Examining the developing regulatory functions of inhibitory control in young children with externalizing problems

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ABSTRACT

Examining the developing regulatory functions of inhibitory control in young children with externalizing problems

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Early emerging aggressive and disruptive behaviour problems are associated with the development of patterns of more serious delinquent, oppositional and violent behaviour. Given that such early externalizing problems (EP) contribute to significant personal, academic and social burdens, research elucidating factors that contribute to the development of such difficulties is prudent. In this series of studies, the developing relations between EP, inhibitory control (IC) and respiratory sinus arrhythmia (RSA) were examined. The early childhood period is a time of dynamic and dramatic change and maturation of prefrontostriatal circuitry, with corresponding changes in regulation of behaviour via improved executive functions, of which IC is one prominent feature, and vagal mediated support of responding during stress or challenge, which is reflected in RSA. Both theoretical and empirical attention was given to how physiological and neuropsychological changes over the early childhood period contribute to effective behavioural regulation versus manifestations of elevated EP.

In Study 1, externalizing difficulties and IC were examined over the toddler to kindergarten period to identify patterns of change in the regulatory functions of IC. In Study 2, the relations between IC and EP were examined in a sample of 4- and 6-year-old children including a large proportion of children with elevated EP, while controlling for

possible confounding factors, including full-scale IQ and working memory. Further, the unique associations of aggression versus inattention with IC were examined. Finally, in Study 3, parasympathetic regulation as reflected by dynamic changes in RSA was examined to elucidate how young children's physiological regulation contributed to the associations between IC and EP.

This collection of studies may provide insight into prediction of risk for aggression and EP. Implications for targeted preventive treatment and early intervention based on identifying children most at risk for poor trajectories of development are examined.

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General Introduction

Externalizing problems (EP) of aggressive, disruptive and disobedient behaviours that emerge early in childhood have been associated with later development of more serious disruptive behaviour disorders, delinquency and antisocial characteristics (Loeber & Dishion, 1993; Parker & Asher, 1987) conferring significant personal, social and financial burdens on health and educational resources in a variety of settings. The successful implementation of early intervention strategies has been a challenge, as the multiplicity of factors associated with children's disruptive and aggressive behaviour poses barriers to the identification of potential focal variables that could be consolidated into a cohesive framework across early developmental periods. Further examination of the ways in which biological and neuropsychological development in early childhood contributes to the development of EP could serve to inform and improve these intervention efforts.

Aggression and other characteristics of EP are typical elements of the behavioural repertoire of toddlers, and moderate levels of EP at this age may be ecologically normative and adaptive (Archer & Côté, 2005; Darwin, 1872). However, atypically high levels are more stable and predictive of poor social adjustment (Krug, Dahlberg, Mercy, Zwi, & Lozano, 2002; McCord, SpatzWidom, & Crowell, 2001). Elevated EP become more atypical and problematic over the transition to preschool-age, as children are expected to develop more self-regulation capacities that support more socially competent skills. The child with limited or delayed neurocognitive development in this period may continue to utilize disruptive and aggressive behaviours as problem-solving strategies, however. With the limitations imposed by immature prefrontal development, in a developmental period when there is still little autonomy, it might make ecological “sense” for a child to have a tantrum or to use aggression to take a toy from another child, in order to gain a desired goal. The short- and long-term adverse consequences of these actions, however, quickly outweigh the immediate benefits that the child might derive.

Understanding how and why some children do not appear to develop self-regulatory capacities at normatively expected ages, or continue to maintain the use of undesirable methods to achieve their goals, requires research over early developmental periods. This is when the prefrontal-striatal system is developing quickly and contributing to greater levels of inhibition of prepotent responding, increased complexity of problem-solving and strategic planning, and integration of these elements to effectively navigate a social environment in an acceptable and non-disruptive manner. Thus, the goals of this program of research were (a) to examine how the emergence of one aspect of neurocognitive self-regulation, inhibitory control, was associated with children’s EP in early childhood, and (b) to consider what role one aspect of regulatory physiological systems, parasympathetic control of arousal via cardiac vagal tone, served in the association between inhibitory control and EP. Examining the early development of EP during formative neurodevelopmental periods could provide valuable information at all levels of prevention and intervention efforts.

Externalizing Problems and the Development of Inhibitory Control

Over the preschool and early elementary periods, EP diminish markedly (Côté, Vaillancourt, Barker, Nagin, & Tremblay, 2007; Trembaly, 2000). Yet, it is consistently reported, both anecdotally and in the literature that preschool-aged children manifesting elevated levels of EP may continue to manifest problematic levels of EP in later years

(Keenan & Wakschlag, 2000). Despite some expert advice that these are normal behaviours that most young children outgrow (Campbell, 1990) many parents become concerned that the child with early-emerging EP will progress to other unwanted, deleterious pathology. This fear is indeed one which unfortunately comes to pass for many children. As children move through and beyond the toddler years, parent and caregiver expectations for more appropriate, socially acceptable behaviour increase. The child who does not progress at the expected rate in social development, and continues to utilize more basic, aggressive and disruptive behaviours to accomplish or achieve goals, is likely to become identified as having noteworthy difficulties or problems. A sizable proportion of young children who persistently demonstrate defiant and aggressive behaviour will exhibit long-term psychopathology both throughout childhood (Campbell, Pierce, Moore, Marakovitz, & Newby, 1996; Shaw, Winslow, & Flanagan, 1999) and into adulthood (Moffitt, 1993).

Poor executive functioning (EF) is one factor that could contribute to children's development of EP (Séguin, Boulerice, Harden, Tremblay, & Phil, 1999; Séguin, Nagin, Assaad, & Tremblay, 2004). EF encompass higher order cognitive processes that contribute to regulation of thoughts and actions (Séguin & Zelazo, 2005) and are supportive of adaptive behaviours (Raaijmakers, 2007). Development of EF parallels that of the prefrontal cortex (PFC; Carlson & Wang, 2007) and can serve as an index of prefrontal function (Fahie & Symons, 2003).

Executive function is a broad-based construct encompassing a variety of cognitive skills and abilities (Norman & Shallice, 1986; Shallice, 1994). These functions are necessary for children's self-regulation of behaviour in social and cognitive domains

(Ciairano, Visu-Petra, & Settanni, 2007). EF is associated with cortical networks, primarily the PFC (Luria, 1973; Durston et al., 2002) and includes working memory, inhibitory control (IC), and attentional shifting during planning and goal-directed behaviour (Blair, Zelazo, & Greenberg, 2005). EF was initially described as consisting of four elements "goal formation, planning, carrying out goal-directed plans, and effective performance" (Jurado & Rosselli, 2007, p. 213). It continues to present as a complex construct encompassing numerous elements of strategizing in the pursuit of goals and successfully navigating the social environment (Lezak, 1983).

The development of the PFC and associated executive processing occurs rapidly during the preschool and early elementary years (Diamond, 1990, 2002; Zelazo & Müller, 2002). The multiple components of EF develop at different rates (Anderson et al. 1996, 2001; Levin et al., 1991; Welsh et al., 1991), and patterns of development for various executive processes may be important in understanding psychopathology (Leon-Carrion, García-Orza, & Pérez-SantaMaría, 2004). Different EF have been localized to different regions of the PFC, rather than showing homogenous distribution across neurophysiological structures, as evidenced through neuroimaging during EF task performance (Jurado & Rosselli, 2007). However, EF are not necessarily isolated and can interact through integrated neural circuits (Stuss & Alexander, 2000) including cerebral, subcortical and thalamic pathways (Kassubek, Juengling, Ecker, & Landwehrmeyer, 2005; Monchi, Petrides, Strafella, Worsley, & Doyon, 2006). This makes intuitive sense when considering the complexity of immediately adapting behaviour to changing circumstances and in unpredictable environments. Regulatory flexibility is a key theme in EF, and without integration of neurological structures with each other, as well as with other regulatory systems (i.e. autonomic systems) EF would likely have limited effect on an organism's ability to respond promptly to a dynamic, challenging environment. The integration of neurological circuitry with autonomic regulation via augmentation or reduction of cardiac activity forms the basis for the conceptualization within this thesis of the inter-relations among EP, EF and parasympathetic activity.

One element of EF in particular, IC, appears to be associated with control of impulsive behaviour and risk for EP (Avila, Cuenca, Félix, Parcet, & Miranda, 2004; Brophy, Taylor, & Hughes, 2002). IC is a relatively independent construct within the EF domain (Carlson, Moses, & Breton, 2002; Hughes, 2002). It is necessary to suppress salient, dominant responses in the face of competing stimuli (Brocki et al., 2007; Ciairano et al., 2007; Diamond, 2002). The preschool-aged or older child who hits, bites, pushes, yells at, or kicks another child to take a toy is exhibiting an immature, socially problematic goal acquisition strategy, no matter how effective this strategy might be in the short term. These aggressive behaviours could be considered prepotent, dominant responses, in that they normatively are common and relatively frequent in toddlerhood, and appear to be among the first rudimentary methods children have for attaining their goals in the face of social challenge. Neurophysiological development in the transition to childhood should facilitate more effective IC, supporting children's ability to utilize more cognitively, linguistically and socially complex, and fewer aggressive or disruptive strategies as they develop. Without normative development of IC and other EF, children may essentially be trapped with an inability to suppress aggressive impulses and utilize more normative, age-appropriate strategies in dealing with others.

Discrepancies exist, however, in efforts to identify the normative course of IC development (Leon-Carrion et al., 2004). Some research shows maturation of IC to adult levels by 10 years (Welsh et al., 1991), while others have found continued maturation into adulthood (see Best, Miller, & Jones, 2009 for review). Different IC tasks utilized across studies may account in part for this discrepancy. Different tasks might measure different aspects of IC (Kramer et al., 1994) such as semantic versus motoric processing tasks, and tasks might assess IC with different levels of sensitivity (Leon-Carrion et al., 2004). Utilizing a variety of IC measures to investigate developmental processes has been recommended (Bedard et al., 2002; Christ, White, Mandernach, & Keys, 2001), and is the strategy used in this program of work. A general consensus across studies, though, is that the preschool period represents a time of dynamic PFC maturation, and dramatic concomitant increase in ability to perform tasks requiring inhibition of dominant responses (Carlson, 2005; Carlson & Wang, 2007). In particular, dramatic maturation of the PFC has been demonstrated between ages 3 and 5 (Carlson, 2005; Carlson & Wang, 2007) and 5 and 8 (Romine & Reynolds, 2005), with further, gradual improvement continuing for a number of years (Diamond, 2002; Huizinga, Dolan, & Molen, 2006; Leon-Carrion et al., 2004).

Numerous studies have shown that children exhibiting poor IC have increased risk of impulsive and externalizing behaviours as they fail to inhibit inappropriate and maladaptive responses to stress or challenge (Giancola, 1995; Lemery, Essex, & Smider, 2002). The link between weak IC and elevated EP has been repeatedly demonstrated in school-age children (Avila et al., 2004; Kooijmans, Scheres, & Oosterlaan, 2000; Oosterlaan, Logan, & Sergeant, 1998; Oosterlaan & Sergeant, 1996; Riggs, Blair, &

Greenberg, 2003; Riggs, Greenberg, Kusché, & Pentz, 2006). Fewer studies have examined this relation in preschoolers, and findings are less consistent. Some research supports the supposition that poorer IC is associated with externalizing psychopathology in preschool children (Hughes, Dunn, & White 1998; Floyd & Kirby, 2001). Other research does not (Lewis et al., 2007; Rhoades, Greenberg, & Domitrovich, 2009; Thorell & Wåhlstedt, 2006). Thus, the transition from preschool-age to the early school-age years may reflect an important period in the emergence of IC as a regulator of EP. Still, exactly when and how deficits in IC might be associated with immature neurological development and elevated EP in early childhood remains to be fully elucidated. The investigations presented in this dissertation examined the inter-relations among neuropsychological and physiological regulation of EP over this developmental period.

Factors that might Influence the Development of Relations between Inhibitory Control and Externalizing Problems

Children's attentional capacity has been postulated as one confounding factor that might contribute to inconsistent findings between IC and EP. Some studies control for inattention while others do not. There is clear comorbidity between childhood EP and Attention-Deficit/Hyperactivity Disorder (ADHD) (Hastings, Fortier, Utendale, Simard, & Robaey, 2009). Reduced EF is also correlated with ADHD (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Studies of EF and EP that control for symptoms of inattention have produced conflicting results. EF deficits continue to be associated with EP when controlling for attention and hyperactivity in some studies (Déry et al., 1999; Floyd & Kirby, 2001; Séguin et al., 1999), but this relation is lost when controlling for these symptoms in others (Clark, Prior, & Kinsella, 2000; Nigg, Hinshaw, Carte, &

Treuting, 1998; Oosterlaan et al., 1998; Pennington & Ozonoff, 1996; Thorell & Wåhlstedt, 2006). This program of work therefore includes a consideration of links between IC and attention problems as well as EP.

Further, both IQ (Mahone et al., 2002; Polderman et al., 2006) and working memory (WM; Diamond, Prevor, Callender, & Druin, 1997; Wolfe & Bell, 2004) have been shown to be associated with measures of IC. Children with more EP, on average, have lower IQ and WM than children with fewer EP (Andersson & Sommerfelt, 2003; Zadeh, Im-Bolter, & Cohen, 2006), such that these factors might contribute to the statistical association of IC with EP. Therefore, the effects of these factors on relations between IC and EP were examined in this series of studies.

Pronounced sex differences also exist in levels of EP, with boys typically demonstrating higher levels from the toddler years and after (Cairns, Cairns, Neckerman, Ferguson, & Gariépy, 1989; Tremblay et al., 1996; Tremblay et al., 2004). Conversely, girls appear to develop IC earlier and more quickly than their male counterparts (Keenan & Shaw, 1997). It is plausible that boys' higher levels of EP could be tied to their comparatively later development of IC (Raaijmakers et al., 2008), but there have been few studies of the development of EP in young girls (Putallaz & Bierman, 2004). Possible sex differences in the relations between IC and EP therefore were examined in these studies.

Parasympathetic Regulation and the Links between Inhibitory Control and Externalizing Problems

The PFC has been implicated in inhibitory processing (Casey et al., 1997; Kawashima et al., 1996; Konishi et al., 1999), particularly the right orbitofrontal gyrus

(Collette et al., 2005), and IC has been described as a major indicator of frontal lobe development (Luria, 1973; Passler, Isaac, & Hynd, 1985). However, IC (and EF more generally) are not subserved by the PFC alone; for example, parietal activation occurs in parallel with PFC activation during EF performance (Collette, et al., 2005). There is growing evidence that the coordination of prefrontal activity with other physiological regulatory systems might also play critical roles in how IC exerts control over impulsive, aggressive and disruptive behaviour (Jurado & Rosselli, 2007).

Parasympathetic regulation of the heart (Porges, 2001, 2007) has been postulated to support IC during periods of challenge (Beauchaine, 2001; Beauchaine, Gatzke-Kopp, & Mead, 2007). The effects of innervation of the sino-atrial (SA) node of the heart by the vagus nerve on patterns of heart rate variability have been shown to be an effective index of children's behavioural, cognitive and emotional self-regulation (Stifter & Fox, 1990). Higher levels of basal parasympathetic activity (i.e. higher vagal outflow) (El-Sheikh & Buckhalt, 2009) and greater reductions in vagal influence during stress (Calkins & Keane, 2004) have been shown to be associated with children's adaptive functioning.

Whether a given pattern of autonomic responding to a given stimulus or context is adaptive versus maladaptive might be related to the particular elements of the situation. Vagal efference decreases during periods of challenge (Huffman et al., 1998) to increase metabolic reallocation. This is considered an index of good regulatory capacity (Beauchaine, 2001; Porges, 2001). Reduction in parasympathetic outflow to the SA node of the heart increases metabolic activity and reorganization during challenge. Some children might perceive benign situations as threatening, however, or challenging situations as neutral or unimportant, such that their patterns of parasympathetic reactivity would not be consistent with the changes in orientation and behaviour needed to cope with situational demands (Hastings et al., 2008; Porges, 2007).

Children exhibiting externalizing psychopathology may have physiological regulatory deficits which stem from reduced or disorganized function within neural structures controlling metabolic activity during cognitive and other challenges (Beauchaine, Gatzke-Kopp, & Mead, 2007). Maladaptive parasympathetic regulation in children with behavioural difficulties has been observed during attentional demand and cognitive tasks (Calkins & Dedmon, 2000; Calkins et al., 2007; Huffman et al., 1998; Porges et al., 1996; Raine, Venables, & Mednick, 1997; Stifter & Fox, 1990). This could reflect children with EP reacting too strongly to situations considered relatively non-threatening or benign, such as cognitive tasks (Friedman, 2007). In contrast, lack of adequate vagal withdrawal during periods in which active responding are necessary could similarly contribute to maladaptive behavioural responding (Hastings et al., 2008).

EP and IC may be interconnected through common underlying neurophysiological substrates, conceptualized as an integrated network, the central autonomic network (CAN; Bennarroch, 1993, 1997). The CAN is composed of a number of structures, including the ventromedial prefrontal cortices and nucleus ambiguus, involved in regulating physiological state and behavioural responding associated with EF (Thayer, 2007). Neuronal tracts project between the nucleus ambiguus and the SA node through the vagus nerve (Richter & Spyer, 1990). Tonic inhibition of the SA node via connections from the PFC is thought to mediate parasympathetic regulation under conditions of stress or challenge (Gianaros, Van der Veen, & Jennings, 2004; Lane, Reiman, Ahern, & Thayer, 2001; Ter Horst & Postema, 1997; Ter Horst, 1999). Inadequate vagal control under conditions of stress may underlie children's poor behavioural responding, as a non-facilitative physiological state may manifest which does not provide the metabolic control necessary for appropriate responding during such periods. Indeed, physiological regulation as indexed by high basal efference and high vagal withdrawal to the heart is associated with better cognitive performance in adults (Hansen et al., 2003; Thayer & Lane, 2000) and children (Blair & Peters, 2003; Staton et al., 2009; Suess, Porges & Plude, 1994).

