, many children have not developed the appropriate strategies needed to cope in such situations, resulting in the impulsive behaviour that typically characterizes children in this age range.

The findings presented by Hooper et al. (2004) and Prencipe et al. (in press) highlight an important difference between the development of hot and cool EF. It seems that cool EF develops earlier and is less affected by challenges to self-regulation, whereas hot EF, due to its affective nature, follows a more protracted developmental course and is more susceptible to events that challenge one’s emotional state. This may tend to make hot EF development prone to deviation from the normative course. The relatively late development of hot EF in connection
with emotionally-laden life events, therefore, may engender a particular vulnerability that may underlie the onset or exacerbation of specific psychopathologies related to self-regulation in children and adolescents, such as problematic aggressive behaviour.

The above studies illustrate that there exist significant developmental differences in EF in childhood on tasks that are emotionally salient. Whether or not children can readily develop the capacities needed to handle emotionally demanding events may be an indicator of the developmental path such children will follow. Furthermore, as these children age, they will increasingly confront emotionally demanding events that will shape their social behaviour in different ways.

1.3 EF and psychopathology

Individuals with externalizing psychopathologies are often compromised in one or more executive functions necessary for self-regulation in regard to their social behaviour. For example, antisocial personality disorder (Gorenstien, 1987), psychopathy (Smith, Arnett, & Newman, 1992), ADHD (e.g., Barkley 1997; Benson, 1991; Denkla, 1996; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), and inattention/overactivity difficulties (McBurnett, Harris, Swanson, Pfiffner, Tamm, & Freeland, 1993) have all been linked to deficits in EF. Similarly, research has now associated aggressive behaviour problems in their various forms (e.g., disruptive behaviour disorders, conduct disorder, oppositional defiant disorder) with impairments in EF (e.g., Morgan & Lilienfeld, 2000; Oosterlaan, Logan, & Sergeant, 1998; Seguin, Nagin, Assaad & Tremblay, 2004; Seguin, Pihl, Harden, Tremblay, & Boulerice, 1995). Seguin et al. (1995) reported that deficient EF was the most dominant factor associated with physical aggression in boys aged 6 to 12 years, over and above deficiencies in verbal learning, tactile-
lateral ability, and incidental spatial learning – all factors also found to be associated with aggression.

Although the Seguin et al. (1995) finding indicates that there is a clear link between EF and aggression, the broad scope of cognitive processes that fall under the EF heading begs the question as to precisely which of these processes are most implicated in the development of children’s aggressive behaviour problems. Upon examination of the literature there does seem to be a consensus that deficits in inhibition are a fundamental problem underlying this type of psychopathology. For example, Oosterlaan et al. (1998) performed a meta-analysis of eight studies examining a total of 456 children in the age range 6-12 years diagnosed with oppositional-defiant disorder (ODD), ADHD, or both. The researchers concluded that deficits in response inhibition were present in children with ODD who were not comorbid for ADHD. This countered previous research suggesting that deficits in executive functions in children with aggressive behaviour problems were due to the presence of comorbid ADHD (e.g., Pennington & Ozonoff, 1996; Nigg, Hinshaw, Carte, & Treuting, 1998). Hughes, Dunn, and Watts (1998) found impairments in the inhibition of maladaptive prepotent responses in young children who display aggressive behaviour. Additionally, Hughes, White, Sharpen, and Dunn (2000) tested 40 hard-to-manage 4-year-olds on a set of executive function tasks and found deficits in planning and inhibitory control but set shifting and working memory remained in tact. In a follow-up to this study, the same hard-to-manage children were again administered EF tasks at 7 years of age. This time, results showed impairments only in inhibitory control (Brophy, Taylor, & Hughes, 2002). More recently, in a compelling study, Raaijmakers et al. (2008) examined which EF components were most impaired in preschoolers who show primarily aggressive behaviour. The researchers conducted a factor analysis to assess whether any of the following EF components could be distinguished as a separate construct from the others: working memory, inhibition,
fluency, and set shifting. Of these, only inhibition was clearly separable. More importantly, aggressive behaviour problems were only associated with impairments in this executive function but not in the others.

In sum, most published research suggests that inhibitory deficits play a fundamental role in the development of aggressive behaviour problems. Given that clinically significant aggressive behaviour problems can be understood as disorders of emotion regulation (e.g., Bradley, 2000), it might be that initial deficits in inhibition become magnified when children are met with events that are emotionally challenging, leading to behaviour that is maladaptive and characterized by problems with aggression. If this reasoning is correct, it suggests that successful treatment for this type of psychopathology should be reflected by improvements in performance on hot EF tasks targeting inhibition.

1.4 The relation among event-related potentials, EF, and emotion regulation

Many neuroscientific methods have now been employed to study executive functions. These include the clinical examination of patients with brain lesions for deficits in EF, the use of neurocognitive tasks to measure different EF components, and the use of fMRI to localize hypothesized brain areas involved in EF. A particularly appealing method to study EF developmentally is electroencephalography (EEG). EEG is relatively inexpensive, noninvasive, and can be applied in several different contexts, making it well suited for both children and clinical populations. Moreover, the high temporal resolution afforded by EEG is ideally suited to the investigation of affective cognition given both the immediacy and the variability of emotional responses. EEG operates through the use of an array of electrodes that are placed on
the scalp and record electrical brain wave activity. Importantly, this activity can be averaged over many trials of a given task producing event-related potentials (ERPs) that are hypothesized to signify specific cognitive or perceptual functions. Certain ERPs generated from medial-frontal sites of the scalp are thought to indicate aspects of cognitive control.

One such ERP is the frontal N2, a negative ERP deflection occurring 200-400 ms post-stimulus on trials in which participants must withhold a prepotent response, such as in a Go/Nogo task (Falkenstein, Hoormann, & Hornsbein, 1999; Eimer, 1993; Jodo & Kayama, 1992). The frontal N2 is generally assumed to be a marker of response inhibition (Jodo & Kayama, 1992; Jonkman, Lansbergen, & Stauder, 2003), but is also thought to be involved in conflict monitoring and response selection (Donkers & van Boxtel, 2004; Nieuwenhuis, Yeung, Van den Wildenberg, Ridderinkhof, 2003). In addition, it is often implicated in processes of self-regulation, including action monitoring and emotion regulation.

Several studies have now examined the frontal N2 and its relation to emotion, providing convincing evidence that it is a marker of emotion regulation and therefore may best exemplify brain processes underlying hot EF. Adult studies have shown that higher N2 amplitudes could be predicted by negatively valenced emotional evaluations of self and others (Tucker, Luu, Desmond, et al., 2003) and that negative feedback concerning one’s performance enhanced an N2-like medial-frontal negativity (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). More recently, studies from our own lab have added to this line of research by linking the N2 and emotion regulation in child populations. For example, 4- to 6-year-olds showed greater N2 amplitudes in response to angry faces than in response to happy faces and had N2 latencies that were correlated with fearful temperament (Lewis et al., 2007). Todd, Lewis, Meusel, & Zelazo (2008) also saw greater N2 amplitudes in response to angry rather than happy faces in 4- to 6-
year-olds and an N2-like component that was greater in response to mothers’ angry faces for these children. In another study, a negative mood induction increased N2 amplitudes in normal children aged 13 to 16 years (Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006). Taken together, these findings suggest that the experience of negative emotion is reflected by changes in the frontal N2, specifically marked by larger amplitudes.