Thus, poor parasympathetic regulation during attentional demand could preclude the ability to respond in an appropriate behavioural manner in children with high levels of EP, as adaptive behaviour via PFC regulation might require parasympathetic facilitation. Vagal dysregulation during IC may therefore be reflected in differences among children as the PFC might not regulate children's externalizing behaviour. Poor parasympathetic (vagal) regulation has been associated with EP in children and adolescents (Mezzacappa et al., 1997; Mezzacappa, Kindlon, Saul, & Earls, 1998; Raine, Venables, and Mednick, 1997) and with deficits in EF (Hansen, Johnsen, & Thayer, 2003; Thayer, 2007). Vagal regulation during attentional demands may therefore be an important component contributing to the negative associations observed between externalizing behaviour and IC (Floyd & Kirby, 2001; Kooijmans, Scheres, & Oosterlaan, 2000). The developmental relations between EP, IC, and physiological self-regulation however, have not been elucidated in young children (Brocki et al., 2007; Calkins, Graziano, & Keane, 2007).

Purpose of Studies

In this series of studies I investigated the developmental relations between EP, IC and parasympathetic regulation.

Study 1. I examined the interrelations among IC and externalizing difficulties over the toddler to kindergarten period (*range* = 2.75-6.00) in an effort to establish the developmental patterns of these relations. Maternal reports of IC were examined in relation to mother-reported, teacher-reported, and laboratory-observed measures of children's EP. Poorer IC was expected to be related to externalizing difficulties, and these relations were expected to be stronger for older children. It was also expected that improvement in IC capacity over one year would be associated with significant decreases in EP over that period.

Study 2. In this investigation the relations between IC and EP in a sample of 4- and 6-year-old children with over-representation of high EP were examined, while controlling for IQ and WM. Differences in the associations of IC with symptoms of aggression versus inattention problems also were examined. Higher levels of IC were expected to be associated with increased latencies to respond and higher levels of correct responses on behavioural IC measures. Poorer IC performance (fewer correct responses and shorter response latencies) was hypothesized to be reflected in greater levels of externalizing symptomatology. The negative association between IC performance and EP was predicted to be stronger for 6-year-old than for 4-year-old children.

Study 3. I examined dynamic changes in vagal regulation during IC for the 4- and 6-year-old children included in Study 2. Reduced parasympathetic outflow from the vagal complex to the heart was hypothesized to be associated with higher levels of EP and poorer IC task performance. Children's EP was also expected to moderate the association between vagal regulation and IC performance such that the relation between RSA suppression and performance would be weaker for children with more EP. Associations between vagal regulation and IC performance were expected to be stronger in older versus younger children.

Study 1[1]

Developmental Changes in the Relations between Inhibitory Control and Externalizing Problems During Early Childhood

Children exhibiting early-emerging externalizing problems (EP) are at greater risk for the development of future juvenile delinquency, antisocial behaviour and disruptive behaviour disorders (DBD; Campbell, 2002; Lynam, 1996). Understanding the underpinnings of early-emerging EP is important for developing effective prevention and intervention programs. Executive functions have been posited as an important regulator of aggressive behaviour (Pennington & Ozonoff, 1996), but there have been relatively few studies of the relation between EP and executive dysfunction in the early preschool period (Brocki et al., 2007). This investigation examined the early development of the relations between aggressive and disruptive behaviours and one component of executive function, inhibitory control (IC).

IC is a unique element of executive functioning, encompassing the capacity to deliberately inhibit or suppress a prepotent, dominant response (Diamond, Carlson, & Beck, 2005; Simpson & Riggs, 2005). While distinct from other executive processing constructs (Olson, Schilling & Bates, 1999), it is related to resistance to temptation (Kochanska, Murray, Jacques, Koenig & Vandegeest, 1996) and delay of immediate gratification (Olson, 1989). During the preschool period substantial maturation of the prefrontostriatal circuitry parallels dramatic increases in executive functioning and IC

[1] This study has been published. Full reference: Utendale, W. T., & Hastings, P. D. (2011). Developmental changes in the relations between inhibitory control and externalizing problems during early childhood. *Infant and Child Development*, *20*, 181-193.

capacity (Carlson & Wang, 2007; Diamond, 2002). Thus, normative neurophysiological development appears to support the emergence of IC over early childhood.

Elementary school-age children expressing EP manifest reduced IC (Avila, Cuenca, Félix, Parcet, & Miranda, 2004). Indeed, many assessment batteries for EP include items measuring children's impulsivity, reflective of poor IC (White et al., 1994). Yet, poor impulse control is developmentally normative for toddlers (Kopp, 1982). The immature prefrontostriatal systems of toddlers and young preschoolers might result in IC not yet being sufficiently developed to function as a regulator of aggressive impulses, as IC would only reach a level of maturity necessary for regulating aggression during late preschool and kindergarten age. At that time, children with relatively immature IC, due to diminished or delayed IC development over the preschool years, would be at risk for elevated EP as they could engage in maladaptive impulsive actions and fail to suppress aggressive responses to developmentally normative frustrations or challenges (Giancola, 1995; Lemery, Essex, & Smider, 2002). To date, however, researchers have not yet determined the specific developmental changes that occur in associations between IC and EP during early childhood.

Research examining associations between IC and EP in early childhood has produced conflicting results. Some studies have shown preschool-aged children with EP or related difficulties have IC deficits (Floyd & Kirby, 2001; Gomes & Livesey, 2008; Livesey, Keen, Rouse, & White, 2006) that can persist over time (Brophy, Taylor, & Hughes, 2002). Other studies, however, have not replicated this (Lewis, Dozier, Ackerman, & Sepulveda-Kozakowski, 2007; Rhoades, Greenberg & Domitrovich, 2009; Thorell & Wåhlstedt, 2006). The concurrent negative association between IC and EP for kindergarten-age and elementary school-age children appears more consistent (Avila et al., 2004; Gomes & Livesey, 2008; Kooijmans, Scheres, & Oosterlaan, 2000; Oosterlaan, Logan, & Sergeant, 1998; Oosterlaan & Sergeant, 1996; but see Livesey et al., 2006; Schachar & Tannock, 1995). Longitudinal investigations have also demonstrated that earlier poor IC predicts later externalizing behaviours for elementary school children (Nigg, Quamma, Greenberg, & Kusché, 1999; Olson et al., 1999; Riggs, Blair & Greenberg, 2003). Support for a causal link between IC and the regulation of aggressive behaviour was shown through a school-based intervention that supported IC increases, leading to corresponding reductions in EP (Riggs, Greenberg, Kusché, & Pentz, 2006).

Overall, current findings suggest that associations between IC and aggression or EP become more pronounced as children reach kindergarten and early elementary school ages. Questions remain, however, as to the pattern of associations between IC and EP during the preschool years. One factor that might have contributed to the inconsistency of past research is the multiplicity of methods used to assess IC; if different aspects of IC are tapped by different measures, this could contribute to varying relations with EP across studies. However, even studies of kindergarteners that have used the same behavioural measure of response inhibition, the Stop Signal Reaction Time protocol, have produced divergent relations with EP and impulsivity (Gomes & Livesey, 2008; Livesey et al., 2006). Thus, further effort to clarify the nature of the developing relations between IC and EP is warranted.

In this investigation the associations between IC and EP were examined in toddlers, preschoolers and kindergarten-age children. Poorer IC was expected to be associated with EP and aggression, and these relations were expected to be stronger in older than in younger children. Changes in IC over time were also expected to predict behavioural improvement such that increases in IC over one year were expected to predict reductions in EP.

Method

Participants

Data were collected in the context of a larger, ongoing longitudinal study (see Hastings et al., 2008 for details on recruitment). For inclusion, children were required to be normatively developing, enrolled in daycare or preschool, and free of cognitive difficulties or delays and of medical conditions that might preclude completion of play activities. The sample for the present analyses included 115 children (49 boys and 66 girls) aged 2.75 to 6.00 years ($M = 4.14$, $SD = 0.78$) at Time 1, their mothers, and their daycare supervisors or preschool teachers. There were 33 boys and 42 girls assessed at Time 2, aged 3.58 to 6.50 years ($M = 5.04$, $SD = 0.76$). The 75 children who completed Time 2 did not differ significantly from the other 40 children on Time 1 measures of age, IC, EP, aggression or family socioeconomic status, all $|t| \leq 1.68$, all adjusted $p > .10$.

Measures

Mothers completed the Child Behavior Checklist 1.5 – 5 yr (CBCL; Achenbach & Rescorla, 2000), and teachers completed the Caregiver-Teacher Report Form (C-TRF; Achenbach & Rescorla, 2000). The broad-band externalizing problems (EP) scale of these instruments was used. The EP scales of the CBCL and C-TRF have high reliability; in this sample, Cronbach's $\alpha = .92$ and .91 at Time 1 and 2, respectively, for CBCL EP, and $\alpha = .95$ for C-TRF EP at Time 1.

To assess children's IC, mothers completed the Inhibitory Control subscale of the Child Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). Parent-reported IC on the CBQ has been shown to have good convergent validity, correlating significantly across reporters and with observed behavioural control (Rothbart et al., 2001; Eisenberg et al., 2001, 2004)[2]. In this sample, Cronbach's α = .83 and .81 at Time 1 and 2, respectively, for CBQ IC.

Procedure

Data at Time 1 were collected in the context of a laboratory visit for mothers and children, and questionnaires were mailed to daycare or preschool teachers. Data at Time 2 were collected through questionnaires mailed to mothers.

For the laboratory visits, sets of three families were invited to participate in playgroups involving triads of same-sex, same-age, unfamiliar children. The timing of each family's arrival for the laboratory session was staggered, and each family was taken to a separate waiting room so children would not see each other prior to the play session. After all families had arrived, each child and mother was taken to the playroom where the children met and were introduced to a female examiner. After the parents left the playroom, the examiner engaged the children in a series of structured and unstructured activities. After about 40 minutes, the examiner introduced a novel, interesting toy for the three children to play with together, providing an opportunity for potential conflict around sharing (Special Toy Task; see Hastings, McShane, Parker, & Ladha, 2007, for more

[2] Providing additional evidence of the construct validity of the Children's Behavior Questionnaire (CBQ) inhibitory control (IC) scale, we have recently completed another project on inhibitory control involving a completely independent sample of children (see Utendale et al., 2011). This study included 86 late preschool-aged children (4.0 – 5.0 years) who were administered two standardized behavioural measures of IC, the Day/Night task (Gerstadt et al., 1994; an age-appropriate adaptation of the Stroop task), and Luria's (1966) Tapping task, and for whom mothers completed the IC scale. The correlations between mother-reported IC and number of correct responses on the Day/Night and Tapping tasks were $r = .28$ and $r = .30$, respectively, both $p < .01$.

details on this procedure). Interactions among the children during the shared toy task were coded for aggressive behaviour, such as hitting, pushing, and refusing to share. Experimenter error or audiovisual recording problems resulted in missing data for 16 children. Thus, the task was completed and coded for 99 children.

Mothers were in an adjacent room while children played, where they completed the CBCL and CBQ. All 115 mothers completed these measures, but errors in the completion of one CBCL resulted in missing Time 1 EP data for one child. Teachers or supervisors were mailed consent forms and the C-TRF to complete and return by mail; 102 measures were returned.

Approximately 10 months after the lab visit, mothers were mailed the CBCL and CBQ to complete again; 75 mothers completed and returned both measures within 4 months.

Behavioural Coding

Aggressive behaviour during the Special Toy Task was coded from videotape by two observers. Aggressive behaviour was defined as a target child either hitting another child, taking away the toy, stopping another child from playing with the toy, or refusing to share the toy. These four behaviours were scored as occurring *never* (0), *once* (1), or *more than once* (2). Kappa coefficients of inter-rater agreement were computed for 25% of the children, mean $\kappa = .73$ (range = .62 – .83). All behaviours were positively inter-correlated with each other, r range .17 - .37, $p < .10 – .001$; Cronbach's $\alpha = .60$. The observed aggression score was the sum of these behaviours over the course of the Special Toy Task.

Socioeconomic Status

Family socioeconomic status (SES) was examined as a possible control variable. Mothers reported on her own and, for two-parent families, her spouse's occupation and years of education completed, as well as net family income before taxes. Occupational prestige was coded using an updated version of the Standard International Occupational Prestige Scale (SIOPS; Hakim, 1998; Treiman, 1977). In two-parent families, the higher of the two occupational prestige scores was retained. A factor analysis including occupational prestige, education, and family income supported a single-factor solution, eigenvalue = 1.84, accounting for 46.08% of the variance. Thus, these scores were standardized and aggregated to form an index of family SES.

Analysis Plan

Factor analysis was used to determine whether the Time 1 measures of observed aggression, teacher-reported EP and mother-reported EP could be aggregated into a single measure. Correlations and *t*-tests were examined to determine whether sex or child or family SES needed to be included in subsequent analyses as covariates. The concurrent associations between IC and children's EP scores and observed aggression were examined using hierarchical linear regression analyses. As recommended by Aiken and West (1991), variables were centered prior to analyses. The concurrent analyses included four steps. Step 1 included necessary control variables (e.g., Sex and/or SES), Age was entered on Step 2, IC on Step 3, and the Age X IC interaction on Step 4. One regression analysis was used to examine the relations between Time 1 IC and the aggregate measure of Time 1 mother-reported EP, teacher-reported EP, and observed aggression. A second regression analysis was used to examine the relation between Time 2 IC and Time 2 mother-reported EP.

For the longitudinal analysis, residualized change scores were used to predict changes in EP from changes in IC over one year. When baseline and follow-up measures are highly correlated, as was the case with these mother-reported measures of EP and IC, residualized change scores are recommended. Calculating residualized change consists of regressing the follow-up measure onto the baseline measure, and provides an estimate of change since variability due to baseline measures is effectively removed in predicting follow-up data. The longitudinal analysis predicting Time 2 EP change included six steps: (1) Age, and possibly Sex and/or SES; (2) Time 1 EP; (3) Time 1 IC; (4) Age X Time 1 IC interaction; (5) residualized change score for Time 2 IC (6) Age X Time 2 IC residualized change score interaction. Variables were centered prior to analyses.

Significant Age X IC interactions were examined by regressing IC onto EP at younger versus older ages of children, in order to clarify how age moderated the association between IC and EP. The slope of IC regressed onto EP was examined at 4 ages within the sample age range, including 2 ages below and 2 ages above the sample mean, in order to examine how the relation changed from toddlerhood and early preschool-age through late preschool and kindergarten-age. This involved recomputing four Age X IC interaction terms, with the centered value for Age shifted to the younger or older age values, then using these interaction terms in four separate regression analyses to chart the relation between IC and EP at each age. By examining relations between the predictor (IC) and outcome variable (EP) with the moderator (Age) set at specific values within its range, greater power is retained than would be the case were the sample split into between-groups sub-samples representing different age-ranges (for review see Aiken & West, 1991; Dawson & Richter, 2006).

Results

Descriptive statistics are presented in Table 1. Preliminary analyses revealed that girls had higher IC than boys, $t(113) = -2.47$, $p < .05$ at Time 1. No significant sex difference in IC was observed at Time 2, $t(75) = -1.09$. Girls also showed less observed aggression than boys, $t(97) = 2.44$, $p < .05$. However, boys and girls did not differ on parental or teacher ratings of EP, all $|t| \leq 0.37$.

Relations Among Measures of Aggression and EP at Time 1

A factor analysis including observed aggression, teacher-reported EP and mother-reported EP supported a single-factor solution, eigenvalue = 1.25, accounting for 41.66% of the variance. Thus, the three scores were standardized and averaged to form an aggregated score of Time 1 Externalizing Difficulties. There were 17 children missing one of the three measures; for these children, the Externalizing Difficulties score was computed as the average of the two available measures.

Check for Control Variables

Boys and girls did not differ on Time 1 Externalizing Difficulties, $t(113) = 1.31$, *ns*, but Sex was included as a covariate because of the difference in Time 1 IC scores. Family SES was not significantly correlated with Time 1 Externalizing Difficulties or IC, or with Time 2 EP or IC, all $|r| \leq .16$, all $p > .10$; therefore SES was not included as a covariate.

Concurrent Relations Between IC and Externalizing Difficulties at Time 1

The regression model predicting the aggregate score for Externalizing Difficulties from IC is presented in Table 2. The regression model was significant, adj. $R^2 = .25$, $F(4,110) = 10.24$, $p < .001$, with two unique predictors. Children who were higher in IC

Table 1. Descriptive Statistics of Observed and Questionnaire Variables

	n	Min	Max	*M*	*SD*
Time 1					
CBQ Inhibitory Control	115	2.77	6.62	4.96	0.82
CBCL Externalizing Problems	114	28	69	48.33	10.86
C-TRF Externalizing Problems	102	36	72	51.83	9.15
Observed Aggression	99	0	7	1.16	1.64
Time 2					
CBQ Inhibitory Control	75	2.85	6.92	4.86	0.88
CBCL Externalizing Problems	75	28	69	45.80	10.36

Note: CBQ = Child Behavior Questionnaire; CBCL = Child Behavior Checklist; C-TRF = Caregiver-Teacher Report Form.

Table 2. Regression Analyses Predicting Externalizing Difficulties from Inhibitory Control

	Step & Predictor	ΔR^2	ΔF	β	*t*
Time 1					
Externalizing Difficulties	1. Sex	0.02	1.71	-.12	-1.31
	2. Age	0.02	2.01	-.13	-1.42
	3. IC	0.21	30.67***	-.47	-5.54***
	4. Age x IC	0.03	4.45*	-.17	-2.11*
Time 2					
Mother reported EP	1. Sex	0.00	0.23	-.06	-0.48
	2. Age	0.03	2.40	-.18	-1.56
	3. IC	0.26	26.63***	-.52	-5.16***
	4. Age x IC	0.04	3.84†	-.20	-1.96†

Note: EP = Externalizing Problems; IC = Inhibitory Control.

† $p < .10$, * $p < .05$, *** $p < .001$.

had fewer Externalizing Difficulties, but this association was moderated by a significant Age X IC interaction.

The significant interaction was examined by plotting the relation between IC and Externalizing Difficulties at four ages within the age range of the sample (see Figure 1). The negative relation between IC and Externalizing Difficulties was found to increase with age. At 3 years, a non-significant negative association between IC and aggression was observed ($\beta = -.19$, $p = .23$). This relation was significant at 3.5 years ($\beta = -.30$, $p < .02$). At 5 years, the negative relation between IC and Externalizing Difficulties was considerably more robust ($\beta = -.63$, $p < .001$), and it was stronger still at 5.5 years ($\beta = -.74$, $p < .001$).