Lewis et al. (2006) investigated the relation between the N2 and emotion regulation more closely by examining it developmentally. Using a negative emotion induction task, they tested children 5-16 years of age and found that both N2 amplitudes and latencies decreased with age. This finding is consistent with other developmental research also showing a decrease in N2 amplitude with age (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Davis, Bruce, Snyder, & Nelson, 2003; Jonkman, et al., 2003). Lewis et al. (2006) explained this reduction in N2 amplitude as the development of cortical efficiency; that is, as children develop, less neural processing is required to successfully perform cognitive tasks as compared to earlier in childhood (Casey, Giedd, & Thomas, 2000). Synaptic pruning and myelination may underpin such developmental changes in cortical efficiency (Casey et al., 2000; Luna et al., 2000). Thus, developmental improvements in emotional self-regulation seem to parallel a developmental increase in cortical efficiency, indexed by changes in N2 amplitudes.

In a recent study, Woltering et al. (in preparation) analyzed the frontal N2 in children aged 8-12 years who had been referred for treatment for aggressive behaviour problems. The children were tested before and after a 14-week treatment intervention using a negative-emotion induction Go/Nogo paradigm similar to the one used in the Lewis et al. (2006) study. The results indicated that those children who improved with treatment, based on scores on various behavioural scales (e.g., Child Behaviour Checklist [CBCL]), had smaller N2 amplitudes post-treatment compared
to pre-treatment amplitudes, and those who did not improve had no significant change in N2 amplitudes. Therefore, children who showed improvement in their aggressive behaviour problems also showed corresponding brain activation changes, which are consistent with the cortical efficiency hypothesis.

Finally, in terms of EF, Lamm, Zelazo, and Lewis (2006) have shown that the N2 is related to at least two EF tasks. Smaller N2 amplitudes were correlated with better performance on the Stroop task and the IGT, over and above the effects of age. This finding provides further support for the cortical efficiency hypothesis.

Taken together, the above studies suggest a relationship between cognitive control and the N2. Improvements in self-regulation, corresponding with either normal development or successful treatment, are accompanied by decreased N2 amplitudes, hypothetically reflecting improved cortical efficiency. Additionally, as Lamm et al. (2006) found, a smaller N2 is predictive of better performance on two well-established EF tasks. Thus, it seems plausible to infer that changes occurring in N2 amplitudes that correspond with successful treatment for behavioural problems will also predict changes in performance on EF tasks as successful treatment increases the efficiency of underlying brain mechanisms. Moreover, given that the N2 is significantly implicated in emotion regulation, and treatment for aggressive behaviour problems is geared towards improving emotion regulation capacities, any changes in EF performance should be more likely to occur on hot EF tasks.

1.5 Evidence-based treatment

Several treatment interventions have been used to target aggressive behaviour problems in children. Among these treatments, parent management training (PMT) is one of the most
effective. PMT targets coercive family interactions and replaces lax and aversive parenting practices with mild sanctions (e.g., time out) that contingently target misbehaviour (Forehand, 1986, 1988). Positive parenting practices such as skill encouragement, problem solving, and monitoring are also encouraged (Forgatch & Degarmo, 1999; Martinez & Forgatch, 2001). To enhance the effects of treatment using PMT, this method can be combined with child-focused cognitive behavioural therapy (CBT; Brestan & Eyberg, 1998; Dumas, 1989; Kazdin, 1997). Techniques such as behaviour management, role playing, modeling, problem solving, cognitive restructuring, social and token reinforcements, contingent consequences and generalization activities are used in CBT to target cognitions and aggressive behaviour (Barkley, 2000; Bloomquist & Schnell, 2002). Several studies have tested and proven the effectiveness of PMT (Forgatch & Degarmo, 1999; Martinez & Forgatch, 2001; Patterson, Chamberlain, & Reid, 1982) and PMT combined with CBT (Brestan & Eyberg, 1998; Tremblay, Pagani-Kurtz, Masse, Vitaro, & Pihl, 1995; Webster-Stratton & Hammond, 1997) as interventions for children with aggressive problems. Results for PMT interventions without CBT see children’s level of aggressive behaviour decrease, in part as the result of reduced coercive parenting. When combining CBT and PMT, treatment is found to be even more effective. Studies comparing the effects of CBT, PMT, and combined programs find that combined PMT-CBT is most successful in reducing aggressive behaviour at least in the age range of 5 to 12 years (Kazdin, Siegel, & Bass, 1992; Lochman & Wells, 2004; Webster-Stratton & Hammond, 1997). The current study was undertaken by partnering with community-based agencies that deliver CBT/PMT to examine neural correlates of self-regulation and their relation to EF tasks.
1.6 Design

The present study was designed to investigate the relation between cortical changes underlying successful treatment for children’s aggressive behaviour problems and performance on EF tasks. Specifically, I sought to determine whether amplitude changes in a frontal ERP (the inhibitory N2) would be related to changes in performance on four EF tasks varying in affective relevance. To this end, children referred for aggressive behaviour problems were tested before and after a community-based treatment program. All participants completed the 14-week program that combined PMT and CBT. Before commencement of the treatment and immediately afterward, participants were brought to the laboratory with a parent, tested for performance on the four EF tasks, and took part in a Go/Nogo task integrated with an emotion induction procedure while their brain activity was recorded using electroencephalography (EEG).

The four EF tasks were chosen so that both hot EF and cool EF were represented. The Digit Span subtest of the WISC-III (Wechsler, 1991) and the Stroop Colour-Word task (Stroop, 1935) were the cool measures, while the Iowa Gambling Task (IGT; Bechara et al., 1994) and the Delay Discounting task (Richards, Zhang, Mitchell, & de Wit, 1999) were the hot measures. The Digit Span provides a measure of working memory, while the Stroop task measures selective attention and response inhibition. Both tasks are considered prototypical cool tasks in that they lack affective relevance. In contrast, the IGT and Delay Discounting task both tap aspects of affective decision making, and have been widely used to assess hot EF (e.g., Carlson, Zayas, & Guthormsen, 2009; Green, Frye, & Myerson, 1994; Hooper et al., 2004; Kerr & Zelazo, 2004; Overman et al., 2004; Steinberg et al., 2009).
The Go/Nogo task consisted of three trial blocks. In block A, children would steadily gain points due to the ease of the task (slow stimulus presentation and a generous points allocation algorithm). In block B, the task became much harder (faster stimulus presentation and a less generous points allocation algorithm) and children lost all of their points. Points were regained in block C as the stimulus presentation was again slowed down. The block design was constructed so as to induce negative emotion as the participants lost all their points in block B, and these negative emotions were expected to carry over into block C. To maintain the children’s motivation, they were continuously reminded that if they gained enough points they would be rewarded. During the Go/Nogo task, brain wave activity was recorded using dense-array EEG. The frontal N2 was then extracted for further processing.

In order to tap regulatory mechanisms recruited for emotionally challenging events – relevant for children who cannot control angry impulses – I was particularly interested in cortical changes in block C, when negative emotions were thought to be experienced as the children struggled to regain points lost in block B. To pinpoint the EF mechanisms underlying these changes, I paid particular attention to changes in the hot EF measures, the IGT and the Delay Discounting task.

Lastly, to assess treatment effectiveness the parent-report form of the Child Behaviour Checklist (CBCL; Achenbach, 1991a, 1991b) was used. Children who showed improvement were classified as improvers and those who did not show improvement were classified as non-improvers.

1.7 Hypotheses

1) Cortical changes accompanying treatment for aggressive behaviour problems in children aged 8 to 12 years will be related to changes in their EF performance. Specifically, a change in N2
amplitudes in the C block (after emotion induction) from pre- to post-treatment will predict a change in performance on EF tasks from pre- to post-treatment for hot tasks (the IGT and the Delay Discounting task) but not for cool tasks (the Stroop task and the Backward Digit Span task).

2) N2 amplitudes will decrease from pre- to post-treatment, reflecting increased cortical efficiency, and EF task performance will improve over that same period. Importantly, this pattern of change will only be observed for children who *improved* with treatment and not for those children who did not improve, as measured by changes in CBCL scores.
Chapter 2
Method

2  Method

2.1  Participants

Data for the present study were taken from a larger project designed to measure cortical changes that underlie successful treatment for aggressive behaviour problems in children. Two outpatient treatment programs for children with aggressive behaviour problems were used for recruitment of participants. Mental health professionals, teachers, and/or parents referred participants to either program. Inclusion in the study required that participants score within the clinical or borderline clinical range on the externalizing subscale of the parent-report form of the child behaviour checklist (CBCL; Achenbach, 1991a, 1991b). Children were excluded from participation in the study if they had significant developmental delay or resided outside the Greater Toronto Area where the study was conducted. In addition, only data acquired from children who had sufficient trial counts on the Go/Nogo task and who performed at least one of the four EF tasks for both pre-treatment and post-treatment assessments were analyzed. A total of 55 children, 8 to 12 years of age (M_{age} = 9.47, SD = 1.3; 40 boys) were included in the analysis. Children’s family demographics are reported in Table 1.
2.2 Intervention

The treatment program was a combination of PMT and CBT called Stop Now and Plan (SNAP; Earls Court Child and Family Centre, 2001; Goldberg & Leggett, 1990). It is an evidenced-based intervention that was free of cost for children between the ages of 8 and 12 years and their parents. Therapists overseeing the program were social workers, childcare workers, and MA or PhD level clinical psychology students. Both parents (PMT) and children (CBT) took part in the program, meeting for 3 hours once a week at the community agencies. In the CBT groups, behavioural strategies such as behaviour management, role playing, problem solving, cognitive

Table 1
Children’s Family Demographics (N = 55)

<table>
<thead>
<tr>
<th>Family demographics</th>
<th>Number of children</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Living arrangement</strong></td>
<td></td>
</tr>
<tr>
<td>Both parents</td>
<td>20 (36.4%)</td>
</tr>
<tr>
<td>With mother and step-parent</td>
<td>6 (10.9%)</td>
</tr>
<tr>
<td>With father and step-parent</td>
<td>1 (1.8%)</td>
</tr>
<tr>
<td>Mother only</td>
<td>18 (32.7%)</td>
</tr>
<tr>
<td>Adoptive</td>
<td>4 (7.3%)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (10.9%)</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
</tr>
<tr>
<td>European</td>
<td>43 (78.2%)</td>
</tr>
<tr>
<td>Asian</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>African/Caribbean</td>
<td>6 (10.9%)</td>
</tr>
<tr>
<td>Latin</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>6 (10.9%)</td>
</tr>
<tr>
<td><strong>Mother’s education (highest level completed)</strong></td>
<td></td>
</tr>
<tr>
<td>Did not graduate high school</td>
<td>7 (12.7%)</td>
</tr>
<tr>
<td>High school</td>
<td>9 (16.4%)</td>
</tr>
<tr>
<td>Community college</td>
<td>23 (41.8%)</td>
</tr>
<tr>
<td>University</td>
<td>8 (14.5%)</td>
</tr>
<tr>
<td>Postgraduate/professional degree</td>
<td>5 (9.1%)</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>3 (5.4%)</td>
</tr>
<tr>
<td><strong>Family income ($)</strong></td>
<td></td>
</tr>
<tr>
<td>0-29000</td>
<td>14 (25.6%)</td>
</tr>
<tr>
<td>30,000-49,000</td>
<td>6 (11%)</td>
</tr>
<tr>
<td>50,000 and above</td>
<td>31 (56.4%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>4 (7.3%)</td>
</tr>
</tbody>
</table>
restructuring, social and token reinforcement and generalized activities (Barkley, 2000; Bloomquist & Schnell. 2002) were used to target and change aggressive behaviours and negatively biased cognitions. In the PMT group, parents were taught to use mild sanctions (e.g., time out) that contingently target misbehaviour (Forehand, 1986) in place of coercive or lax discipline strategies. Positive parenting practices such as skill encouragement (e.g., providing contingent praise for success, prompting for appropriate behaviour), problem solving and monitoring (Forgatch & Degarmo, 1999; Martinez & Forgatch, 2001) were also stressed.

The efficacy of the combined PMT and CBT treatment is well established. The SNAP program itself has also been subject to randomized testing and has been proven to be an effective intervention for the treatment of aggressive behaviour problems. A randomized control trial was recently completed (Augimeri, Farrington, Koegel, & Day, 2007) and found that children randomly assigned to the treatment group, compared to an “attention” control group, showed decreases in externalizing scores and that these treatment gains were maintained over 6- and 12-month follow-up periods. A past evaluation that used a within-group design to compare data from baseline, discharge (3 months later), and 6- and 12-month follow-ups for 104 children admitted between 1985 and 1988 also showed significant decreases in children’s externalizing behaviour (as measured by scores on the CBCL; Achenbach, 1991a). Treatment gains for this evaluation were also maintained at 6- and 12-month follow-up periods (Hrynkiw-Augimeri, Pepler, & Golberg, 1993).

2.3 Procedure

Two testing sessions were conducted in the laboratory, one immediately prior to the commencement of the treatment and a second immediately after. During each session children
were accompanied to the laboratory by a parent and familiarized with the testing environment. Parental consent and child consent were obtained. Parents were then asked to sit in an adjacent room to complete the CBCL while their child took part in the testing. Children first completed the four EF tasks. They were then taken to the EEG testing room where they completed the computerized Go/Nogo task while their brain activity was recorded using EEG.

Four EF tasks were administered to participants in a quiet room, with no distracting elements. The experimenter and participant were seated side by side at a table with the participant seated in front of a computer screen. The following tasks were presented in a fixed order alternating between hot and cool tasks: IGT, Stroop Colour-word, Delay Discounting, and Digit Span. Upon completion of the four EF tasks, participants were told that they would next play the EEG computer game. Before entering the EEG testing room participants were shown two bins of toys. One bin contained small, less desirable toys such as small plastic cars, while the other bin contained larger, more desirable toys such as large action figures, stuffed animals, games, and $10 gift certificates from a local music store. Participants were asked to choose a toy from each of the bins. They were then told that if they performed successfully on the EEG computer game (measured by an accumulation of points), they would receive the more desirable toy, but that if they performed poorly, they would receive only the less desirable toy. Such measures were undertaken so as to ensure that children were motivated to do well on the Go/Nogo task, and to elicit challenging emotions, as detailed later. Participants were then taken to the EEG testing room and seated in front of a computer monitor at a pre-specified distance. They were instructed to make responses during the game by clicking a button on a response pad using the index finger of their dominant hand (writing hand). Children were then given instructions on how to play the game and given a practice block of 30 trials to ensure proficiency with the task.
2.4 Measures and tasks

2.4.1 Child Behaviour Checklist (CBCL)

The CBCL (Achenbach, 1991) is a standardized, highly reliable, and valid measure of children’s emotional and behavioural problems. Parents completed the CBCL at both pre- and post-treatment assessments, indicating whether, and to what degree, their child exhibited a list of symptoms. The measure yields standardized T scores for numerous subscales. For the present study, only the externalizing subscale, which combines scores for aggressive behaviour and delinquent behaviour, was used.