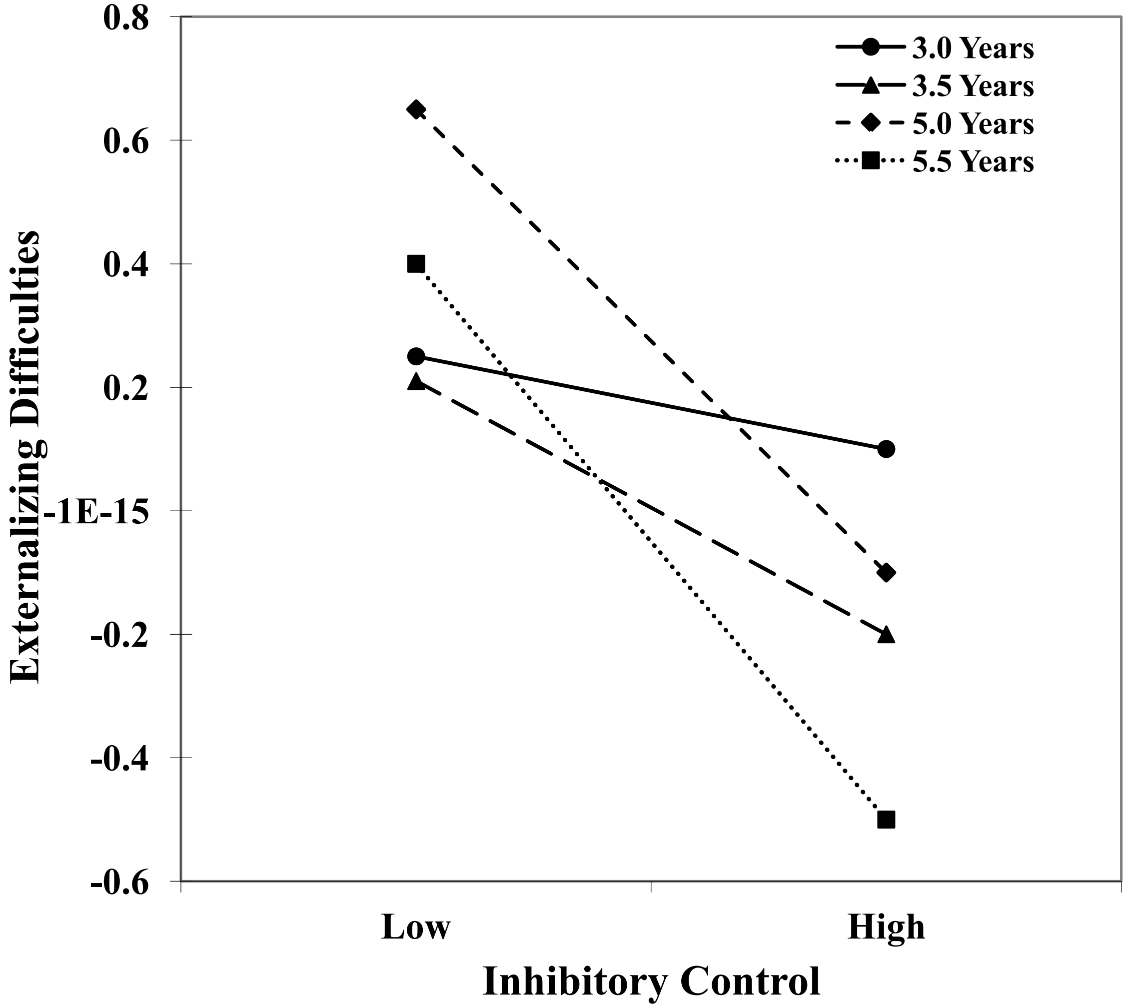
Concurrent Relations between IC and EP at Time 2

Mother-reported externalizing problems (Table 2). The regression model predicting mother-reported EP at Time 2 from IC at Time 2 was significant, adj. $R^2 = .34$, $F(4,70) = 8.82$, $p < .001$. Children with higher IC had fewer EP, and this relation tended to be moderated by child age (Figure 2). Paralleling the findings for Time 1 Externalizing Difficulties, the negative association between IC and EP was stronger for older children. At 4 years, the relation was not significant ($\beta = -.26$, $p = .12$). At 4.5 years, the relation was significant and negative ($\beta = -.39$, $p < .01$). This negative relation increased at both 5.5 years ($\beta = -.64$, $p = .001$) and 6 years ($\beta = -.77$, $p < .001$).

Do Increases in IC Predict Decreases in EP over One Year?

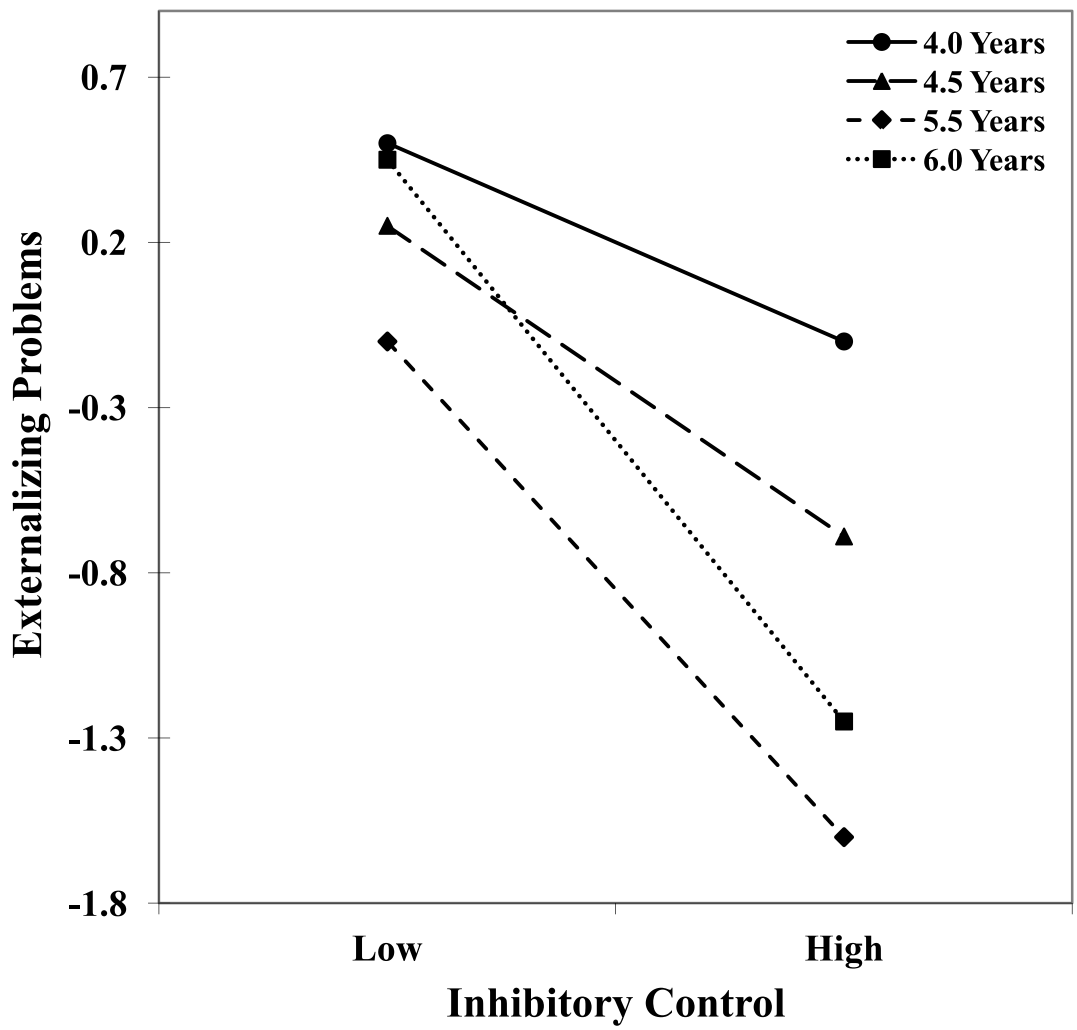
Mother-reported externalizing problems (Table 3). The regression model predicting the development of children's EP from the development of their IC

Figure 1. Interaction between Age and Time 1 CBQ Inhibitory Control Predicting Externalizing Difficulties Factor



Note: CBQ = Child Behavior Questionnaire.

Figure 2. Interaction between Age and CBQ Inhibitory Control Predicting CBCL Externalizing Problems at Time 2



Note: CBCL = Child Behavior Checklist; CBQ = Child Behavior Questionnaire.

Table 3. Regression Analysis Predicting Change in Externalizing Problems from Change in Inhibitory Control

Step & Predictor	ΔR^2	ΔF	β	*t*
1.	0.10	2.43†		
Sex			-.08	-0.67
T1 Age			-.98	-2.24*
T2 Age			.80	1.83†
2. T1 EP	0.00	0.05	-.03	-0.23
3. T1 IC	0.00	0.20	.07	0.44
4. Age x T1 IC	0.01	0.94	-.12	-0.97
5. T2 IC Change	0.08	6.72*	-.30	-2.59*
6. Age x T2 IC Change	0.00	0.00	-.01	-0.40

Note: EP = Externalizing Problems; IC = Inhibitory Control.

†$p < .10$. *$p < .05$.

approached significance, adj. $R^2 = .09$, $F(8,64) = 1.94$, $p = .06$. Earlier IC did not predict changes in EP. However, children who experienced greater increases in IC from Time 1 to 2 also manifested stronger reductions in EP over this period. Age did not moderate associations between IC or IC change and EP change.

Discussion

The inverse association between preschoolers' IC and EP was demonstrated to be strong, and to increase with age, suggesting that within this relatively young age group poor IC might contribute to the development of externalizing psychopathology. Maternal reports of IC in toddler- to kindergarten-aged children were concurrently associated with fewer externalizing difficulties, while mother-reported improvement in IC over one year was found to predict reductions in EP. Older and younger children, however, differed in their patterns of association between IC and the aggregate measure of externalizing difficulties at time 1, and between IC and mother reported EP at time 2.

Considering this pattern of developmental change, as expected, poorer IC predicted higher amounts of EP in older preschoolers and kindergarten-aged children. However, there was a non-significant association between IC and externalizing difficulties in the younger children. This might indicate that IC does not begin to become an effective regulator of aggressive behaviour until the preschool development of prefrontostriatal circuitry has progressed sufficiently. Additionally, it might also be reflective of the fact that impulsivity (Kopp, 1982) and relatively high levels of aggressive behaviour (Keenan & Shaw, 1997) are commonly observed in very young children and are considered part of the normal developmental process.

Aggressive behaviour has been shown to increase from 2 to 3 years (Shaw, Lacourse, & Nagin, 2005), and both physical aggression and externalizing behaviours typically begin to decline after children's 3rd birthdays (Campbell, 1995; Tremblay et al., 2004), at least in non-clinical samples.

The change in association observed between IC and young preschoolers' externalizing difficulties may represent a shift in goal-acquisition strategies from passive and parent-dependent during infancy to more independent problem-solving behaviours in toddlerhood (Keenan & Wakschlag, 2000). At this early stage of executive development, aggression may serve as a relatively effective goal acquisition strategy when children have a relatively limited problem-solving skill set and immature social competence (Brownell & Hazen, 1999). In very young children, some aggressive behaviour during play could reflect a strong approach or engagement motivation and good prefrontal cortex development, which in turn could predict subsequent increases in more advanced, socially appropriate strategies. With appropriate development of the frontal structures, social and social-cognitive competence increases, with a concomitant reduction in aggressive strategies (Brownell & Hazen, 1999). Continued development of IC, and other executive functions, would increase older preschoolers' self-regulatory capacity and ability to implement non-aggressive goal-acquisition strategies during peer interactions (Côté, Tremblay, Nagin, Zoccolillo, & Vitaro, 2002; Tremblay, 2000). This was reflected in the much stronger negative association between IC and externalizing behaviour in 5 year-olds. Conversely, this could be interpreted as reflecting poorer or delayed IC development in kindergarteners who persist in the use of aggressive methods of achieving their social goals.

Using a mother-reported index of disruptive and dysregulated behaviour at time 2, a similar negative association between IC and EP was evident across early childhood. Again, this pattern was increasingly stronger in the older children, who were approaching early elementary school-age. Our findings are concordant with existing literature supporting an inverse association between IC and EP in school-age children (Avila et al., 2004; Kooijmans et al., 2000; Oosterlaan et al., 1998; Oosterlaan & Sergeant, 1996; Riggs et al., 2003, 2006). Moreover, children who showed stronger increases in IC over one year also manifested more pronounced decreases in EP over this period. Thus, IC appears to become an increasingly strong regulator of aggressive and disruptive behaviour as children proceed into the elementary school-age years, paralleling the maturation of their prefrontal systems.

Our data imply neurocognitive deficits could underlie at-risk children's development of behaviour problems. Interventions designed for young children manifesting poor neurocognitive functioning to increase executive processing abilities may reduce their risk for future development of EP (Riggs et al., 2003, 2006). Educational programs may include content that focuses on the development of executive functioning, as well as changing at-risk children's school environment to a more facilitative one. Smaller classrooms with fewer distractions could enhance children's ability to remain task-focused, while promoting their ability to inhibit disruptive behaviour (Riggs et al., 2003).

Certain limitations are evident in this study. Principally, IC was assessed from maternal reports exclusively. Although the measure of IC provided by the CBQ has good evidence of reliability and validity, further research including alternate measures of IC will be necessary to provide support for the current findings. Similarly, only mother-reported EP was available for the longitudinal analyses. Future studies should include multiple raters across multiple domains of EP and IC. Both laboratory and field observations of aggressive and disruptive behaviours by independent raters of constructs assessed by parent and teacher questionnaires, as well as a behavioural battery to measure IC, would provide stronger evidence for the developmental patterns observed here. The suggested relations between neurophysiological development and the changing relations between IC and EP are hypothetical; functional neuroimaging studies will be necessary to confirm this explanatory model. Recognizing that neurocognitive development does not occur independently of social context, measures of parenting characteristics could also identify potential contributions of socialization experiences to developmental relations between EP and IC.

This study demonstrated the interconnections between young children's executive processing and their adjustment as interpreted by three different raters, mothers, teachers, and laboratory observers. The maladaptive, deviant behaviours associated with the EP spectrum appears associated with poor IC in older preschoolers and kindergarten-aged children, reflective of delayed or diminished prefrontal cortex development. Examining the development of patterns of adjustment and executive control therefore is important in understanding young children's functioning. Early intervention strategies, identifying children at risk and targeting prevention efforts to increase children's executive processes may be an effective avenue toward reducing future externalizing psychopathology.

Study 2[3]

Neurocognitive Development and Externalizing Problems: The Role of Inhibitory Control Deficits from 4 to 6 Years

Deficits in executive control may underlie the symptomatology observed in children with externalizing problems (EP; Oosterlaan, Scheres, & Sergeant, 2005; Séguin, Nagin, Asaad, & Tremblay, 2004; Séguin & Zelazo, 2005). Executive control processes refer to a broad category of cognitive capacities subserved by the prefrontal cortex (PFC) and subcortical system (Diamond, 2002; Luria, 1973, 1980; Miller & Cummings, 1999; Welsh, Pennington, & Groisser, 1991). These capacities are necessary for the execution of goal directed behaviours (Brocki, Nyberg, Thorell, & Bohlin, 2007) and include maintenance of information in working memory, attentional allocation in formulating and executing goal-directed action, and inhibition of prepotent responding (Blair, Zelazo, & Greenberg, 2005; Pennington, 1997; Stuss, 1992). This latter capacity of inhibitory control (IC) is defined as "the deliberate suppression of a salient, prepotent cognition or response" (Ciairano, Visu-Petra, & Settanni, 2007, p. 336). Diminished IC, meaning a reduced capacity to inhibit a prepotent, dominant action, seems to be particularly characteristic of children at risk for aggressive, disruptive and dysregulated trajectories of development (Avila, Cuenca, Félix, Parcet, & Miranda, 2004; Brophy et al., 2002). Questions remain, however, regarding the age at which IC begins to regulate EP. This investigation was

[3] This study has been published. Full reference: Utendale, W. T., Hubert, M., Saint-Pierre, A. B., & Hastings, P. D. (2011). Neurocognitive development and aggression: The role of inhibitory control deficits from 4 to 6 years. *Aggressive Behavior*, *37*, 476-488.

conducted to examine the relations between IC and EP in preschool-aged and early elementary school-aged children, a period of rapid growth in IC capacity.

EP in early childhood encompasses a range of under-controlled, outwardly-directed behaviours that cause harm or distress to others (Mash & Wolfe, 2005). These include physical aggression, such as hitting, kicking, biting, and pushing, verbal aggression, such as teasing and threatening, disruptive behaviour, such as yelling and tantrums, disobedience, inattentiveness and hyperactivity (Achenbach & Rescorla, 2000; Tremblay, 2010). Early-emerging EP have been linked with social and academic difficulties (Krug, Dahlberg, Mercy, Zwi, & Lozano, 2002; McCord, Widom, & Crowell, 2001) and are indicative of risk for future juvenile delinquency, antisocial behaviour and disruptive behaviour disorders (Bongers et al., 2004; Campbell, 2002; Campbell, Shaw, & Gilliom, 2000; Lynam, 1996; Tremblay, 2010).

EP in childhood have been associated with poor executive control processes (Moffitt, Lynam, & Silva, 1994; Séguin, Boulerice, Harden, Tremblay, & Pihl, 1999; Séguin, Pihl, Harden, Tremblay, & Boulerice, 1995). However, the development of associations between EP and executive dysfunction over the preschool and early elementary-school period has not been examined in great detail (Raaijmakers et al., 2008). Elucidating these associations may increase understanding of how dysregulated executive control processes contribute to EP during a critical period of children's neurocognitive development.

Development of Inhibitory Control

The rapid development of executive control during early childhood parallels that of the PFC (Diamond, Kirkham, & Amso, 2002) although myelination of the prefrontal system (Cummings, 1993; Klingberg et al., 1999) and synaptogenesis (Huttenlocher, 1994) continue into adolescence. In young children IC is functionally distinct from other executive control constructs (Hughes, 2002; Olson, Schilling, & Bates, 1999) such as resistance to temptation (Kochanska et al., 1996) and delay of immediate gratification (Olson, 1989). It represents the ability to suppress the activation, processing and expression of information that is unnecessary or problematic for achieving cognitive or behavioural goals (Christ et al., 2007; Dagenbach & Carr, 1994). Examples include interference control within and between tasks (Brocki et al., 2007), ignoring competing information during tasks requiring working memory (Brocki et al., 2007; Hasher & Zacks, 1988), and inhibiting prepotent responses (Diamond, Carlson, & Beck, 2005; Simpson & Riggs, 2005). During the preschool years IC develops quickly (Carlson & Wang, 2007). At 3 years children demonstrate difficulty with tasks requiring inhibition of attentional and motor elements; however, by 5 years children are much better at performing these tasks (Carlson, 2005).

Conversely, EP decrease markedly in most children over this period (Broidy et al., 2003; Chang, Halpern, & Kaufman, 2007), implicating normative maturational increases in IC in the regulation of disruptive and harmful responses. The parallels in the timing of prefrontal development, increased executive functioning, and improved behavioural self-regulation have contributed to speculation that deficits in executive processes might be attributable to delayed or disorganized development of the PFC. Delayed or diminished IC could make it difficult for children to generate situation-appropriate, autonomously-controlled responses to challenging or goal-directed environmental stimuli, resulting in the propensity to express aggressive, impulsive, oppositional and disruptive behaviour (Giancola, 1995).

Relations between IC and EP in Childhood

To this point, there have been relatively few studies of the neuropsychological correlates of EP in early childhood, particularly with respect to IC development during the preschool years (Brocki et al., 2007). Hughes, Dunn and White (1998) found that preschoolers rated by parents as "hard to manage" had lower IC than normatively behaving preschoolers, and maintained these relative IC deficits when assessed again at 7 years (Brophy et al., 2002). Poor IC and other executive function skills have also been associated with aggressive behaviour during peer play (Hughes, White, Sharpen, & Dunn, 2000). The relations between IC and EP in preschoolers are not consistent across studies, however. Thorell and Wåhlstedt (2006) found that teachers reported more Oppositional Defiant Disorder (ODD) and Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms in 4 to 6 year-old children with lower IC, but when accounting for the comorbidity of problems, IC was robustly associated only with ADHD symptoms, not ODD symptoms. Conversely, Floyd and Kirby (2001) found negative associations between IC and teacher-rated aggressive behaviour in 3- to 5-year-old children, independent of children's inattention problems. Whereas Rhoades, Greenberg and Domitrovich (2009) found that IC was not significantly associated with teacher-rated EP in 4 - 5 year-olds, Lewis and colleagues (2007) found that IC was inversely related to parent-reported EP in 5 and 6 year-old children, although relations with specific indices of aggression or inattention problems were not significant. Finally, using a combined index of mother-reported, teacher-reported and observed EP, Utendale and Hastings (2011) demonstrated that the negative relation between IC and EP became increasingly stronger over the 2 ½ - 6 year period. IC was not significantly associated with EP in the youngest preschoolers, but was robustly negatively associated with EP in 5 to 6 year-olds.

These studies of preschool- and kindergarten-aged children suggest that the association between IC and EP might not be robust until later in development. Most studies of elementary school-age children have found negative relations between IC and various measures of EP (Avila, Cuenca, Félix, Parcet, & Miranda, 2004; Kooijmans, Scheres, & Oosterlaan, 2000; Oosterlaan, Logan, & Sergeant, 1998; Oosterlaan & Sergeant, 1996; Riggs, Blair, & Greenberg, 2003; Riggs, Greenberg, Kusché, & Pentz, 2006), although exceptions to this pattern exist (Daugherty, Quay, & Ramos, 1993; Schachar & Tannock, 1995). Given the maturational course of IC, it might not be sufficiently developed in preschool-aged children to serve as an effective regulatory mechanism for aggressive, impulsive and oppositional behaviour. Alternatively, it might be the case that the development of IC is delayed or diminished in children with EP, such that their IC deficits appear to worsen from preschool-age to childhood.

There are also methodological factors that might have contributed to the inconsistencies in findings across studies of young children. Differing constructs have been used to define IC and EP, and studies have tended to use relatively small samples, typically drawn from normative, community populations (Brophy et al., 2002; Hughes et al., 1998). If the link between IC and disruptive behaviour problems is weak in young children, then larger samples would be necessary to confer the power required to detect the relation. Similarly, if deficits or delays in the development of IC only characterize children with highly elevated EP, then documenting the association could necessitate including a sufficient number of such children. Thus, comparing IC performance in a large sample of preschoolers and elementary school-aged children targeted to have an over-representation of high levels of EP would help to clarify understanding of this developmental process.

Factors Potentially Affecting the Relation between IC and EP

EP constitute a broad construct, encompassing a diverse spectrum of challenging and inappropriate behaviours. Particularly in preschoolers, inconsistent findings have emerged in the relations between IC and specific aspects of EP, namely aggression and ADHD-related problems of hyperactivity, impulsivity and inattention (e.g., Floyd & Kirby, 2001; Thorell & Wåhlstedt, 2006). The link between ADHD and poor executive functioning is well established (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and, of course, ADHD and aggression problems are highly comorbid (Hastings, Fortier, Utendale, Simard, & Robaey, 2009). Some studies have demonstrated that the association between impaired executive functioning and aggressive behaviour is lost when accounting for ADHD-related problems (Clark, Prior, & Kinsella, 2000; Nigg, Hinshaw, Carte, & Treuting, 1998; Oosterlaan et al., 1998; Pennington & Ozonoff, 1996; Raaijmakers et al., 2008; Thorell & Wåhlstedt, 2006). Other studies have challenged these findings, showing decrements in executive processing remain significantly associated with aggressive behaviour when controlling for ADHD-related deficits (Déry et al., 1999; Floyd & Kirby, 2001; Oosterlaan et al., 1998; Séguin et al., 1999, Séguin et al., 2004). Therefore, as well as examining the relations between IC and EP, in this study we considered whether IC was associated specifically with children's aggression problems and their hyperactivity, impulsivity and attention problems (hyperactive-impulsive-attention problems; HIA).

IC is also not independent of other aspects of children's cognitive and neurocognitive development, including general intelligence (Mahone et al., 2002; Polderman et al., 2006) and working memory. Early childhood appears to be a period of rapid development of working memory capacity in concert with PFC development (Diamond, Prevor, Callender, & Druin, 1997; Wolfe & Bell, 2004). Indeed, it has been suggested that IC performance requires cognitive skills associated with both inhibition and working memory (Diamond, 1990; Wolfe & Bell, 2004). Therefore, we included measures of both working memory and general intelligence (IQ) in our examination of the relations between IC and EP.

Questions also exist with regard to whether the development of executive processes might be related to the pronounced sex difference in EP (Thorell & Wåhlstedt, 2006). Most research suggests that from the toddler years onwards, boys manifest markedly higher levels of aggressive, inattentive and disruptive behaviour than girls (Broidy et al., 2003; Cairns, Cairns, Neckerman, Ferguson, & Gariépy, 1989; Tremblay et al., 1996; Tremblay et al., 2004), although some studies have not demonstrated this (Keenan & Wakschlag, 2000; Munson, McMahon, & Spieker, 2001). Conversely, young girls develop IC earlier and more rapidly than young boys (Keenan & Shaw, 1997). The relative delay in development of IC capacity compared to girls might make boys more likely to exhibit EP (Raaijmakers et al., 2008). Young girls exhibiting elevated EP are an understudied group (Putallaz & Bierman, 2004), and few studies have had sufficient sample sizes to examine sex differences in the relations between IC and EP. Whereas Olson and colleagues (1999) found that teacher-reported aggression was associated with lower IC only in 6 year-old girls, neither Raaijmakers et al. (2008) nor Rhoades et al. (2009) found differences between boys and girls in the relation between IC and EP. Examination of potential sex differences in the relations among age, IC and EP is therefore warranted.

The Current Study

In this investigation we examined the relations between IC and EP in preschool-age and elementary school-age children. Because it takes time to inhibit a prepotent response and produce a correct response on an IC task, better IC was expected to be reflected in longer latencies and larger numbers of correct answers. We hypothesized that children with poor IC (increased error rates and shorter response latencies) would show higher levels of EP. This inverse association between IC and EP was expected to be stronger in elementary school-age children than in preschoolers. Diminished IC performance was expected to be associated with EP independently of IQ and working memory, and was expected to be evident both in elevated aggression and elevated inattention problems. Boys were expected to perform more poorly than girls on IC tasks, particularly at preschool-age. However, the inverse relation between IC and EP was expected to be similar for boys and girls.

Method

Participants

180 children (85 girls) were recruited as part of an ongoing longitudinal study. Children were either 4.0 - 4.9 years (n = 98) or 6.0 - 6.9 years (n = 82) at screening, M = 5.37, SD = 1.10. There were 148 English-speaking and 32 French-speaking children. Families were predominantly Caucasian (77.2 %) and middle to upper-middle SES (M = $85210, SD = $54694, Mode = $50-60000). Targeted recruitment was used to over-sample for children with aggression and externalizing problems. Interested families were asked to contact the laboratory to be provided with more information about the study and complete an initial screening to assess inclusion criteria, including child age (4 or 6 years), child living with mother, and 6 year-olds being enrolled in first grade. Children with serious physical or cognitive challenges were excluded from the study. Based on telephone screening (see Procedure), there were 92 children with CBCL Aggression and/or Externalizing T-scores equal to 60 or higher (at least one SD above age and sex norms), 41 children with T-scores between 51 and 59 (less than one SD above norms), and 47 children with T-scores equal to 50 or lower (at or below age and sex norms). Parents were remunerated $75 and children received a T-shirt for their participation.

Procedure

This study was conducted at a university-based developmental psychology laboratory. A variety of targeted advertisements, with some including words such as “challenging,” “difficult,” and “naughty,” and letters distributed through preschools, elementary schools and direct mailing that included language such as “hitting, yelling and temper tantrums,” were used for recruitment. Interested parents contacted the laboratory and underwent a screening procedure that included the administration of all items on the externalizing scale of the age-appropriate version of the CBCL. After the screening but prior to the lab visit, mothers were mailed the consent forms to review and a battery of questionnaires to complete, including the age-appropriate full CBCL; all analyses reported in this paper utilized scores from the full CBCL. Most lab visits were scheduled within 3 months of the telephone screening. However, due to scheduling conflicts there were four younger and eight older children who had turned 5 or 7 years, respectively, shortly before testing; age at testing $M = 5.58$ years, $SD = 1.10$. At the lab visit, the mother signed the consent forms for her own and her child's participation. The laboratory visit was conducted either in English or French, matched to the child's greater linguistic competence, and lasted approximately three hours.

During the first hour of testing, one examiner provided information about the lab visit, discussed informed consent, and answered any questions for the mother, while a second examiner played and established rapport with the child. The second examiner then discussed the laboratory procedures with the child, and obtained assent. Both mother and child were informed they may take a break at any time if needed. Subsequently, several procedures were done which do not pertain to the current analysis. They included mother-child interaction tasks and assessment of child physiology. These procedures took approximately one hour. Following this, children were tested on two IC tasks (Day/Night task, Tapping task; both of which are validated tests of IC in this age range, e.g., Diamond & Taylor, 1996; Rhoades et al., 2009) and a working memory control task. Following the IC and working memory tasks, the child had a break and a snack, after which the IQ test was administered.

For each of the Day/Night (D/N) task, Tapping task, and working memory control task, the rules were explained and the children were asked to repeat them. Children had to pass a training period consisting of two trials in order to move on to the 16 testing trials. Feedback was given during the training trials; children were praised for a correct response and corrected for an inaccurate response or for the lack of a response; no such feedback was given during the testing trials. There were 11 children who did not want to participate in the IC portion of the study or who did not pass the training trials for the D/N task, and 2 additional children who did not complete the Tapping task. There were 13 children who did not want to complete the working memory control task.

After the snack break, the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 2004) was administered to English-speaking children. The Quebec-normed version of the Wechsler Intelligence Scale for Children, Fourth Edition (Weschler, 2003) was administered to 6 year-old French-speaking children, and the Stanford-Binet Intelligence Scale, Fourth Edition (Thorndike, Hagen, & Sattler, 1986) was administered to 4 year-old French-speaking children, because respective age-based norms for French children were available using these instruments.

Measures

Child Behavior Checklist (*CBCL*; Achenbach & Rescorla, 2000, 2001). Mothers completed the age-appropriate (1.5 - 5 yr or 6 - 18 yr) version of the CBCL. In these analyses the broadband Externalizing Problems scale was used for the main analyses, and the narrow-band subscales of Aggression Problems and Attention Problems were used for secondary analyses. The reliability and validity of the CBCL have been examined in several studies (Bingham, Loukas, Fitzgerald, & Zucker, 2003; Mattison & Spitznagel, 1999). Reliability was good in this sample; for Externalizing, Aggression and Attention Problems, α = .91, .94 and .62 in 4 year-olds, and α = .88, .90 and .86 in 6 year-olds, respectively. Because T-scores for the narrow-band dimensions of the CBCL have a lower limit of 50 and thus reduce sample variability for low Aggression and Attention Problems, the raw scale scores (mean of item ratings) were used in analyses of these narrow-band scales.

Day-Night Task (Gerstadt, Hong, & Diamond, 1994). The D/N task assesses IC in much the same way as the Stroop test (Lewis et al., 2007). Children must maintain two rules in mind while inhibiting a dominant response. This task has been used to investigate the development of executive control and frontostriatal circuitry in children from 3.5 to 7 years old (Diamond et al., 2002; Diamond & Taylor, 1996; Gerstadt et al., 1994), with performance improving with age in normative samples. Sixteen laminated cards were used. Half of the cards had an image of a sun, and the other half had an image of the moon and stars. The size of the pictures was 13.5 × 10 cm. There were two practice trials and 16 testing trials. Children had to engage in an alternative response (inhibiting the prepotent response) by saying the word that was semantically opposite of the card presented to them. Children were instructed to say "day" when presented with an image of a moon and stars, and to say "night" when presented with an image of a sun. Cards were presented in pseudo-random order.

Tapping Task (Luria, 1966). Luria's Tapping task (Luria, 1966) has also been used with children 3.5 - 7 years old (Diamond & Taylor, 1996). The examiner and child took turns tapping a wooden dowel on a table, with children being required to remember two rules to correctly perform this task ("Tap once when I tap twice. Tap twice when I tap once."), which are counter to the dominant response of mimicking the experimenter. There were two practice trials and 16 testing trials. The examiner tapped the wooden dowel either once or twice according to a predetermined pseudo-random protocol. After the experimenter tapped, the dowel was offered to the child to grasp, whereupon the child tapped it on the table (either following or failing to follow the rules). After the child completed the turn, the examiner asked for the dowel back, and then proceeded to the next tapping trial. Thus, an important distinction between the Tapping Task and Day/Night Task was the requirement for motoric versus verbal responses, respectively.

Working Memory Control Task. In addition to controlling prepotent responses, the two IC tasks required the children to retain two rules in memory simultaneously. Thus, it was important to measure children's working memory capacity, independent of their IC. The working memory (WM) task was a motor-based memory task adapted from similar sorting tasks used in prior studies (Gerstadt et al., 1994; Lewis et al., 2007; Zelazo, Müller, Frye, & Marcovitch, 2003). Instructions and training trials for this task were similar to that for the preceding IC tasks. The child was presented with either a yellow ball or an orange block and was instructed to place yellow balls into a red bucket and orange blocks into a blue bucket. Therefore, the task involved retention of two arbitrary rules, but without the need to inhibit a prepotent response. Following instructions, 16 test trials were conducted. This task provided an estimate of the influence of working memory on performance. Most children performed well on this task; no child made more than 3 errors.

IQ Composite. The full-scale IQ composite was derived from one of three IQ measures, each of which provides a full-scale IQ score with $M = 100$ and $SD = 15$. Tests were administered by trained raters as per standard instructions. All children had full-scale IQ scores > 70 ($M = 107.17$, $SD = 13.76$).

Coding. Coding was performed by trained raters blind to children's CBCL scores. Response accuracy and latency were derived from DVD recordings using Imovie software which permitted a frame-by-frame analysis (30 f/s). Accuracy was scored as correct or incorrect for each testing trial, with the sum of correct responses for each task recorded as the score for response accuracy by two trained raters (coder reliability $r = 1.00$ for both tasks). Latency was scored as the number of centiseconds required to respond to each testing trial, with the total of the 16 latencies being the child's final score. Latency for the D/N task was recorded from the moment the card was at a forty-five degree angle with the testing table until the child's first verbal response. Latency for the Tapping task was recorded from the moment the wooden dowel was grasped by the child to the child's first tap. Coder reliability (two coders) for both tasks was $r \geq .95$. For the memory control task, almost all children had perfect or near-perfect (one error) responses, and coder reliability (two coders) was $r = 1.00$.

Data analyses

Correlations among control variables (Language of Testing, full-scale IQ and WM), Sex and Age, IC indices and EP score were calculated. Boys and girls were compared on control and focal variables using independent samples *t*-tests.

Hierarchical linear regression analyses were used to test the associations between EP and the IC correct and latency scores. Therefore, 2 regressions were examined, one with IC scores on the D/N task and one with IC scores on the Tapping task. All variables were centered around their mean prior to computation of interaction terms, and centered variables were used in analyses. Potential covariates (language, full-scale IQ and/or the memory index) were entered into step 1 of the model. Age Group and Sex were entered on step 2, then number correct and latency to respond on step 3. Sex x Age, IC x Sex, and IC x Age interaction terms were entered on step 4. The 3-way Sex x Age x IC interaction terms were entered on step 5.

As child age formed a bimodal distribution, significant interaction terms involving Age were examined by regressing IC onto EP at older (6 years) and younger (4 years) values, in order to clarify how Age moderated the associations between IC and EP. Significant interactions involving sex were examined by regressing IC onto EP separately for boys versus girls.

Results

Descriptive statistics are presented in Table 4. Zero-order correlations are presented in Table 5. As expected, older children had shorter latencies to respond for the D/N and Tapping tasks, $t(167) = -3.61$, $p < .001$, $t(165) = -2.25$, $p < .05$, respectively, and responded correctly more often on both IC tasks, $t(167) = 5.54$, $t(165) = 4.96$, both $p < .05$. Performance on the two IC tasks was convergent, significantly so for number of correct responses, and approaching significance for latency to respond. On each task, children who responded more quickly also responded more accurately. Children with more EP made more errors (fewer correct

Table 4. Summary Statistics for 4 year-old and 6 year-old Children.