2.4.2 EF tasks

2.4.2.1 Iowa Gambling Task (IGT)

Children were administered a computerized version of the IGT (Bechara et al., 1994). In this task, participants were shown four decks of cards (A, B, C, D). They could select cards from a deck by clicking on the deck with the mouse. When turned, the card revealed a combination of gains and losses (measured in play money). At the beginning of the task, participants were given $2000 and instructed to try to win as much money as possible by choosing cards from any of the four decks (one card per trial). Participants were told that when a card was flipped over they would win the amount of money shown on the card, but that occasionally the card would also display a monetary loss that would be deducted from their total earnings. They were also instructed that the money should be treated as real money. In addition, children were told that some of the decks were more profitable than others. In fact, the task was designed so that choosing consistently from two of the decks (the advantageous decks) would result in a net gain,
whereas choosing consistently from the other two decks (the disadvantageous decks) would result in a net loss. Decks A and B produced large monetary gains but even larger losses, so that, over consecutive trials, choices from these decks resulted in a substantial loss of money. Decks C and D, on the other hand, produced smaller monetary gains, but even smaller losses, resulting in an increase in money over consecutive plays. The number of trials to be played was not specified to the participants, and, regardless of their choices, the game ended at 100 trials.

A performance score was computed by subtracting the number of disadvantageous choices from the number of advantageous choices for the last 20 trials of the task. The use of later trials on the IGT has been shown to provide a more reliable index of performance (Monterosso, Ehrman, Napier, O’Brien, & Childress, 2001). Scores ranged from -20 to +20, with positive difference scores indicating relatively good performance and negative difference scores indicating relatively poor performance.

2.4.2.2 Stroop Colour-Word task
In the Stroop Colour-Word task, participants were shown a series of words and asked to name the colour in which each word appeared (Stroop, 1935). Each series consisted of 21 words printed on a laminated card. Participants were presented with two conditions and asked to complete the list of words as quickly as possible without errors. The first condition was a list of congruent items (e.g., the word RED in red ink) and the second condition was a list of incongruent items (e.g., the word RED in blue ink). Performance for each condition was measured using a stopwatch, and the number and types of errors (corrected or uncorrected) were recorded. To account for errors, twice the average time per word for each corrected error was subtracted from the total reaction time per condition (Stroop, 1935). Performance on incongruent trials was then subtracted from performance on congruent trials to yield a measure
of interference. This interference score was used as a measure of performance in the analysis. Higher scores indicated better performance.

2.4.2.3 Delay Discounting task

A computerized Delay Discounting task was adapted from Richards et al. (1999). The task was used to measure the rate at which participants discounted delayed reinforcers. Participants were given a series of choices between a small immediate amount of money and $10, which would be delayed by 1, 2, 30, 180, or 365 days. For each delay period, an adjusting-amount algorithm adjusted the magnitude of the immediate reinforcer until it was equal in value to the delayed reward. The value of the adjusted immediate reinforcer was referred to as the indifference point (ID). A measure of performance was obtained by computing $k$ values for each participant. The $k$ value represents the rate at which participants discounted the delayed reward in favour of the immediate reward. $k$ values were computed by fitting participants’ data to the hyperbolic function, $ID = A/(1+kD)$ (Mazur, 1987). In this function, $A$ is the nominal amount of the delayed reward ($10) and $D$ is the length of the delay. Once $k$ values were computed, they were log transformed since their distribution was skewed, which is typical for this type of data (Johnson & Bickel, 2002). Lower log $k$ values indicated better performance.

To ensure appropriate engagement with the task, participants were told that when finished, one of their choices would be granted at random. Regardless of their choices, however, children were given $10 upon completion of the task.
Digit Span task

Participants completed the Digit Span subtest of the WISC-III (Weschler, 1991). The subtest was comprised of two tests: Forward Digit Span and Backward Digit Span. The former required participants to repeat verbatim increasingly longer strings of digits to the examiner, and the latter required participants to repeat the digits in reverse order. The examiner read each digit at a rate of 1 digit/s. Two trials were administered at each string length. The test was ended if participants erred on both trials of a single string length. If they successfully repeated the digits, the string length was increased by one digit. Only performance scores from the Backward Digit Span were used in the analysis, and were computed by counting the highest number of digits repeated in the correct order. Higher scores indicated better performance.

For each of the four EF tasks, outlier analysis was performed. Participants were considered outliers and removed from further analysis if they scored above or below three standard deviations from the mean score for each task. One outlier was deleted from both the IGT and Backward Digit Span analyses, two outliers were deleted from the Stroop task analysis, and three outliers were deleted from the Delay Discounting analysis.

ERP task

The emotion induction Go/Nogo task was adapted from a task used by Garavan, Ross, and Stein (1999), and presented using E-Prime software (Psychological Software Tools, Pittsburgh, PA). During the task, a letter would appear at the centre of the screen. Participants were required to press a button as accurately and quickly as possible when the letter appeared – the Go condition. If the letter appeared twice in succession, however, participants were required to withhold their response – the Nogo condition. After the practice block, children completed three blocks (A, B, C): block A and C consisted of 200 trials (including 66 Nogo trials in a pseudorandom sequence).
and block B consisted of 150 trials (40 Nogo trials). Each block used different pairs of similarly shaped letters (Block A: x, y; Block B: o, p; Block C: u, d) to enhance novelty without modifying the level of difficulty. The error rate for Nogo trials for all three blocks was kept at 50 ± 10% by adjusting the stimulus duration, and thus the intertrial interval, dynamically. When a correct Nogo trial followed a correct Go trial, stimulus duration was decreased by 50 ms in block A and C and 60 ms in block B. When an incorrect Nogo trial occurred, the stimulus duration was increased by 50 ms in block A and C and by 30 ms in block B. The dynamic adjustment of the stimulus time was intended to provide the same level of challenge for all participants irrespective of age, and to obtain a sufficient number of correct Nogo trials for ERP averaging. Error feedback was provided by a red bar in the middle of the screen following incorrect responses, omitted responses, and late responses.

The block paradigm was created to successfully induce emotion. Each time 20 trials had been completed a point total appeared on the screen. Points were accumulated for correct Nogo responses and taken away for incorrect Nogo and Go responses. In block A, children gained points quite steadily, usually to over 1000. In block B, however, the difficulty of the task was significantly increased by a combination of the dynamic adjustment (see above) and changes to the point adjustment algorithm. By the end of block B all points were lost. In block C, with a return to the more generous algorithm, children regained their points to win the more desirable toy. At the beginning of the task and at the start of each block, children were reminded that a high number of points was needed to win the desirable toy.
2.5 EEG data collection

EEG was recorded using a 128-channel Geodesic Sensor Net and sampled at 250 Hz, using EGI software (Electrical Geodesic, Inc., Eugene, OR). Impedances for all channels were kept below 50 kΩ. All channels were referenced to Cz (channel 129) during recording. Eye blink and eye movement artifacts (70 µV threshold), signals exceeding 200 µV, and fast transits exceeding 100 µV were removed during the averaging process before the EEG was re-referenced to an average reference (Bertrand, Perrin, & Pernier, 1985; Tucker, Liotti, Potts, Russell, & Posner, 1993). Data were filtered using an FIR bandpass filter with a low pass frequency of 30 Hz and a high-pass frequency of 1 Hz. Data were then segmented into epochs from 400 ms before to 1000 ms after stimulus onset for Nogo trials and baseline corrected for the 400 ms preceding the stimulus. Correct Nogo trials that were not preceded by and followed by correct Go trials were removed (they most likely reflected attentional lapses or chronic non-responding). The Nogo N2 was coded as the largest negative deflection with a medial-frontocentral topography occurring between 200 and 500 ms post-stimulus. A coder blind to any participant characteristics performed coding.