	4 Years					6 Years				
	n	Min.	Max.	*M*	*SD*	*n*	Min.	Max.	*M*	*SD*
Full Scale IQ	98	79.78	137.00	107.92	11.31	82	71.00	155.00	105.24	16.26
Memory Task Correct	89	13	16	15.77	0.39	78	14	16	15.86	0.45
Externalizing Problems T-Score	98	32	80	51.49	11.45	82	33	75	55.34	11.76
Attention Problems Mean Score	98	0.00	1.80	0.54	0.43	82	0.00	1.90	0.43	0.39
Aggression Problems Mean Score	98	0.00	1.74	0.63	0.43	82	0.00	1.28	0.44	0.34
Day/Night Correct	89	0	16	11.11	4.96	80	2	16	14.35	2.18
Tapping Correct	87	0	16	12.17	4.27	80	0	16	14.84	2.29
Day/Night Latency	89	6.88	80.00	23.19	10.64	80	10.15	36.67	18.35	5.14
Tapping Latency	87	8.06	68.69	28.62	13.46	80	6.62	54.76	24.14	10.99

Table 5. Correlations among Primary Measures.

	2	3	4	5	6	7	8	9	10
1.Language of Testing	-.01	-.09	.01	.00	.02	-.10	.02	.02	-.37***
2. Sex		-.06	-.12†	.10	.00	.01	.15†	.05	.00
3. Age			.16*	-.10	.11	.39***	.36***	-.27***	-.17*
4. Externalizing Problems				-.16*	-.09	-.09	-.16*	-.16*	.05
5. Full-scale IQ					-.01	.12	.02	-.08	-.07
6. Memory Task Correct						.08	.21**	.15†	-.09
7. Day/Night Correct							.34***	-.15†	-.20*
8. Tapping Correct								-.02	-.29***
9. Day/Night Latency									.14†
10. Tapping Latency									

†$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

responses) on the Tapping task, and had shorter response latencies on the D/N task. Boys had significantly higher Attention Problems scores than girls, $t(178) = 1.98$, $p = .05$ and tended to have fewer correct responses on the Tapping task, $t(165) = -1.93$, $p < .10$. Boys had slightly higher EP than girls, $t(178) = 1.66$, $p = .10$.

Check for Control Variables

Three potential confounding variables were examined to determine if they were associated with the variables of interest: Language of testing (French or English), IQ, and WM index (number correct on the Bucket task). French children scored significantly higher on measures of IQ, $t(178) = -2.33$, $p < .05$. They also had shorter response latencies on the Tapping task, $t(165) = 6.05$, $p < .001$. IQ was not associated with IC, all $|r| \leq .12$.

Higher IQ was associated with fewer EP, $r(180) = -.16$, $p < .05$. The memory index was significantly positively correlated with number correct on the Tapping task, $r(169) = .21$, $p < .01$. However, preliminary analyses indicated that inclusion of language of testing, IQ score, or WM as covariates did not affect any of the relations in the regression analyses for either IC index. Therefore these three variables were not retained in the final analyses.

Associations between EP and Day/Night Task Performance

The regression model for the D/N task was significant, adj. $R^2 = .06$, $F(11,157) = 1.91$, $p < .05$ (see Table 6a). There was a significant negative association between number correct on the D/N task and EP, such that children with more EP made more errors. This was equally true for younger and older children, and for boys

Table 6a. Regression Analysis Testing Associations between Day/Night (D/N) Task Performance and Externalizing Problems

Step and Predictor	ΔR^2	*df*	ΔF	β	*t*
1	0.05	(2,166)	4.39*		
Sex				-.16	-2.05*
Age Group				.15	1.97†
2	0.04	(2,164)	3.51*		
D/N Correct				-.18	-2.19*
D/N Latency				-.12	-1.60
3	0.01	(5,159)	0.32		
Age Group x Sex				.01	0.16
D/N Correct x Sex				.00	-0.03
D/N Correct x Age Group				.02	0.20
D/N Latency x Sex				.01	0.16
D/N Latency x Age Group				.13	1.25
4	0.02	(2,157)	1.76		
D/N Correct x Sex x Age Group				.01	0.10
D/N Latency x Sex x Age Group				-.19	-1.77†

†$p < .10$, *$p < .05$.

and girls, as children's age group and sex did not significantly moderate associations between EP and performance on the D/N task.

Associations between EP and Tapping Task Performance

The regression model for the Tapping task was significant, adj. $R^2 = .07$, $F(11,155) = 2.19$, $p < .05$ (see Table 6b). Children with higher levels of EP made significantly more errors on the Tapping Task. There was also a significant interaction between Sex and Tapping latency (see Figure 3). Boys with more EP had longer response latencies ($\beta = .21$, $p = .05$). This relation was not observed for girls ($\beta = .07$, $p = .56$).

Associations between IC and Specific Indices of Aggression and Attention Problems

The relations between IC scores and children's Aggression and Attention Problems were quite similar (see Table 7). Children with more Aggression and Attention Problems made more errors on the D/N and Tapping task, and tended to have longer response latencies on the Tapping task. The similar relations between IC and Aggression and Attention Problems were not surprising, given the high correspondence in mother-reported problem scores, $r = .62$, $p < .001$. Nevertheless, partial correlations were used to examine whether there were unique associations between IC and the two narrow-band CBCL scores. Controlling for Attention Problems, children with more Aggression Problems tended to make more errors on both the D/N and Tapping tasks, partial rs = -.15 and -.14, respectively, both $p < .10$. Controlling for Aggression Problems, children with more Attention Problems made more errors only on the Tapping task, partial $r = -.16$, $p < .05$. No other associations

Table 6b. Regression Analysis Testing Associations between Tapping (TP) Task Performance and Externalizing Problems

Step and Predictor	ΔR^2	*df*	ΔF	β	*t*
1	0.05	(2,164)	4.41*		
Sex				-.14	-1.88†
Age Group				.16	2.12*
2	0.05	(2,162)	4.21*		
TP Correct				-.23	-2.68**
TP Latency				.03	0.39
3	0.03	(5,157)	1.09		
Age Group x Sex				-.02	-0.21
TP Correct x Sex				-.05	-0.53
TP Correct x Age Group				-.07	-0.73
TP Latency x Sex				-.17	-2.07*
TP Latency x Age Group				-.12	-1.46
4	0.01	(2,155)	0.56		
TP Correct x Sex x Age Group				-.10	-0.69
TP Latency x Sex x Age Group				.05	0.61

†$p < .10$, *$p < .05$, **$p < .01$.

Figure 3. Sex Moderates the Relation between Latency to Respond on the Tapping Task and Externalizing Problems

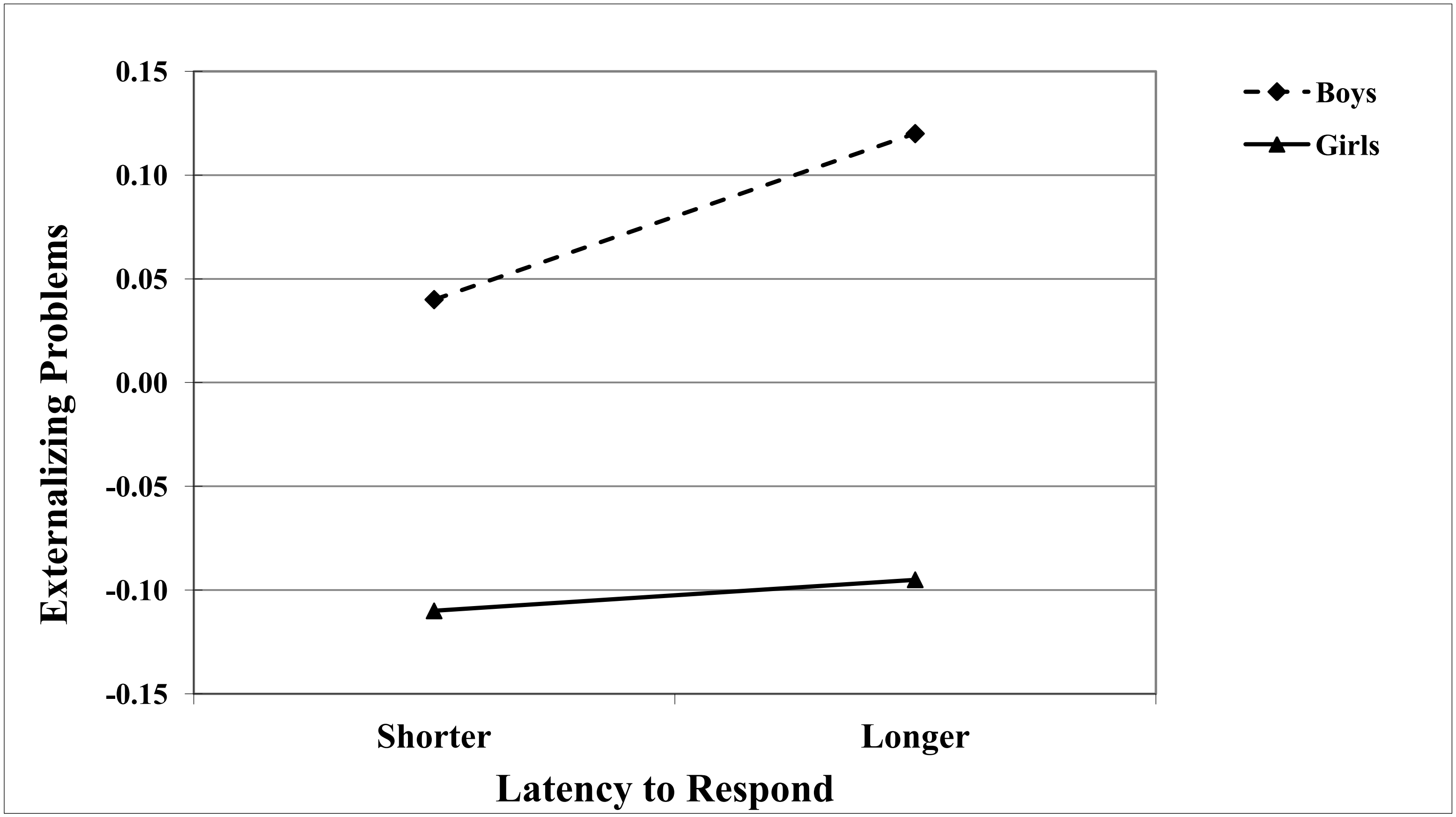


Table 7. Correlations between Inhibitory Control Measures and Aggression and Attention Problems.

	Day/Night Correct	Tapping Correct	Day/Night Latency	Tapping Latency
Aggression Problems	-.25**	-.30***	0.02	.14†
Attention Problems	-.27***	-.29***	-0.06	.14†

†p < .10, **p < .01, ***p < .001.

approached significance.[4] Thus, there were only weak unique associations between children's accuracy on the IC tasks and both their Aggression and Attention Problems, suggesting that IC deficits were associated with what is common to the two (EP), rather than what is unique to each.

Discussion

The expected negative relations between EP and performance on IC tasks were observed for both preschoolers and early elementary school-aged children. Poor IC was not specific to either aggressive behaviour or HIA problems, but rather characterized children who displayed the broader range of aggressive, disruptive, defiant, impulsive, hyperactive and inattentive behaviours encompassed within externalizing difficulties. The association between IC deficits and EP also appeared to be independent of children's general intelligence and working memory, suggesting a particular role for executive control processes in the aetiology of children's dysregulated behaviour. As it reflects an inability to keep oneself from acting upon prepotent responses, and specifically for the tasks used in this investigation, an inability to inhibit such acts in order to comply with adult-defined rules, poor IC might contribute to young children's impulsive and destructive behaviours that upset or harm others. These findings serve to clarify discrepancies in the existing literature regarding the age at which the inverse relation between IC and EP becomes apparent,

[4] Similarly, in regression analyses, D/N performance did not significantly predict Attention Problem scores when controlling for Aggression Problems, whereas children with longer latencies on the D/N task had more Aggression Problems ($\beta = -.13$, $t = -2.11$, $p < .05$) after controlling for Attention Problems. Conversely, Tapping task performance did not significantly predict Aggression Problem scores when controlling for Attention Problems, but the Sex X Latency interaction predicted Attention Problems ($\beta = -.16$, $t = -2.43$, $p < .05$) after controlling for Aggression Problems. Tapping latency tended to be positively associated with Attention Problems in boys ($\beta = .15$, $p = .09$), but negatively in girls ($\beta = -.15$, $p = .11$). Thus, the associations between IC performance and children's problems were stronger and more consistent when the broad-band Externalizing Problems scale scores were examined, compared to the narrow-band scores.

and further support those studies documenting that IC appears to be an important regulator of EP in children as young as four years old (Hughes et al., 1998, 2000; Utendale & Hastings, 2011).

There was both consistency and divergence in how EP were related to children's performance on the two IC tasks. On the Day/Night task, children with more EP performed more poorly, as expected. The Day/Night task draws on semantic processing, perceiving a cue, accessing the response rule, and generating a verbal response. Given the lack of moderating effects, at least with this semantically-based task, PFC development might equally regulate the association between IC and EP among both boys and girls over the 4 - 6 year period.

On the Tapping task, which required motor processing, number correct was also negatively associated with EP, and this relation appeared independent of both sex and age, as with the Day/Night Task. Divergent patterns of association were observed on latency to respond, however. Examination of how sex and age moderated the relation between EP and response latency on the Tapping task revealed that boys showed a *positive* association between EP and latency such that children with more problems had *longer* latencies. Work with normatively developing children has shown better performance is related to longer response latencies on the Day/Night task (Gerstadt et al., 1994). The discrepancy in findings between the two IC tasks in terms of response latency may be related to a difference in processing capacity for the two IC measures, one of which required children's semantic processing (Day/Night task) and the other motor processing (Tapping task). For boys with elevated EP, poor motor processing efficiency may contribute to increased response latency, as more time is required to determine the appropriate, non-dominant response, particularly when no explicit time demands are part of task performance. Under these conditions, given the time to attempt correct responding, poor motor processing may manifest as increased latency while boys are trying to perform the task correctly. This may represent an important developmental distinction between potentially inefficient processing and limited or minimal processing expected for impulsive behaviour. (This inference is consistent with the secondary analyses which suggested that longer Tapping latencies were particularly associated with boys' HIA problems; see Footnote 1.) This is in contrast to the Day/Night task for which the expected inverse association between latency to respond and EP was observed in the zero-order correlation analyses, although it was not retained in the multiple hierarchical regression, after accounting for sex and age differences in performance.

The differences observed between the two IC tasks could also be related to differing rates of neuropsychological maturation; that is, they might be differentially affected by poor PFC development. In adolescents, semantic and motor processing have been shown to be distinct elements of IC ability, demonstrating different levels of inhibition in the presence of conduct problems (Herba, Tranah, Rubia, & Yule, 2006). Developmental trends in semantic and motor processes also demonstrate differences in processing efficiency with age (Klenberg, Korkman, & Lahti-Nuuttila, 2001). Therefore, children of different ages could be expected to manifest different capacities within each domain, and children with elevated EP might reveal evidence of their diminished IC differentially across these domains.

Sex differences in externalizing psychopathology are consistently reported in the literature, such that boys are over-represented in both clinical and community samples (Hinshaw, 2003). Sex differences in IC have also been reported, with girls performing superior to boys (Raaijmakers et al., 2008), although sex differences in IC diminish after preschool-age (Gerstadt et al., 1994). It has been argued that sex differences in EP might be attributable to those in IC development. It should be noted that we oversampled for girls with elevated EP, such that the typically identified sex difference in problems was quite weak in this sample. Perhaps as a consequence, we also found only one weak tendency for girls to slightly outperform boys on one of the IC tasks. This would suggest that both young girls and young boys with similarly elevated levels of EP are likely to show evidence of poor IC development. This was also reflected in the general tendency for relations between IC performance and EP to be similar for boys and girls; of eight interaction terms involving gender, only one was significant. This one finding revealed a unique association between boys' EP and increased latency on the Tapping task, suggesting that relatively poor performance on motor-based IC tasks is a greater risk factor for EP in boys. Alternatively, our findings may simply suggest boys develop motor skills later than girls (Hanlon, Thatcher, & Cline, 1999). Certainly, this is a finding that warrants efforts for replication and further exploration.

Thus it appears that, from at least the preschool years forward, IC serves as a regulatory mechanism for EP. IC deficits appearing over the preschool and early elementary period might provide an early indicator of poor PFC development, independent of children's intelligence and working memory. These deficits could contribute directly to the development of EP and future psychopathology. Poor IC characterizes both girls and boys with elevated EP, although weak or delayed IC development might carry a slightly greater risk for EP in young boys.

Limitations and Future Directions

It is possible that the two IC tasks used may have been differentially sensitive over the preschool and early elementary school period for boys and girls. Preschoolers may have found the Tapping task too difficult while older children may have found it too easy. Modified, more difficult versions of the D/N task have shown increases in IC over the preschool and early to middle elementary school period (Pasalich, Livesey, & Livesey, 2010; Simpson & Riggs, 2005), suggesting that some change in IC may still occur into middle childhood (Diamond, 2002), and that more difficult IC tasks may be required to identify these more modest changes. Including IC tasks across a range of difficulties may help illuminate IC-EP relations more thoroughly across both age and sex.

Observed IC deficits could also reflect a diverse array of underlying processes (Milich et al., 1994). Although the IC tasks used tap behavioural inhibition (semantic and motor components), they are only two of many tasks available. Several other inhibitory constructs have been described. Nigg (2000) identified interference control, cognitive inhibition, behavioural inhibition and oculomotor inhibition. How our findings might generalize to IC as measured using other tasks and to other inhibitory control constructs is unknown. Future research should include multiple methods of assessing inhibition across a range of difficulty levels, in order to examine whether the relations between inhibition and aggression differ across constructs or change over development.

Further, it should be recognized that the exact behaviours assessed in the CBCL Externalizing, Aggression and Attention Problems scales differ somewhat between the versions used for preschool- versus school-age children. While this might accurately reflect the nature of heterotypic continuity in problem development, it might also mask changes in relations between problems and IC. Thus, the current findings should be replicated with alternative measures of children's externalizing and other problems.[5] Similarly, future research should include clinical samples of children with confirmed diagnoses of ADHD, ODD/CD, and comorbid ADHD/ODD/CD. Without inclusion of a clinical group for comparison we were unable to infer whether the observed associations are continuous in normative and diagnostic samples. As well, no causal relations may be inferred from this cross-sectional study. Longitudinal designs in examining developmental relations for EP and IC are warranted. These results might lead one to consider the diagnostic utility of adding IC assessment to predicting high risk groups and early prevention efforts.