The present study was only concerned with the analysis of the frontal Nogo N2 from the C block. Because the first step in the statistical analysis (see below) involved a calculation using both pre- and post-treatment N2 values, correct Nogo trial counts from the C block for pre- and post-treatment were averaged together. Only those participants who had an average of 20 or more artifact-free trials were included in the analysis.
2.6 Statistical analysis

All statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS), Version 17. Means and standard deviations were calculated for all variables of interest. In order to perform the primary analysis, change scores were calculated for both N2 amplitudes and EF task scores by subtracting pre-treatment values from post-treatment values. Four hierarchical multiple linear regression analyses were then used to test whether a change in N2 amplitudes predicted a change in EF performance for the four different tasks. A subsequent analysis employed three repeated-measures analyses of variance (ANOVAs) in order to test planned contrasts. These planned contrasts were used to assess whether changes in N2 amplitudes and EF task performance from pre- to post-treatment were observed only for children who improved with treatment.
Chapter 3
Results

3 Results

3.1 CBCL

Based on the results from the externalizing subscale of the CBCL, children were split into two groups: improvers and non-improvers. In order to be included in the improver group, a drop in score of at least 0.5 standard deviations ($T$ score = $\geq5$) was required (Hodges et al, 1998; Hodges & Wong, 1996). Based on this criterion, 29 children were classified as improvers and 26 children were classified as non-improvers. Table 2 presents the means and standard deviations for CBCL scores from the externalizing subscale for improvers and non-improvers at pre- and post-treatment.

Table 2

Descriptive Statistics for CBCL Externalizing Scores

<table>
<thead>
<tr>
<th></th>
<th>$M$</th>
<th>$S.D.$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Improvers ($N = 29$)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>72.07</td>
<td>6.92</td>
</tr>
<tr>
<td>Post-treatment</td>
<td>62.31</td>
<td>9.24</td>
</tr>
<tr>
<td><strong>Non-improvers ($N = 26$)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>69.62</td>
<td>5.45</td>
</tr>
<tr>
<td>Post-treatment</td>
<td>69.15</td>
<td>6.04</td>
</tr>
</tbody>
</table>
3.2 Behavioural analysis: EF tasks

Performance scores on all four EF tasks were calculated for both pre- and post-treatment sessions. In addition to pre- and post-treatment scores, change scores were computed by subtracting pre-treatment scores from post-treatment scores for all four tasks. The behavioural data for the four EF measures are summarized in Table 3.
Table 3

*Descriptive Statistics for EF tasks*

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pre</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa Gambling Task (N = 47)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>-3.49</td>
<td>6.96</td>
<td>-18.00 to 8.00</td>
</tr>
<tr>
<td>Post</td>
<td>-0.60</td>
<td>7.38</td>
<td>-16.00 to 20.00</td>
</tr>
<tr>
<td>Change</td>
<td>2.89</td>
<td>8.51</td>
<td>-18.00 to 20.00</td>
</tr>
<tr>
<td>Stroop Interference (N = 50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>-13.71</td>
<td>7.36</td>
<td>-33.18 to 2.79</td>
</tr>
<tr>
<td>Post</td>
<td>-10.69</td>
<td>5.53</td>
<td>-23.38 to 1.05</td>
</tr>
<tr>
<td>Change</td>
<td>2.98</td>
<td>8.23</td>
<td>-19.06 to 16.99</td>
</tr>
<tr>
<td>Delay Discounting (N = 45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>-1.25</td>
<td>1.24</td>
<td>-4.17 to 1.18</td>
</tr>
<tr>
<td>Post</td>
<td>-1.31</td>
<td>1.28</td>
<td>-3.76 to 1.18</td>
</tr>
<tr>
<td>Change</td>
<td>-0.05</td>
<td>1.1</td>
<td>-2.35 to 2.42</td>
</tr>
<tr>
<td>Backward Digit Span (N = 52)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>4.19</td>
<td>1.22</td>
<td>2 to 7</td>
</tr>
<tr>
<td>Post</td>
<td>4.69</td>
<td>1.60</td>
<td>2 to 9</td>
</tr>
<tr>
<td>Change</td>
<td>0.50</td>
<td>1.53</td>
<td>-2 to 3</td>
</tr>
</tbody>
</table>

*Note.* Higher scores indicate better performance for all EF measures except the Delay Discounting task, in which case lower scores indicate better performance.

### 3.3 Behavioural analysis: Go/Nogo task

Behavioural data for performance on the Go/Nogo task from the C block are presented in Table 4. Data are shown for pre- and post-treatment sessions (N = 55). Performance on the Go/Nogo
task was measured by reaction times (RTs) on correct Go trials and also by stimulus duration. Better performance on the task resulted in shorter stimulus duration as a result of the dynamic adjustment (e.g., fewer errors resulted in faster stimulus durations). Thus, stimulus duration was considered the best summary measure of performance accuracy.

Table 4

*Descriptive Statistics for the Go/Nogo task during the C block*

<table>
<thead>
<tr>
<th>Measure</th>
<th>M</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go RTs (ms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>404.73</td>
<td>66.29</td>
<td>299.55 to 579.58</td>
</tr>
<tr>
<td>Post</td>
<td>358.10</td>
<td>54.71</td>
<td>260.24 to 530.31</td>
</tr>
<tr>
<td>Go/Nogo stimulus (ms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>633.74</td>
<td>114.56</td>
<td>471.21 to 911.48</td>
</tr>
<tr>
<td>Post</td>
<td>567.09</td>
<td>110.66</td>
<td>427.50 to 865.55</td>
</tr>
<tr>
<td>Go accuracy (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>.73</td>
<td>.05</td>
<td>.65 to .78</td>
</tr>
<tr>
<td>Post</td>
<td>.76</td>
<td>.05</td>
<td>.65 to .89</td>
</tr>
</tbody>
</table>

3.4 ERP analysis

To obtain a reliable measure of the frontal N2, N2 amplitudes were recorded from three medial-frontocentral sites (Fz, FCz, and Cz) during the C block of the Go/Nogo task, and averaged together. N2 amplitudes measured at pre-treatment were then subtracted from N2 amplitudes measured at post-treatment to create a change score.
Next, to assess whether a change in N2 amplitudes predicted a change in EF performance, a series of multiple linear regressions was performed. For each of the four EF tasks, a regression analysis was conducted using the change score for task performance as the dependent variable (Table 5). Two steps were included in each regression. In the first step, age and gender were entered as predictors in order to control for the variance accounted for by these two variables. Trial count was also entered as a predictor in the first step, since the number of trials can potentially affect ERP amplitudes. In the second step, the change score for N2 amplitudes was entered.