Conclusion

This study provides evidence that the transition from the preschool-age to the early elementary school-age years represents a period of change in the relations between different (semantic versus motor) types of IC and EP. Deficits in IC appear to

[5] Recognizing that the differing contents of the broad-band scale and narrow-band subscales of the two versions of the CBCL might have affected our findings, we conducted supplementary analyses with alternative ways of aggregating the CBCL items, including the aggression scores derived by NICHD (2004) and Bongers et al. (2004). Overall there were only small differences between the findings we obtained with these alternative scales and those obtained using the original CBCL aggression subscale. Further, of those small differences that emerged, the stronger findings were obtained with the original CBCL scales.

be differentially present for preschoolers and early elementary school children, and boys versus girls with elevated levels of EP. Differences in the associations of IC with EP that tap motor versus semantic processing suggest that controlling motor responses may require greater effort from boys. Overall our data imply neurocognitive deficits could underlie children's risk for the development of EP.

Study 3[6]

Differences in Parasympathetic Regulation of Inhibitory Control in Young Children with and without Externalizing Problems

Self-regulation is a key factor in children's cognitive development and behavioural adjustment (Blair & Peters, 2003; Cole, Zahn-Waxler, Fox, & Usher, 1996). Dynamic regulation of cardiovascular activity through parasympathetic pathways might be important for the support of cognitive processing during periods of challenge or stress (Duschek, Muckenthaler, Werner, & del Paso, 2009). This suggests that parasympathetic regulation plays a role in the negative association between externalizing problems (EP) and inhibitory control (IC) that have been documented in preschoolers (Floyd & Kirby, 2001; Utendale & Hastings, 2011) and elementary school children (Kooijmans, Scheres, & Oosterlaan, 2000). Basal and dynamic parasympathetic activity have been associated with attention and adaptive cognitive functioning in adults (Hansen, Johnsen, & Thayer, 2003; Healy, Treadwell, & Reagan, 2011; Thayer & Lane, 2000), children (Becker et al., 2012; Calkins, 1997) and infants (Huffman et al., 1998). Further, parasympathetic activity has also been related to children's externalizing behaviour (Beauchaine, 2012; Calkins, Graziano, & Keane, 2007; Hinnant & El-Sheikh, 2009) and risk for future psychopathology (Calkins et al., 2007; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Porges, 2007).

In this investigation we examined respiratory sinus arrhythmia (RSA), a quantification of vagal control over cardiac activity, during cognitively challenging IC tasks in young children with varying levels of EP. We investigated the interrelations of

[6] This study is currently under review. Full reference: Utendale, W. T., Nuselovici, J. M., Saint-Pierre, A. B., Hubert, M., & Hastings, P. D. (Under review). Differences in parasympathetic regulation of inhibitory control in young children with and without externalizing problems. *Developmental Psychobiology*.

RSA, EP and IC, and whether parasympathetic regulation moderated the association between EP and IC.

Parasympathetic Regulation and Externalizing Behaviour

Porges (2001, 2007) has described parasympathetic regulation of the heart as a useful index of physiological self-regulation. Higher resting RSA (a quantification of the influence of the vagus nerve, or cranial nerve X, on the cardiac muscle) is associated with children's behavioural, cognitive and emotional regulatory capacities (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997; Marcovitch et al., 2010; Stifter & Fox, 1990). Dynamic changes in vagal efference, or how basal RSA is suppressed or augmented under task conditions, reflect physiological changes associated with adaptive responding during periods of stress (Beauchaine, 2001; Calkins, 1997).

Researchers have suggested that children's adaptive functioning is supported by higher basal RSA (Blandon, Calkins, Keane, & O'Brien, 2008; Staton, El-Sheikh, & Buckhalt, 2009) and greater RSA suppression in response to challenge (Calkins & Keane 2004; Porges, Doussard-Roosevelt, & Maiti, 1994). Indeed, cardiovascular indices of autonomic regulation have been shown to be associated with child functioning and psychopathology (Calkins & Dedmon, 2000; Calkins et al., 2007; Huffman et al., 1998; Porges et al., 1996; Raine, Venables, & Mednick, 1997; Stifter & Fox, 1990). Measuring both basal vagal influence and the ability to withdraw and re-engage vagal control can provide, respectively, indices of reactivity and regulation of social and attentional behaviours (Hastings et al., 2008).

Greater vagal withdrawal in infants during laboratory assessment has been associated with greater attention span and ease of soothing (Huffman et al., 1998), and fewer behavioural problems at 3 years (Porges et al., 1996). Calkins and Keane (2004) showed that greater ability to sustain RSA suppression during periods of focused attention and problem solving was associated with lower emotional reactivity and fewer EP. Further, Calkins and colleagues (2007) found marginally reduced levels of vagal withdrawal for 5 year-olds with EP, compared to children with fewer problems, during multiple activities including effortful control of motor responses and attention. Hinnant and El-Sheikh (2009) demonstrated that, for children in middle childhood, EP was associated with RSA augmentation rather than suppression during a social problem-solving task. Some investigations, however, have failed to support consistent relations between EP and basal or reactive RSA (Dietrich et al., 2007; El-Sheikh, Harger, & Whitson, 2001; El-Sheikh & Whitson 2006).

The contextual nature of challenge or stress could contribute to these contradictory findings. Situational elements and associated task demands contribute to whether a given change in RSA would be an adaptive or maladaptive application of parasympathetic control (Porges, 2007). Reduction in vagal outflow may support appropriate (adaptive) responding in one instance but represent a maladaptive response in another. Inhibitory vagal influence via innervation of the SA node of the heart reduces sympathetic efference and facilitates a calm state (Porges, 2007). During periods of threat, vagal outflow diminishes (Huffman et al., 1998) and sympathetic activity increases to support mobilization of resources. Both Porges (2001) and Beauchaine (2001) suggest that reallocating resources (corresponding with vagal suppression) during environmental demand indicates good (adaptive) regulatory processing. Children's perception of threat or challenge may be inconsistent with the nature of situational demands, however. Vagally mediated release of the sympathetic mobilization system in the face of non-threatening stimuli may represent maladaptive physiological responding in children with behavioural problems (Friedman, 2007; Hastings et al., 2008). Conversely, failure to suppress vagal influence in response to conditions that necessitate orienting and active responding also could undermine adaptive behaviour.

Parasympathetic Regulation and Executive Function

Executive functions have been described as those capacities encompassing ‘‘planning, flexible strategy employment, impulse control, and organized search’’ (Welsh, Pennington, & Groisser, 1991, p. 132). They are reflected in such processes as developing plans for future actions, holding those plans and action sequences in working memory until they are executed and response inhibition (Pennington & Ozonoff, 1996). They are utilized when tasks are non-automatic and novel (Hayes, Gifford, & Ruckstuhl, 1996) and during competing, prepotent responding (Pennington & Ozonoff, 1996). Growing interest in the complex associations among neural structures involved in physiological regulation during such tasks has led to the identification of integrated neuroregulatory systems.

One such system, the central autonomic network (CAN; Bennarroch, 1993, 1997), regulates physiology during periods of stress or challenge, including behavioural responses associated with executive processing (Thayer, 2007). This is a functionally integrated physiological system consisting of numerous structures, including the ventromedial prefrontal cortices and nucleus ambiguus. The prefrontal system is associated with executive control (Diamond, 2002; Luria, 1973, 1980), while the nucleus ambiguus innervates the sino-atrial (SA) node of the heart via vagal projections (Porges, 2001; Richter & Spyer, 1990). Within the CAN, neural connections exist between the prefrontal system and the SA node. It is hypothesized that tonic inhibition by the frontal cortex of subcortical structures mediates autonomic regulation during defensive behaviours (Ter Horst & Postema, 1997; Ter Horst, 1999). Neuroimaging has supported this supposition (Gianaros, Van der Veen, & Jennings, 2004; Lane, Reiman, Ahern, & Thayer, 2001). Thus, poor vagal regulation during periods of cognitive challenge might not provide an adaptive physiological state to support appropriate PFC regulation of attention and behaviour, as these regulatory structures are inextricably interconnected. Those children manifesting behavioural problems, particularly EP, might have poor or disorganized development of the CAN. This might represent a global deficit in prefrontal or vagal development, or in interconnectivity. Such deficits could effectively reduce communication among these regulatory structures, and thus, parasympathetic regulation during periods of stress might not support adaptive behavioural responding during cognitive or social challenge.

The ability to physiologically self-regulate via parasympathetic outflow has been posited as a potential index of cognitive function (Morgan, Aikins, Steffian, Coric, & Southwick, 2007). Greater RSA suppression may provide more adaptive responding to stress and facilitate better cognitive function during such periods (Beauchaine, 2001). Indeed, higher basal RSA is associated with better attention (Hansen et al., 2003), greater suppression during cognitive performance (Thayer & Lane, 2000) and physiological recovery after challenge (Porges, 1991) in adults. High heart rate variability (HRV; an index of parasympathetic regulation) has also been associated with more correct responses, lower error rates (omission and commission), and reduced latencies on an IC task (Hansen et al., 2003). Further, electrical stimulation of the vagal complex has been shown to increase verbal memory (Clark, Naritoku, Smith, Browning, & Jensen, 1999) and attention (Rizzo et al., 2003). Reduced parasympathetic outflow (RSA suppression) also co-occurs with increasing attentional demands (Backs & Ryan, 1992; Suess, Newlin, & Porges, 1997; Weber, van der Molen, & Molenaar, 1994). Similar results have been demonstrated in infants (Bornstein & Seuss, 2000b; DiPietro, Porges, & Uhly, 1992; Linnemeyer & Porges, 1986; Richards, 1985; Stifter & Fox, 1990). Thus, parasympathetic regulation appears to be a facilitating component of adaptive cognitive functioning.

The few studies investigating relations between cognitive activity and RSA in elementary school-age children have demonstrated findings that are generally consistent with adult and infant work. Suess, Porges and Plude (1994) found that fourth and fifth-grade children with higher basal RSA performed better on a continuous performance task (CPT; a measure of sustained attention). Staton and colleagues (2009) found that higher basal RSA was associated with measures of cognitive function that tap EF; however, they did not find reactive RSA associated with these measures among 6 – 13 year old children. Stronger RSA suppression on attention and inhibitory control tasks has been found to predict better academic achievement (Becker et al., 2012) and to distinguish children without learning disabilities from those with communication problems, who showed less suppression (Althaus, Mulder, Mulder, Aarnoudse, & Minderaa, 1999).

In preschoolers, higher basal RSA and greater RSA suppression during cognitive challenge has been related to teacher ratings of social competence (Blair & Peters, 2003). Marcovitch and colleagues (2010) found that 3.5 year-old children tended to perform best on two tests of EF when they evidenced high baseline RSA and moderate RSA suppression during the tasks, relative to children who showed lower and baseline RSA and either stronger or weaker RSA suppression. In light of the preceding consideration of the relative adaptiveness of RSA suppression depending on contextual demands, this latter finding could suggest that the young preschoolers showed weaker behavioural and cognitive self-regulation when they reacted to EF task administration as a threat or stressful challenge (strong RSA suppression), or when they failed to orient their resources upon task demands (weak RSA suppression).

EP, *IC and RSA Regulation*

Few studies have examined the relation between IC and dynamic parasympathetic regulation in preschoolers, and we are unaware of any studies to date examining the inter-relations of RSA regulation, EP, and IC in early childhood. However, the period from early preschool to late kindergarten or early elementary school-age involves very dynamic changes in PFC function and the associated capacity for IC (Carlson, 2005; Carlson & Wang, 2007; Diamond, 2002; Gerstadt, Hong, & Diamond, 1994). Research examining relations between EP and IC over this period have shown a negative association for elementary school children (Gomes & Livesey, 2008; Kooijmans et al., 2000) and preschoolers (Floyd & Kirby, 2001; Gomes & Livesey, 2008; Livesey, Keen, Rouse, & White, 2006). In previous examinations of this (Utendale, Hubert, Saint-Pierre, & Hastings, 2011) and other samples (Utendale & Hastings, 2011), we have found the inverse relation between IC and EP to be robust by 4 years. This negative relation appears to grow stronger from the early preschool to early elementary period (Utendale & Hastings, 2011). Normatively, aggression also tends to decrease over the preschool and elementary years (Côté, Vaillancourt, Barker, Nagging, & Tremblay, 2007; Tremblay, 2000), suggesting that developing IC capacities might be important regulators of externalizing behaviour. The divergent associations between parasympathetic regulation and EP versus IC, and the normative development of greater RSA from birth through middle childhood (Bornstein & Suess, 2000a), suggest that it would be reasonable to expect associations among these three factors.

Considering Gender

Boys generally have higher levels of EP (Keenan & Shaw, 1997), and sex differences in vagal regulation have been shown to be related to children's adjustment (Beauchaine, Hong, & Marsh, 2008). Some research has also suggested that boys and girls differ in levels of RSA, with boys having higher basal levels than girls (El-Sheikh, 2005, Salomon, 2005; but see Calkins et al., 2007; Suess et al., 1994). High risk boys (Calkins & Dedmon, 2000) and boys with clinical levels of EP (Beauchaine et al., 2008) have been shown to have reduced levels of baseline RSA compared to normatively developing boys, a relation that has not been observed as consistently in girls. Boys show higher levels of overt and physical aggression than girls from the toddler years onwards (Tremblay et al., 1996), while IC develops later and less rapidly for young boys than girls (Keenan & Shaw, 1997). Thus, relations between RSA suppression, IC and externalizing behaviour might be expected to differ for boys and girls.

Current Study

Poor vagal regulation during periods of demand for focused attention might interfere with the ability of children with EP to produce behaviourally appropriate responses, as adaptive functioning of the PFC in regulating behaviour may require physiological facilitation by the vagal complex. Thus, vagal dysregulation during IC could serve as an index of the PFC being unable to effectively regulate these children's cognitive and behavioural engagement with task demands. In this study we examined dynamic changes in RSA in relation to IC task performance among preschool and early elementary school-aged children with low to clinical levels of EP. Poorer vagal regulation (less RSA suppression) was expected to be associated with more EP and poorer performance on the IC tasks (fewer correct responses and longer latencies to respond). Children's EP was also expected to moderate the association between vagal regulation and IC performance such that the relation between RSA suppression and performance would be weaker for children with more EP. Exploratory hypotheses relating to age and sex differences in the relations between EP, RSA and IC were also considered. Associations between RSA suppression and IC task performance were expected to be stronger for 6 year-old versus 4 year-old children, and boys with EP were expected to show reduced RSA suppression during the IC task compared to girls with EP.

Method

Participants

The sample included 95 boys and 85 girls, aged 4.0 – 4.9 years (n = 98) or 6.0 – 6.9 years (n = 82) at screening. The majority of lab visits occurred less than 3 months after screening, but there were four younger and eight older children who had turned 5 or 7 years, respectively, shortly before testing, M = 5.58 years, SD = 1.10. There were 146 children tested in English and 34 children tested in French. Families were predominantly Caucasian (78.7%) and middle to upper-middle SES (M = $79700 CND, SD = $43470, Mode = $50-60000). Children with aggression and externalizing problems were actively recruited using targeted advertising. Inclusion criteria for families included child age 4 or 6 years, child living with mother, and 6 year-olds having started Grade 1. Exclusion criteria included presence of marked cognitive or physical challenges. By mother-report in a telephone screening interview (see Procedure), there were 86 children with CBCL Aggression and/or Externalizing Problems T-scores equal to 60 or higher (at least one SD above age and sex norms), 46 children with T-scores between 51 and 59 (less than one SD above norms), and 47 children with T-scores equal to 50 or lower (at or below age and sex norms). Mothers received $75 for participation and children received a T-shirt.

Due to experimenter error, audiovisual recording problems, or child refusal, there were 11 children without valid IC task data. An additional 25 children either refused to wear the cardiac monitor, or did not provide usable cardiac data during baseline or IC tasks. Thus, there were 144 children (62 girls; 74 four year-olds) for whom valid data were available for the current analyses. The 36 children excluded from the current analyses did not differ significantly from the other 144 children on measures of age, EP or family income, all $|t| \leq 0.80$, but more girls (23) than boys (13) were excluded, $\chi^2 = 5.02$, $p < .05$.

Procedure

Data were collected at a university-based developmental laboratory and all procedures were approved by the university's Internal Review Board. Parents were contacted through direct mailing, letters distributed to daycares, preschools and elementary schools, and advertisements in local free magazines. Parents wanting more information about participating in the study contacted the laboratory and were preliminarily screened with items on the age-appropriate EP sub-scale of the CBCL (Achenbach & Rescorla, 2000). Those parents whose children met criteria for inclusion attended a visit to the laboratory for the mother and child. Mothers were mailed the consent forms and questionnaires prior to the laboratory assessment, including the age-appropriate, full version of the CBCL. Mothers signed the consent forms for their own and their child's participation at the start of the lab visit. Testing was conducted in the child's first language (French or English) and lasted approximately 3 hours. Only activities pertaining to the current analyses are described here. The behavioural data described in this report have been examined previously (Utendale et al., 2011), but all physiological data are new.

One hour into the laboratory session a MiniLogger Series 2000 (Mini-Mitter Company, Inc., 1999) telemetric ambulatory cardiac monitor was attached to the child's chest using two adhesive electrodes to record heart period (HP) via inter-beat intervals (IBI). After the monitor was attached, the child was asked to sit quietly with eyes closed while listening to a 1-minute audio clip of soft music (Audio baseline). Then, the child was asked to sit quietly and watch a 3-minute video of a gentle lullaby (Video baseline). The final baseline consisted of the child sitting quietly for 1 minute with eyes closed, without audio or visual stimuli (Quiet baseline). There were no significant differences between the three baseline measures of RSA, all $|t| \leq 1.86$, average $r \geq .80$, all $p < .001$. Therefore, an aggregated average was calculated and this was used as the measure of Baseline RSA in the calculation of RSA Residualized Change scores.

After the baseline recordings, children completed two IC tasks, the Day/Night task and the Tapping task, which were presented as "games." For each task, children were asked to repeat the rules back to the experimenter after they were explained. Two training trials were administered, and needed to be passed, in order for the child to move on to the 16 testing trials. During the pre-test children were praised for a correct response and corrected for inaccurate or lack of a response. There was no feedback provided during testing trials. There were 2 children who did not complete the Tapping task. After the IC tasks, a control task assessing working memory, specifically ability to remember two rules simultaneously, was administered.

For each child a full-scale IQ score was derived. For English-speaking children the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 2004) was administered. For French-speaking children the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003) was administered to 6 year-olds, and the

Stanford–Binet Intelligence Scale, Fifth Edition (SB5; Roid, 2003) was administered to 4 year-olds, as these latter instruments provide respective age-based norms for French-speaking children.

Measures

Child Behavior Checklist (CBCL; Achenbach & Rescorla, *2000).* Mothers completed the age-appropriate version of the CBCL for their child (1.5 – 5 yr or 6 – 18 yr). The Externalizing Problems broad-band scale was used in current analyses. The CBCL has been shown to have good reliability and validity (Bingham, Loukas, Fitzgerald, & Zucker, 2003; Mattison & Spitznagel, 1999). For Externalizing Problems, in this sample $\alpha = .93$ for 4 year-olds, and $\alpha = .87$ for 6 year-olds. Raw scale scores were used in all analyses to maximize sample variability for EP.

Day-Night Task (Gerstadt et al., *1994).* This task assesses prepotent responding in a manner similar to the Stroop test (Lewis, Dozier, Ackerman, & Sepulveda-Kozakowski, 2007). Two rules must be held in mind while inhibiting the dominant action. The Day-Night task been used to explore the development of executive functioning and the PFC in young children (Gerstadt et al., 1994; Diamond, Kirkham, & Amso, 2002; Marcovitch et al., 2010; Simpson & Riggs, 2005). Sixteen laminated cards were used of which half had an image of a sun, and the other half had an image of the moon and stars. Each card was 13.5 × 10 cm. There were two practice trials and 16 testing trials. Children had to inhibit the prepotent response (saying the picture presented) by saying the word that was semantically opposite. Children were instructed to say “day” when presented with a picture of moon and stars, and “night” when presented with an image of a sun. The cards were presented in pseudo-random order by trained graduate students. No feedback was given during the testing trials.

Tapping Task (Luria, 1966). Luria's Tapping task is also difficult for preschool children (Diamond & Taylor, 1996; Luria, 1966). For this task, two rules must be used for accurate responding ("Tap once when I tap twice. Tap twice when I tap once."), which are counter to the dominant response (i.e. mimicking the experimenter). Again, there were two practice trials and 16 testing trials. Trials were presented in pseudo-random order by trained graduate students.

Working Memory Control Task (Bucket Task). Instructions and training trials for this task were similar to that for the preceding IC tasks. Either a yellow ball or an orange block was presented, and the child was instructed to place yellow balls into a red bucket and orange blocks into a blue bucket. This task involved retention of two arbitrary rules, not related to prepotent response tendencies. Following instructions, 16 test trials were conducted. Rather than providing an estimate of inhibition of a dominant response on performance, this task provided an estimate of the influence of working memory. Most children performed well on this task; no child made more than 3 errors. Working memory for rules, therefore, did not appear to be impaired among these children.

IQ Composite. The full-scale IQ composite was derived from one of three IQ measures, each of which provides a full-scale IQ score with $M = 100$ and $SD = 15$. Tests were administered by trained raters as per standard instructions. All children had full-scale IQ scores > 70 ($M = 107.17$, $SD = 13.76$).

Coding. Trained, reliable raters were blind to children's levels of CBCL EP or Attention Problem scores. Ratings of accuracy (number correct) and response latency were obtained from DVD recordings using Imovie software which permitted a frame-by-frame analysis (30 f/s). The sum of correct responses for each task was recorded as the score for response accuracy (coder reliability $r = 1.00$ for both tasks). The number of centiseconds required to respond to each testing trial provided a measure of response latency, with the total of the 16 latencies being the final score. Latency for the Day/Night task was recorded from the moment the card was at a forty-five degree angle with the table until the child's first verbal response. Latency for the Tapping task was recorded from the moment the wooden dowel was grasped by the child (see Diamond & Taylor, 1996) to the child's first tap. Coder reliability (two coders) for both tasks was $r \geq .95$. For number of correct responses on the memory control task, coder reliability (two coders) was $r = 1.00$.

Cardiac Data

Cardiac data were uploaded onto a computer for editing and analysis. The raw IBI values were inspected to correct recording artifacts using MXedit computer software (Delta Biometrics, Inc., Bethesda, MD) by trained, reliable IBI editors, as outlined by Berntson and colleagues (1997). Children's refusal to wear the ambulatory cardiac monitor, as well as equipment failure, resulted in reduction of available IBI data. For the baseline condition, 155 IBI files contained useable data for MXedit artifact editing. Usable cardiac data were available for 152 files during IC task performance. Complete cardiac data (both baseline and during IC task performance) was available for 144 children. Dynamic parasympathetic control of cardiac activity was indexed as respiratory sinus arrhythmia. This index reflects the variability in cardiac function that is specifically attributable to the influence of the PNS via the vagus nerve. RSA was computed from IBI using Porges' (1985, 1988) algorithm in the MXedit software package. This algorithm applies a 21-point moving polynomial filter to mathematically account for periodicity in HP slower than RSA. HP variance is then determined by applying a band-pass filter between .24 and 1.04 Hz, the frequency band of young children's spontaneous respiration (Huffman et al., 1998; Stifter & Fox, 1990), with sampling rate set at 250ms. The rolling algorithm developed by Porges takes advantage of the greater number of IBI that young children have within relatively brief samples to compute reliable measures of RSA (Porges, 1985), and more reliable estimates of RSA are extracted from using the complete interval for each phase of the procedure (Berntson et al., 1997). Mean duration of IC tasks was 23.18s (*SD* = 7.56s), and epoch lengths of 10-15s have proven effective in other studies of young children (Calkins & Dedmon, 2000; Doussard-Roosevelt, Montgomery, & Porges, 2003; Hill-Soderlund et al., 2008); therefore, RSA was calculated utilizing full epoch lengths.

To reduce the impact of floor effects, ceiling effects, and regression towards the mean, residualized change[7] scores were calculated to index reactive change. This method consists of regressing the measure(s) of reactivity onto the baseline measure, effectively controlling for baseline (Krantz et al., 1996; Nazzaro et al., 2005). Residualized change scores calculated in this manner represent reactive change from baseline, and more negative scores represent greater RSA suppression (i.e. greater reduction in vagal outflow to the sino-atrial node of the heart).

Results

Children's performance on the two IC tasks was convergent for number correct, $r(144) = .34$, $p < .001$, but not significantly so for latency to respond, $r(144) = .10$, $p > .10$. Scores across the two tasks were averaged to create one IC Correct and one IC Latency score. Descriptive statistics are presented in Table 8. Zero-order correlations are presented in Table 9. The mean raw CBCL Externalizing Problem score ($M = 12.55$, $SD = 9.07$)

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[7] The analysis plan was also conducted utilizing arithmetic change scores. Basal RSA values, when subtracted from reactive RSA, produce arithmetic change scores such that negative values represent reductions in RSA (RSA suppression) during the IC task. Positive scores calculated in this way represent RSA augmentation. There were no substantive differences in analyses using residualized change or arithmetic change scores. Therefore, residualized change scores were retained for analyses.

Table 8. Summary Statistics

	N	Min.	Max.	*M*	*SD*
Age	144	4.08	7.37	5.61	1.09
Full-scale IQ	144	71	155	107.39	14.09
CBCL Externalizing Problems	144	0	38	12.55	9.07
Memory Control Task	144	13	16	15.81	0.55
Mean IC Correct	144	1	16	12.98	3.35
Mean IC Latency	144	10.06	49.21	23.18	7.56
Baseline RSA	144	1.78	9.63	6.77	1.23
IC RSA	144	2.91	8.68	6.36	1.09
IC RSA Residualized Change	144	-2.76	3.32	0.00	1.00

Note. CBCL = Child Behavior Checklist; RSA = Respiratory Sinus Arrhythmia; IC = Inhibitory Control. More negative residualized RSA change scores imply greater RSA suppression over the inhibitory control tasks, while less negative and positive scores imply less RSA suppression, or augmentation. The residualized change score represents a standardized index, therefore *M* necessarily = 0.00 and *SD* = 1.00 for change measures.

Table 9. Correlations of Variables

	2	3	4	5	6	7	8	9	10
1. Sex	-.09	.14	-.12	.09	.12	.00	-.07	-.08	-.04
2. Age		-.10	-.42***	.12	.46***	-.33***	.13	.21*	.17*
3. Full-Scale IQ			-.09	-.05	.08	-.15	-.07	-.08	-.04
4. CBCL Externalizing Problems				-.08	-.45***	.15	-.08	-.26**	-.32***
5. Memory Control Task					.18*	.06	.06	.02	-.04
6. Mean IC Correct						-.31***	.00	.13	.22**
7. Mean IC Latency							.02	.04	.05
8. Baseline RSA								.80***	-.02
9. IC RSA									.58***
10. IC RSA Residualized Change									

Note. CBCL = Child Behavior Checklist; RSA = Respiratory Sinus Arrhythmia; IC = Inhibitory Control. More negative residualized RSA change scores imply greater RSA suppression over the inhibitory control tasks, while less negative and positive scores imply less RSA suppression, or augmentation.

*$p < .05$, **$p < .01$, ***$p < .001$.

translated into a T-score = 53. There were 95 children in the normative (T-score < 60) range and 49 children in the borderline to clinical (T-score $\geq$ 60) range for EP on the full CBCL. A paired samples *t*-test revealed a significant degree of RSA change from baseline to the IC tasks, $t(143) = 6.47$, $p < .001$, such that 107 children demonstrated RSA suppression and 37 children augmentation. Boys and girls did not differ on IC number correct, IC latency to respond, RSA at baseline, RSA during IC, or the measure of RSA change, all $|t| \leq 1.36$. Boys tended to have higher EP scores, $t(142) = 1.66$, $p = .10$, than girls.

The correlations showed that older children had higher IC task RSA and lower RSA suppression (more augmentation) during IC task performance. They also had more correct IC responses and shorter latencies to respond. Baseline RSA was not significantly associated with IC task performance, but children who made more correct responses had higher RSA residualized change scores. Thus, better task performance was associated with more RSA augmentation or less RSA suppression. Children with more EP had significantly lower RSA during the IC tasks, reflecting greater suppression from baseline RSA, and also performed poorly (made more errors) on the IC tasks. Performance on the IC tasks converged for number correct and response latency, demonstrating the expected negative relation (Carlson & Moses, 2001); children who responded more accurately also responded more quickly.

Check for Control Variables

Three potential covariates were examined: language of testing (French or English), IQ, and a memory control index (number correct on the Bucket task). Full-scale IQ was not significantly associated with IC number correct or latency to respond, both $|r| \leq .15$. The memory control index was significantly associated with IC number correct

$r(144) = .18$, but not response latency, $r(144) = .06$. IQ and the memory control index were not associated with baseline RSA, reactive RSA, or RSA change, all $|r| \leq .08$. None of the RSA measures differed between French-speaking and English-speaking children, all $|t| \leq 1.39$. French and English children also did not differ on IC number correct, $t(142)= -0.02$, however, they differed on latency to respond $t(142) = 4.20$, $p < .001$. Because of some indications that the control variables were associated with the variables of interest in this study, preliminary regression analyses were conducted to compare findings when the control variables were included versus excluded. These analyses confirmed that including Language, IQ, and the memory control index as covariates did not affect any of the relations between EP, IC performance and RSA in the regression analyses. Therefore, language, IQ, and the memory control index were not retained in the final analyses.

General Format for Regression Analyses

Two hierarchical linear regression analyses were used to predict the two IC indices from RSA Residualized Change scores and Externalizing Problem scores. Sex and Age were entered on step 1 of the model. RSA Residualized Change score was entered on step 2, then EP on step 3. The 2-way interaction between EP and RSA Residualized Change was entered on step 4. All other 2-way and 3-way interactions involving Sex, Age, EP and RSA Residualized Change were also examined on subsequent steps, including Sex X Age, Sex X EP, Sex X RSA Change, Age X EP, Age X RSA Change, Sex X EP X RSA Change, Age X EP X RSA Change, Sex X Age X EP, and Sex X Age X RSA Change. However, none of these other interaction effects were significant, and inclusion of these terms in the regression analyses did not attenuate the strength of the other significant associations. Therefore, only the 2-way EP X RSA Residualized Change score interaction term was retained in the final analyses. As recommended by Aiken and West (1991), variables were centered prior to analyses. Significant interaction terms were examined by regressing IC onto RSA Residualized Change at high (+1 *SD*) and low (-1 *SD*) values of Externalizing Problem score, in order to clarify how EP moderated the association between IC and RSA Residualized Change.

Respiratory Sinus Arrhythmia and EP Predicting IC

Number Correct. The regression model predicting number of correct responses on the IC tasks is presented in Table 10. The regression model was significant, adj. $R^2 = .29$, $F(5,138) = 12.90$, $p < .001$. Higher RSA Residualized Change (i.e., more RSA augmentation, or less suppression) was significantly associated with more correct responses. This association was significantly moderated by EP. Examining this interaction (see Figure 4), for children with more EP, more RSA suppression (lower RSA Residualized Change scores) significantly predicted poorer performance (fewer correct responses) on the IC tasks ($\beta = .25$, $t = 2.33$, $p = .02$). There was no significant relation between RSA suppression and correct responding for children with fewer EP ($\beta = -.06$, $t = -0.31$, $p = .54$). Thus, it was only for children with elevated EP that greater parasympathetic withdrawal was associated with making more errors on the IC tasks.

Response Latency. The regression model predicting latency to respond on IC tasks is presented in Table 11. The regression model was significant, adj. $R^2 = .13$, $F(5,138) = 5.32$, $p < .001$. The interaction between RSA Residualized Change and EP was significant (see Figure 5). For children with fewer EP, greater RSA suppression significantly predicted shorter response latency ($\beta =.36$, $t = 3.23$, $p < .01$); thus, these children responded more slowly when they were in a state of greater parasympathetic influence

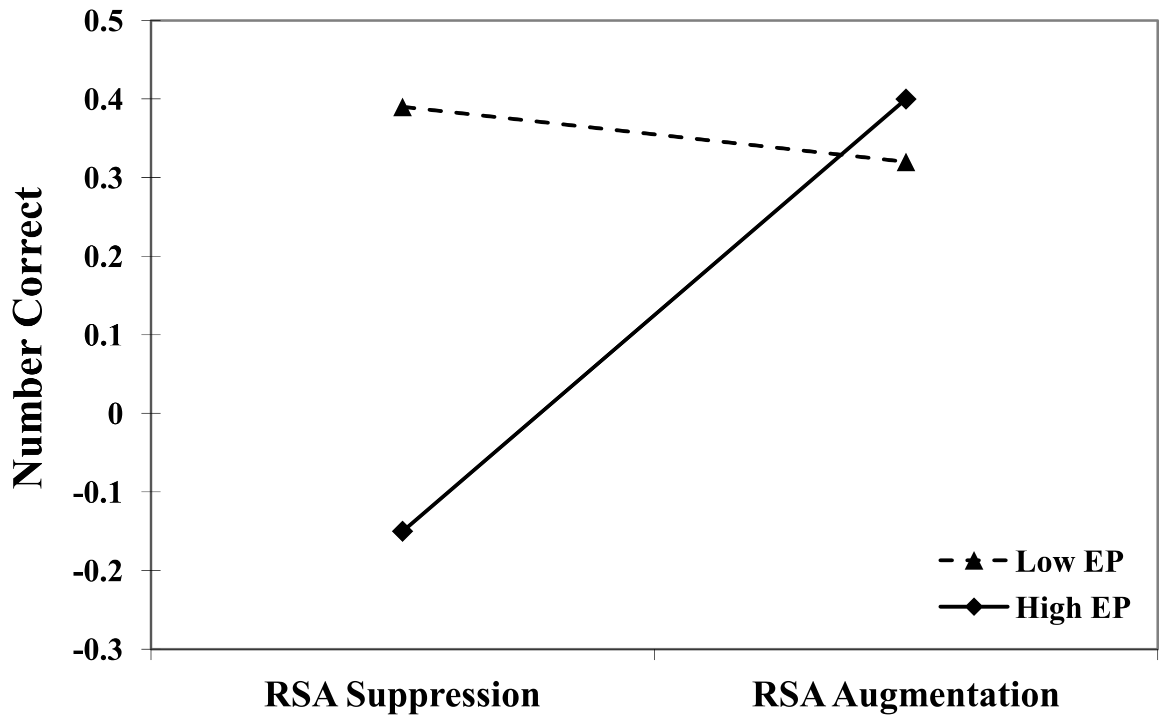
Table 10. Regression Analyses Predicting Mean IC Correct Responses from RSA Standardized Residual Change and Externalizing Problems

	Step and Predictor	ΔR^2	*df*	ΔF	β	*t*
Mean Correct	1.	0.21	(2,141)	19.23***		
	Sex				.16	2.11*
	Age				.45	6.01***
	2. RSA Residualized Change	0.02	(1,140)	4.42*	.16	2.09*
	3. Externalizing Problems	0.02	(1,139)	11.30***	.21	2.66**
	4. RSA Residualized Change x Externalizing Problems	0.02	(1,138)	4.61*	-.28	-3.36***

Note. CBCL = Child Behavior Checklist; RSA = Respiratory Sinus Arrhythmia.

*$p < .05$, **$p < .01$, ***$p < .001$.

Figure 4. RSA Suppression is Associated with Fewer Correct Responses on IC Tasks by Children with more Externalizing Problems



*Note.*RSA = Respiratory Sinus Arrhythmia; EP = Externalizing Problems.