Table 5 displays the results for each of the four regressions, showing only the prediction by the N2 variable for each EF measure. For detailed tables displaying the results for each step in the regressions for each task see Appendix A. As can be seen in Table 5, N2 amplitudes significantly predicted performance on the IGT only. However, N2 amplitudes also predicted Backward Digit Span performance at trend level ($p = .06$). Table 6 shows $R^2$-change values, reflecting the amount of variance in EF change accounted for by change in N2 amplitudes.
Table 5  
*Summary of Regression Analyses for N2 Amplitudes Predicting EF Performance for each EF task*

<table>
<thead>
<tr>
<th>EF task</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa Gambling Task</td>
<td>1.16</td>
<td>.45</td>
<td>.37*</td>
</tr>
<tr>
<td>Stoop Interference</td>
<td>.34</td>
<td>.44</td>
<td>.12</td>
</tr>
<tr>
<td>Delay Discounting</td>
<td>.09</td>
<td>.06</td>
<td>.22</td>
</tr>
<tr>
<td>Backward Digit Span</td>
<td>.15</td>
<td>.08</td>
<td>.27*</td>
</tr>
</tbody>
</table>

*Note.* Age, gender, and trial count were entered into the first step for each analysis. Values shown here are for the prediction by N2 amplitudes when entered in the second step.

+ *p < .10. *p < .05.

Table 6  
*Multiple Regression Analyses showing R²-Change Values, reflecting the amount of Variance in EF Change accounted for by Change in N2 Amplitudes*

<table>
<thead>
<tr>
<th>EF task</th>
<th>ΔR²</th>
<th>F change</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa Gambling Task</td>
<td>.14</td>
<td>6.57</td>
<td>.01</td>
</tr>
<tr>
<td>Stroop interference</td>
<td>.01</td>
<td>0.23</td>
<td>.64</td>
</tr>
<tr>
<td>Delay Discounting</td>
<td>.05</td>
<td>2.22</td>
<td>.14</td>
</tr>
<tr>
<td>Backward Digit Span</td>
<td>.07</td>
<td>3.60</td>
<td>.06</td>
</tr>
</tbody>
</table>

*Note.* Age, gender, and trial count were entered into the first step for each analysis. ΔR² reflects the amount of variance in EF change accounted for by change in N2 amplitudes when the N2 variable was entered in the second step.
Based on the findings from the regression analyses indicating that change in N2 amplitudes significantly predicted change in IGT performance, and predicted change in Backward Digit Span performance at trend level, I chose to continue investigating only data from these three variables.

In order to perform planned contrasts to test for differences between improvers and non-improvers, a 2 (Session: pre- vs. post-treatment) x 2 (Group: improver and non-improver) repeated-measures ANOVA was conducted for N2 amplitudes, IGT performance, and Backward Digit Span independently. Age and gender were entered into the three models as covariates, and trial count was also included as a covariate in the N2 analysis. Results indicated no group-by-session interaction predicting N2 amplitudes, $F(1, 49) = 2.30, p = .14$. However, planned contrasts revealed a significant decrease in N2 amplitudes for improvers ($p = .03$), and no change for non-improvers ($p = .97$), as illustrated in Figure 1. Results also indicated no group-by-session interaction, $F(1, 41) = 1.14, p = .29$, predicting IGT performance. However, planned contrasts revealed a significant improvement in IGT performance for improvers ($p = .02$), and no change for non-improvers ($p = .43$), as illustrated in Figure 2. Lastly, results once again indicated no group-by-session interaction, $F(1, 48) = .03, p = .86$, predicting Backward Digit Span performance. Unlike the IGT analysis, however, planned contrasts did not reveal a change in performance for improvers ($p = .11$), as shown in Figure 3. Planned contrasts also revealed no change in performance for non-improvers ($p = .10$; Figure 3). These findings demonstrate that both cortical changes and improvement on the IGT from pre- to post-treatment occurred only for children for whom treatment was successful, as measured by changes in CBCL scores.
Figure 1. Group differences in N2 amplitudes from pre- to post-treatment.
Figure 2. Group differences in IGT performance from pre- to post-treatment. Higher scores indicate better performance.
Figure 3. Group differences in Backward Digit Span performance from pre- to post-treatment. Higher scores indicate better performance.
Chapter 4
Discussion

4 Discussion

This study was designed to determine whether successful treatment for children with aggressive behaviour problems would be related to changes in EF performance associated with changes in frontocentral ERPs. The brain measure of interest was the frontal N2, which is thought to tap inhibitory control mechanisms. Moreover, the N2 is also significantly implicated in emotion regulation (e.g., Lewis, et al., 2006; Luu et al., 2003; Todd et al., 2008; Tucker et al., 2003). Given that the present study recorded the N2 while participants engaged in an emotional Go/Nogo task, and because of the N2’s involvement in emotion regulation, I hypothesized that any changes occurring in N2 amplitudes with treatment would correlate with changes in hot executive function performance only. Subsequently, I predicted that N2 amplitudes would decrease from pre- to post-treatment and hot EF performance would improve over that same period only for those children whose relevant CBCL scores dropped significantly.

4.1 Relation between N2 amplitudes and the EF tasks

As expected, N2 amplitudes recorded during the Go/Nogo task significantly predicted change in performance on the IGT, a hot EF task, but did not significantly predict change in performance on the cool EF measures – the Backward Digit Span and the Stroop task. The Go/Nogo task used in this study was designed as an emotional version of the more common Go/Nogo paradigm. The N2 component recorded during the Go/Nogo task was assumed to reflect the
activity of brain systems that are used in emotion regulation (e.g., Lewis et al., 2006, 2008). As argued in the introduction, emotion regulation is thought to be underpinned by hot EF capacities. Thus, it was not expected that N2 amplitudes would predict performance on cool EF measures.

The relationship between N2 amplitudes from the Go/Nogo task and the IGT was expected, as both tasks are inhibition tasks that are complicated by the need for emotion regulation. Again, the Go/Nogo task was constructed so as to embed emotion within the task, and data for the present study were taken from the C block, a time during which the children are thought to be most emotionally aroused due to the loss of points and the likely increase in negative emotion in the B block. Hence, during the C block hot EF capacities were assumed to be maximally recruited; children needed to inhibit a motor response in the nogo condition while under significant emotional strain. Success on the IGT involved two broad constraints: to successfully choose the right decks and to manage an emotionally driven impulsive reaction to choose from the more tempting but disadvantageous decks. Insofar as subjects were able to better regulate their affective responses they could maximize their performance on the task. Therefore, both the IGT and the Go/Nogo task require regulation of an affective state to achieve a cognitive goal, thus requiring inhibitory processes. ERPs derived from the Go/Nogo task were assumed to index brain mechanisms underlying hot EF, and, hence, it was expected that these ERPs would correspond with performance change on a task designed to assess hot EF.

A further reason why N2 amplitudes predicted IGT performance may involve the nature of Go/Nogo tasks. Such tasks typically require a rapid inhibition of response. Thus, it is likely that Go/Nogo tasks rely predominantly on activation from the ventral prefrontal system, which is generally assumed to be responsible for reactive, immediate responses, and particularly response inhibition (e.g., Philips, Ladouceur, & Drevets, 2008). Similarly, hot tasks such as the IGT are
thought to rely on the ventral system, specifically the orbitofrontal cortex (OFC; Zelazo and Mueller, 2002). From this viewpoint, then, both the IGT and the Go/Nogo task rely on the same brain areas, and, hence, the greater the chance that brain activation recruited for the Go/Nogo task will correspond with performance on the IGT. This conjecture is supported by findings from the study by Lewis et al. (2008), which used a similar emotional Go/Nogo paradigm as the present study and produced a decrease in activation only in ventral regions of the PFC and no change in activation in dorsal regions, suggesting that the ventral PFC is most sensitive to performance on this type of Go/Nogo task. Additionally, the orbitofrontal region has been identified as a likely cortical generator of the N2 in studies with children and adults (Bokura, Yamaguchi, & Kobayashi, 2001; Lavric, Pizzagalli, & Forsmeier, 2004; Pliszka, Liotti, & Woldorff, 2000), and in studies from our own lab using the emotional Go/Nogo paradigm (Lewis, Granic, et al., 2006; Lewis, Lamm, et al., 2006). Thus, it is possible that the N2 recorded in the present study was generated primarily from the OFC, further supporting the likelihood that N2 amplitudes from this task are related to hot EF skills necessary for IGT performance. This line of reasoning is also consistent with the finding that cool EF measures did not significantly relate to the N2 from the emotional Go/Nogo task, since proficiency with such measures relies on the dorsal system as opposed to the ventral system (Zelazo & Mueller, 2002).

The lack of a significant association between the N2 and the Delay Discounting task contradicts my hypothesis; given that the Delay Discounting task and IGT are both considered hot EF tasks, a similar pattern of results was expected. However, there is strong evidence to indicate that inhibition and delay discounting are two independent constructs measuring different aspects of impulsivity (e.g., Reynolds, Richards, & de Wit, 2006). For instance, impulsivity due to acute alcohol consumption has been found to affect inhibition (de Witt, Crean, & Richards, 2000) but to have no effect on delay discounting (Ortner, MacDonald, & Olmstead, 2003; Richards et al.,
Because the IGT more directly measures inhibition, and the Delay Discounting task more directly measures the relative value of immediate versus delayed rewards, it follows that the IGT, and not the Delay Discounting task, would be related to the N2 – again, a brain measure generally believed to index inhibition.

The above findings call into question whether the Delay Discounting task and IGT share a similar position on the hot/cool EF continuum. Besides affective content, hot EF tasks may tap a temporal feature such as motivational pressure, defined as the immediacy and consistency with which the motivational saliency of the task is reinforced. The crucial additional element might then be the rate of feedback: tighter feedback between response and outcome might maintain the motivational pressure of a highly affective stimulus, while slower, less immediate feedback might tend to dilute it. Treating affective relevance as signal strength, a signal beamed ten times per second would be more urgent than one beamed every ten seconds. We can see how the IGT and the Delay Discounting task vary in this feedback dimension. The IGT provides affectively laden feedback every trial; in contrast, the Delay Discounting task does not confront the subjects explicitly with the consequences of their choices. The disparity in performance is never made immediately salient to them; it requires inference or abstraction. Thus, the IGT maintains motivational pressure much more consistently and overtly than the Delay Discounting task. Considering the hot/cool classification on a continuum, it might prove more valuable to position the IGT at the far, “hot” end because it is both high in affective content and motivational pressure. In contrast, the Delay Discounting task might be better positioned near the middle of the continuum, as it lacks motivational pressure but maintains affective content since subjects are motivated to obtain money.
Although N2 amplitudes did not significantly predict performance on the cool EF measures, they did predict performance on the Backward Digit Span at trend level \((p = .06)\). Concerning this finding, working memory is in part an inhibitory process, as it requires the suppression of extraneous information while maintaining and manipulating relevant information. Insofar as the N2 is thought to index both emotional inhibition and more general inhibitory processes, it would be expected that variance in working memory tasks would be reflected in some changes in N2 amplitudes. Although the Backward Digit Span may tap some form of inhibition, the absence of affective content may explain the lack of anything more than a trend level relationship.

### 4.2 Clinical change: N2 amplitudes and IGT performance

When examining changes in N2 amplitudes and changes in IGT performance from pre- to post-treatment, the results supported the prediction that only those children who improved with treatment would show significant differences in both variables. Specifically, only for improvers did N2 amplitudes decrease and IGT performance improve. Additionally, Backward Digit Span performance was also tested for differences between improvers and non-improvers due to the trend level association between performance on the task and N2 amplitudes (see above). On this task, neither improvers nor non-improvers showed significant differences from pre- to post-treatment. However, given that the treatment was aimed at improvements in emotion regulation, additional benefits to working memory were not expected.

A reduction in N2 amplitudes for improvers is consistent with a related study that found a decrease in N2 amplitudes when examining a larger sample of children who underwent the same treatment intervention (Woltering et al., in preparation). As previously discussed, improved cortical efficiency is one of the main hypotheses explaining the decrease in N2 amplitudes from
pre-to post-treatment and over development. Not only is this explanation consistent with the present findings, but also with those reported by Woltering et al. (in preparation). That is, those children who showed improved self-regulation with treatment also showed reduced activation in areas of the PFC thought to become more efficient. Woltering et al. interpreted their findings as suggesting that performance on the Go/Nogo task became more automatic and required less effort. In addition, Woltering et al. found a decrease in ventral and dorsal PFC activation, and Lewis et al. (2006) found a decrease in ventral PFC activation when using a paradigm similar to the Woltering et al. study. Thus, considering the results of the present study in connection with the two studies above, it seems that successful treatment is accompanied by reduced activation in the PFC in general and in the ventral PFC in particular. This phenomenon parallels an increase in cortical efficiency thought to characterize normal development (e.g., Casey et al., 2000).

In the present study, improved performance on the IGT corresponded with decreased aggressive behaviour problems; this lends credence to the notion that there are common cognitive processes underlying both. As previously mentioned, the IGT requires participants to inhibit their propensity to choose from the more desirable, yet disadvantageous, decks. Thus, it was expected that individuals with aggressive behaviour problems would perform poorly on the task due to their impulsive style and poor self-regulation. In essence, they may have been unable to suppress their affective response to large rewards, and thus tended to select from the disadvantageous decks. Indeed, this connection between poor performance on the IGT and aggressive behaviour problems has also been found in other studies (e.g., Best, Williams, & Coccaro, 2002; Blair, Colledge, & Mitchell, 2001). Insofar as hot EF is implicated in emotion regulation, treatments aimed at emotion regulation should also see improved performance on tasks requiring hot EF, as was the case in this study.
In light of the findings related to the main hypothesis, which associated changes in N2 amplitudes with changes in IGT performance, it is possible to extend the argument for cortical efficiency to performance on the IGT. Cortical processes underlying specific cognitive skills that become more efficient should, in theory, lead to better performance on tasks requiring such skills. This idea finds support in Lamm et al.’s (2006) study, which related smaller N2 amplitudes to better EF performance. Hence, a decrease in N2 amplitudes was likely reflected in clinical change with treatment and better performance on the IGT because both tapped brain processes that the N2 is thought to index – namely, response inhibition, one of the important capacities utilized in emotion regulation. This conclusion is further supported by the data on the non-improving children; whereas the children who improved showed reduced N2 amplitudes and improved IGT performance, the non-improvers showed no change in N2 amplitudes or IGT performance.

In sum, aggressive behaviour problems can be understood as resulting from deficits in emotion regulation underpinned by hot EF capacities – deficits that correspond with a less mature and less efficient style of cortical response. The present findings indicate that these deficits are tapped by differences in cortical activation patterns as well as reduced performance on hot EF tasks. Correspondingly, improved capacity for self-regulation was reflected by improved performance on a hot EF measure, but only for children whose aggressive behaviour problems improved with treatment. Consequently, this change in EF performance was probably not simply a result of practice effects or some other superficial factor, but due to a fundamentally different way of regulating impulses.
4.3 Implications for the development of aggressive behaviour problems

As discussed previously, it appears that deficits in inhibition in early childhood may be associated with aggressive behaviour problems later in life (e.g., Brophy, et al., 2002; Kochanska, Murray, & Harlan, 2000). How could this initial deficit in inhibition become amplified, manifesting in full-blown aggressive behaviour problems in later childhood and adolescence? Considering the findings of this study in the context of the literature on aggressive behaviour problems and emotion regulation, a developmental model can be suggested.

A study by Van Goozen et al. (2004) assessed whether problems underlying aggressive behaviour are a matter of inadequate EF or whether the problems lie in children’s motivational processes. The researchers compared children aged 7-12 years with oppositional-defiant disorder (ODD) with a group of normal children on abstract, cognitive tasks and on motivationally relevant tasks, such as those involving the possibility of monetary reward. The results demonstrated that ODD children performed significantly worse than the control group only on tasks that had a significant motivational component. The authors explained these findings by reasoning that aggressive behaviour disorders (at least ODD) are not executive in nature but motivational. Rather than positing executive and motivational processes as distinct, however, these findings can be interpreted in terms of a hot/cool continuum. From this perspective, the aggressive behaviour problems reported by Van Goozen et al. can be seen as reflecting ineffective hot EF (i.e., EF in response to motivation). This finding is consistent with many other studies of this nature (e.g., Blair, Colledge, & Mitchell, 2001; Matthys, Van Goozen, Snock, & Engeland, 2004; Vries, Cohen-Kettenis, & Engeland, 1998). Additionally, Van
Goozen et al. explained the deficits in motivational processes as deficits in motivational inhibition, therefore characterizing aggressive behaviour problems as deficits in both motivational features and a specific executive feature, inhibition.

The results of the present study further support this view by establishing neurobiological correlates common to aggressive behaviour problems, inhibitory processes, and hot EF. Specifically, the reduction in N2 amplitudes with treatment, thought to represent an increase in cortical efficiency, showed a neurobiological link to improvements in performance on a hot EF task requiring impulse control, and this association only occurred for children whose aggressive behaviour problems improved with treatment.

Accordingly, one could speculate that significant emotional challenges during development would tend to magnify and exacerbate initial inhibitory deficits. These deficits would be consolidated through feedback between the individual and the social surround, causing children to follow a developmental path that is more complicated and challenging when interacting in situations that are emotionally demanding. This follows because aggression is highly correlated with problematic social conditions, such as low socioeconomic status (e.g., Kupersmidt, Griesler, DeRosier, Patterson, & Davis, 1995) and poor parenting practices (Stormshak, Bierman, McMahon, & Lengua, 2000), which cause significant emotional distress. Furthermore, such a developmental path might be accompanied by a pattern of increasingly inflexible cortical activity. However, if such children undergo a therapeutic intervention that fosters greater flexibility in appraising the emotional meaning of events and greater flexibility in their responses to those events, inhibitory deficits that have magnified over time may be overcome. Moreover, this occurrence may correspond with increasing cortical flexibility and efficiency, as hypothesized to have occurred in the present study. Indeed, the treatment undergone by children
in this study included a CBT portion that specifically taught strategies for both the reappraisal of social situations and the inhibition of response until such reappraisals took hold. Additionally, the PMT portion was aimed at reducing the frequency and intensity of hostile interactions between children and their parents, so that everyday situations are not as emotionally loaded and threatening.

In sum, problems with aggressive behaviour develop primarily due to deficits with inhibitory control, which potentiates increasing difficulties with affective control if the developmental course is marked by significant stressors. The present findings, however, suggest that this developmental pattern may be ameliorated by effective treatment regimes. Specifically, the results of this study indicate that such treatments most likely function by directly addressing both emotional/motivational issues and executive (regulatory) issues simultaneously.

### 4.4 Limitations

The present study has three limitations that need to be addressed. First, data from several participants were excluded from the study because these participants had too few artifact-free trials. The 20-trial inclusion criterion was set arbitrarily and no rigorous statistical analysis was conducted to compare included and excluded participants in order to test for systematic differences. Replication of this study is needed to ensure findings are not unique to the participants selected for inclusion in this study. A second limitation is that the study did not include a wait-list control group or a comparison group to ensure that any changes from pre- to post-treatment in EF performance and N2 amplitudes did not simply reflect practice effects. However, two previous studies from our lab using the same EEG task (Lewis et al., 2008; Woltering et al., in preparation) did include a group of nonclinical children tested over the same
time interval (14 weeks) and found that there were no significant differences for N2 amplitudes from the first assessment to the second assessment. In addition, the present study provided a built-in control by comparing improvers and non-improvers on both the N2 measure and EF task performance. Lastly, the majority of the participants included in the study also scored in the clinical range for internalizing problems. Thus, it is unclear whether neural changes with treatment reflected changes in mechanisms relevant for externalizing problems, internalizing problems, or both. Future studies focusing on children who are pure externalizers and not comorbid for internalizing behaviour are needed to isolate neural decrements specific to externalizing behaviour. Nevertheless, because children with behaviour problems are often comorbid for externalizing and internalizing behaviour (Fleming & Offord, 1990; Harrington, Fudge, Rutter, Pickles, & Hill, 1991; Zoccolillo, 1992), the sample used in this study may better represent behaviour problems as they exist in the real world.

4.5 Conclusion

This study is among the first to examine the relationship between neural changes underlying successful treatment for aggressive behaviour problems in children and changes in performance on a well-validated and reliable measure of “hot” executive function. Given that hot EF is a key resource underlying emotion regulation, this finding supports the claim that deficits inherent to children’s aggressive behaviour problems stem from difficulties in the executive aspects of emotion regulation, with response inhibition as the most likely candidate. In addition, the neurobiological and behavioural markers (i.e., decreases in N2 amplitudes and improvements in hot EF task performance) established in this study could find potential use as instruments of diagnosis and assessment, thus increasing the complement of effective clinical tools. Lastly, the results of this study provide further support for the view that the N2 component is a marker of
response inhibition, a key constituent of emotion regulation. In closing, I suggest that future research will benefit from measuring treatment outcomes for childhood psychopathologies using both neural markers and behavioural tasks, including EF tasks varying in affective relevance. Such research has the potential to provide insight into the fundamental issues underlying the development and treatment of childhood psychopathology, as well as the specific role of executive function in emotion regulation processes necessary for effective social behaviour.
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doi:10.1037/0022-006X.63.4.560


doi:10.1002/hbm.460010206


Appendices A

Hierarchical regression analyses

Table A1

*Summary of Hierarchical Regression Analysis for Variables Predicting IGT Performance*

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*<p < .05.*
Table A2

*Summary of Hierarchical Regression Analysis for Variables Predicting Stroop task Performance*

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Table A3

Summary of Hierarchical Regression Analysis for Variables Predicting Delay Discounting task Performance

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Table A4

*Summary of Hierarchical Regression Analysis for Variables Predicting Backward Digit Span Performance*

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+ $p < .10.$