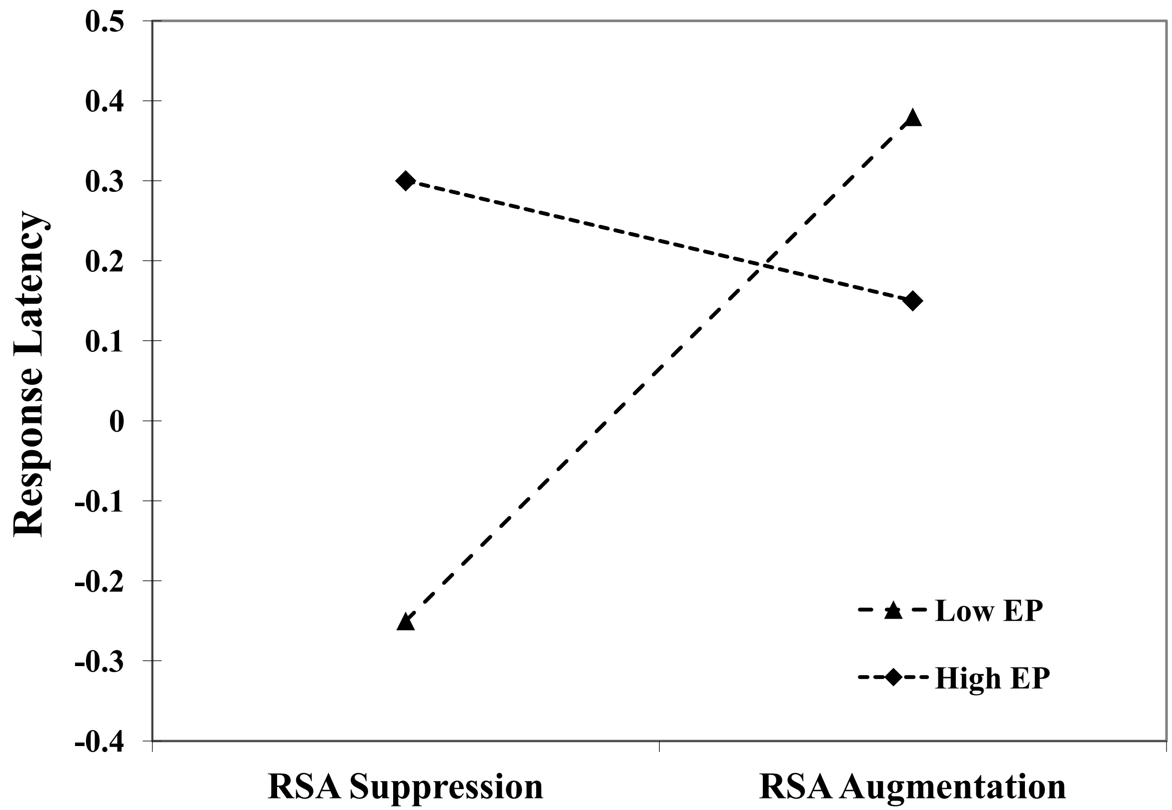
Table 11. Regression Analyses Predicting Mean IC Response Latency from RSA Standardized Residual Change and Externalizing Problems

	Step and Predictor	ΔR^2	*df*	ΔF	β	*t*
Mean Latency	1.	0.08	(2,141)	6.47***		
	Sex				-.02	-0.30
	Age				-.30	-3.60***
	2. RSA Residualized Change	0.01	(1,140)	1.43	.10	1.20
	3. Externalizing Problems	0.00	(1,139)	0.42	.06	0.65
	4. RSA Residualized Change x Externalizing Problems	0.07	(1,138)	10.78***	-.45	-3.28***

Note. CBCL = Child Behavior Checklist; RSA = Respiratory Sinus Arrhythmia.

***$p < .001$.

Figure 5. RSA Suppression Moderates the Association between Children's Externalizing Problems and Latency to Respond on IC Tasks



Note. RSA = Respiratory Sinus Arrhythmia; EP = Externalizing Problems.

over cardiac arousal. For children with more EP, there was a negative but non-significant relation between RSA suppression and latency to respond (β = -.17, t = -1.44, p = .15).

Considering Non-Linear Associations between RSA Suppression and IC

Extending from the analysis of relations between RSA suppression and IC performance in preschoolers by Marcovitch and colleagues (2010), we conducted a triadic split of RSA suppression to identify children with low, moderate or high values for RSA Residualized Change, corresponding to strong suppression, moderate suppression and augmentation groups, respectively (n = 48 per group). A one-way ANOVA on IC correct responses was significant, $F(2,141) = 7.80$, $p < .01$, as was the linear contrast, $F(1,141) = 13.77$, $p < .001$, but the quadratic contrast was not, $F(1,141) = 1.83$, $p > .15$. Post-hoc comparisons using Tukey's HSD test showed that children in the low RSA change group (strong suppression) had fewer correct IC responses (M = 11.51, SD = 4.24) than children in the moderate (M = 13.49, SD = 2.79) and high (M = 13.94, SD = 2.25) RSA change groups; the latter two groups did not differ. The comparable analysis for IC response latency was not significant, overall F = 0.32, linear contrast F = 0.05, quadratic contrast F = 0.58. Thus, there was not clear evidence for the association between RSA suppression and IC performance that was reported in the Marcovitch et al. (2010) paper.

Discussion

We examined the inter-relations of parasympathetic regulation, inhibitory control and externalizing behaviour problems in a sample of preschool- and early elementary school-age children with an over-representation of EP. Older children demonstrated better IC performance but less RSA suppression during the IC tasks than did younger children, suggesting that RSA suppression to these cognitive challenges was not a response reflecting greater maturity of self-regulatory capacity. For children with relatively few EP, greater RSA suppression predicted faster response times, which could be seen as evidence for parasympathetic withdrawal supporting children's facility with applying their inhibitory control. In contrast, there was more consistent evidence that greater RSA suppression during the IC tasks was associated with worse self-regulation. In particular, children with more EP demonstrated greater RSA suppression, and for these children, greater RSA suppression was associated with making more incorrect responses on the IC tasks.

These data provide evidence that RSA suppression relates to IC performance differently for children with fewer versus more EP. Regression analyses revealed a main effect such that children with fewer EP problems had less RSA suppression during the IC tasks than children with higher levels of EP. However, for these children analysis of the interaction between EP and RSA demonstrated some RSA suppression was associated with faster responding on the tasks. This was consistent with the expected pattern of parasympathetic regulation during orienting and engaging with environmental stimuli that has been suggested as adaptive and facilitative of appropriate behaviour (Calkins et al., 2007; Porges, 2007). The relation differed for children with more EP. These children demonstrated greater RSA suppression during the IC tasks, and for them, stronger RSA suppression was associated with making more errors. As stronger RSA suppression reflects parasympathetic withdrawal to allow greater arousal to aversive stimuli, our findings support the hypotheis that children with higher levels of EP manifest deficits or deviations in vagal-PFC regulation of tasks that challenge their capacities for self-control. Observing this pattern during performance of IC tasks parallels relations that have been observed during social interactions (Hastings et al., 2008), which could suggest that parasympathetic dysregulation underlies multiple aspects of the observed constellation of self-regulatory difficulties that are characteristic of children with high EP.

Resource allocation during periods of focused attention and environmental challenge is mediated through the central nervous system (CNS; Friedman & Thayer, 1998; Thayer & Friedman, 1997), and a variety of integrated neurophysiological sub-systems, including the CAN (Bennarroch, 1993, 1997). Interconnections among CNS structures provide for a high degree of flexibility (Thayer, 2007), or effective allostatic regulation, and the CAN has been implicated in physiological regulation during periods of focused attention and cognitive challenge (Thayer, 2007). Poor coupling within the integrated neural circuits of the CAN would be expected to undermine one's ability to respond physiologically to cognitive challenge in a manner that effectively and efficiently facilitates cognitive performance.

This poor coupling between vagal and prefrontostriatal structures could undermine facilitative physiological regulation during the IC task, making children with more EP less able to perform accurately. For these children, tonic inhibition by the frontal structures of the vagal complex (see Ter Horst & Postema, 1997; Ter Horst, 1999) may be too great, providing for overly defensive behaviours that are maladaptive in situations where cognitive engagement is required. As a consequence, children with EP might be more sensitive to environmental challenge, or more specifically, they might be more vulnerable to responding to relatively innocuous events as being stressful. This suggests that children with EP might be demonstrating over-arousal, responding to benign cognitive challenges as environmental threats, which could contribute to their increased error rates. Porges (2001, 2007) has argued that parasympathetic inhibition facilitates calm engagement with others and adaptive behaviour in safe contexts, such as learning to play a new game with a friendly adult (which is how these IC tasks were presented), and that is how children with few EP appeared to function. Conversely, if the children with more EP perceived cognitively-demanding tasks as threatening or unsafe, perhaps due to their past experience of difficulties with these tasks or having received negative feedback about their abilities from others (parents, teachers, peers), they could have experienced apprehension or defensiveness during situations that challenged their limited performance capabilities. For children with EP who manifested the most RSA suppression, mobilization of physiological resources in the face of cognitive challenge to support defensive reactions represents maladaptive regulation.

In contrast, the more modest level of RSA suppression in children with fewer EP appeared to support better responding on the IC tasks, as indicated by shorter response latencies (Diamond & Kirkham, 2005; Leon-Carrion, García-Orza, & Pérez-SantaMaría, 2004), suggesting this was a pattern of facilitative parasympathetic regulation. It might be that normatively developing children perceived the tasks as relatively non-threatening and benign and therefore experienced less tonic inhibition of the vagal complex, with this modest RSA suppression facilitating rather than reducing cognitive performance. Indeed, some RSA suppression is not necessarily indicative of a maladaptive response, but rather might facilitate appropriate behavioural responding (Lovallo, 2005) and attention allocation during non-threatening cognitive tasks (Marcovitch et al., 2010; Suess et al., 1994).

Children with few EP might also have found the tasks to be easier, or less challenging, than the children with more EP. In normatively developing children (Diamond & Kirkham, 2005; Leon-Carrion et al., 2004) performance on cognitive tasks appears to follow a performance efficiency rule (Roncadin, Pascual-Leone, Rich, & Dennis, 2007). This rule implies that, for more cognitively demanding (difficult) tasks, increased latency is observed, while the opposite is true for easier tasks. This suggests that our sample of non-externalizing children might have found the tasks relatively easy, potentially due to good (facilitative) vagal regulation during task performance. Therefore, how children perceive cognitive tasks might reflect whether their parasympathetic regulation is facilitative of cognitive performance, or sacrifices cognitive efficiency in order to facilitate more dynamic, defensive behaviour.

We did not observe sex differences in parasympathetic regulation, consistent with previous finding (Calkins et al., 2007; Suess et al., 1994), and boys and girls demonstrated similar relations among RSA suppression, IC performance and EP. Although boys are typically over-represented in clinical and community samples of children with externalizing behaviour problems (Hinshaw, 2003), we deliberately over-sampled for girls with EP, which might have minimized sex differences that some past studies have identified. These have included boys and girls differing in the relations among measures of RSA and EP (Beauchaine et al., 2008; Calkins & Dedmon, 2000; El-Sheikh, 2005), and girls performing better than boys on measures of IC (Raaijmakers et al., 2008), a difference that might decline after preschool (Gerstadt et al., 1994). Our findings could suggest that any sex differences in IC and EP might not be directly associated with the development of parasympathetic regulation, and that, at least during cognitive challenge, boys and girls demonstrate equivalent degrees of parasympathetic regulation according to their levels of externalizing symptomatology.

Limitations

Although this work supports the tenets of polyvagal theory, there are certain caveats which have been outlined with respect to this model (see Grossman & Taylor, 2007). Parasympathetic regulation is only one of a number of self-regulatory physiological systems. Elucidation of other biological processes which contribute to self-regulation, particularly during periods of stress and challenge, could provide more thorough understanding of these relations. Also, causal effects cannot be derived from this work, and longitudinal investigation of inter-relations among RSA, IC and EP are warranted.

We also utilized an aggregated measure of IC. Although performance on the two tasks was correlated, they do not necessarily tap the same construct, and semantic (Day/Night task) and motoric (Tapping task) (Rhoades, Greenberg, & Domitrovich, 2009) processing can be considered distinct elements of IC (Herba, Tranah, Rubia, & Yule, 2006) that develop at different rates (Klenberg, Korkman, & Lahti-Nuuttila, 2001). Thus, future research should utilize a battery of IC measures, as well as assessing other aspects of EF.

This study also utilized a targeted community-based sample, which may differ from clinical samples in relations between RSA, behaviour and adjustment (Beauchaine, Katkin, Strassberg, & Snarr, 2001). Future research should include children with confirmed diagnoses of ADHD, ODD/CD, and comorbid ADHD/ODD/CD so that clinical groups are available for comparison. Without these clinical groups no inference can be made as to whether observed associations are continuous across normative and diagnostic samples.

Some researchers have called into question the accuracy of estimating RSA without controlling for fluctuations in respiration rate periodicity (Grossman & Taylor, 2007). However, Denver, Reed and Porges (2007) have shown that controlling for respiration frequency is unnecessary, such that RSA may be reliably inferred from HP spectra. It should also be noted that RSA estimates do not necessarily represent complete vagal outflow to the heart, nor do they represent pure indices of vagal efference (Grossman & Taylor, 2007). As well, the PNS and SNS interact in complex ways through both direct neuronal tracts as well as through second-messenger systems. Incorporating sympathetic measures could be informative for elucidating overall autonomic regulation and provide a fuller picture of autonomic-IC-EP relations.

Conclusion

Our data demonstrate that vagal regulation of IC changes as a function of EP. For children with fewer EP, modest RSA suppression appeared to facilitate IC. For children with more EP however, stronger RSA suppression appeared to be maladaptive and was associated with poorer performance on IC tasks. This might be due to differences between how children with fewer versus more EP perceive cognitively-demanding activities as being relatively benign versus stressful, respectively, such that children with more EP produce levels of RSA suppression that would prepare them for defensive behaviours. This suggests that there could be practical applications of these findings. Autonomic markers of poor behavioural and cognitive function (RSA) might provide a means for identifying children at risk for behavioural difficulties, and monitoring progress of psychosocial intervention. Altering aggressive, disruptive and defiant children's perception of cognitive tasks as stressful, fear-inducing demands could facilitate a more positive relation between RSA suppression and cognitive performance and support better, more appropriate behavioural responding in other situations.

General Discussion

This collection of studies was undertaken to further elucidate young children's normative and abnormal development of inhibitory control (IC) and respiratory sinus arrhythmia (RSA) in relation to externalizing psychopathology. The early preschool to elementary school period is a dynamic period of prefrontostriatal maturation. It represents a period of dramatic change in children's regulation of behaviour through maturation of structures associated with executive function (EF), through vagal-PFC coupling. The health burden of childhood psychopathology, in particular externalizing problems (EP), speaks to the necessity of research that will improve identification of those children at risk, and allow targeted intervention strategies as early as possible. Over the course of this program of work, I attempted to integrate developmental changes in IC-EP relations with young children's emerging capacities for parasympathetic regulation.

Study 1

The relations among IC and externalizing difficulties were examined to elucidate differential developmental associations across the toddler to kindergarten periods. As expected, maternal ratings of IC were associated with maternal, teacher and laboratory ratings of EP. There was a strong negative relation between older preschool and kindergarten children's IC and EP, while the negative relation appeared non-significant for toddlers. Further, mother-reported improvement in IC over one year was significantly associated with reductions in EP over that period for both older and younger children.

The differential association between IC and EP according to age provides evidence for the increasing role of IC as a regulator of externalizing behaviour as children progress from toddlerhood to kindergarten age. The differences in EF between children with low and high EP may not become apparent until prefrontostriatal structures have developed enough to significantly regulate impulsive and externalizing behaviour. For toddlers, immature PFC development might be relatively typical and invariant across children, such that it is not yet capable of supporting neurocognitive regulation of aggressive and impulsive behaviours for any toddlers. With increasing maturation over the following months and years, however, individual deficits in IC can become more pronounced, as some children might have slower or less well organized development of the PFC and the associated regulatory EF. In effect, these children may be left behind, with immature PFC development and poorer EF regulation of behaviour, exhibited as EP.

Normative development for toddlers includes relatively high and increasing levels of externalizing behaviour and impulsivity (Keenan & Shaw, 1997, Kopp, 1982, Shaw, Lacourse, & Nagin, 2005) with declines after the third birthday (Campbell, 1995, Tremblay et al., 2004). What appears to be a normative process of utilizing aggressive and externalizing behaviour as part of problem-solving and goal acquisition in toddlerhood, though, may be reflective of immature PFC development when these behaviours are seen in older children. Children manifesting high levels of EP after three to four years of age appear to be less mature or functional in their behavioural evidence for PFC development (Brownell & Hazen, 1999) in comparison to their more well-behaved counterparts who manage to employ more complex and socially appropriate problem-solving behaviour (Keenan & Wakschlag, 2000).

The associations among IC and EP were very similar at 1-year follow-up, with increasing strengths of association with child age, as demonstrated in other work over the elementary-school period (Avila et al., 2004, Koojimans et al., 2000, Oosterlaan et al., 1998, Oosterlaan & Sergeant, 1996, Riggs et al., 2003, 2006). Importantly, investigation of residualized change in IC demonstrated increases in the ability to inhibit prepotent responding, which was significantly associated with reductions in externalizing behaviours.

Overall, these results support the supposition that PFC development becomes an ever more important regulator of behaviour, in particular providing children with functional neuropsychological components to utilize more advanced, socially appropriate behaviours for strategic planning in goal acquisition. Those children who do not exhibit such changes in behaviour (reductions in EP) with development (improvements in IC), and instead continue to manifest high levels of aggression and EP, are in effect manifesting poor PFC development.

Study 2

As an extension of Study 1, Study 2 examined the interrelations of IC and EP in a sample of 4- and 6-year-old children with over-representation of high levels of EP, while controlling for IQ and WM. The design and control measures of this study were used to clarify inconsistent associations observed in the prior literature. Measures of IC (both correct responding and latency to respond on both a semantic and motoric processing task) and maternal ratings of EP were expected to be related such that more correct responses and longer latencies would be significantly associated with lower levels of EP. This relation was supported by our data. For both younger and older children negative relations were observed between IC (number correct on both tasks) and EP.

Low levels of IC were not, however, strongly associated differentially with either aggressive, ADHD or inattentive symptomatology. Rather, they were characteristic of the more inclusive construct of EP. Further, we delineated the unique associations among IC and EP independent of IQ and WM, implying that IC plays a significant role in children's development or maintenance of EP above and beyond their general intelligence and working memory processes. By 4 years of age IC, and presumably the underlying prefrontaostriatal circuitry that supports IC, appears inextricably and directly associated with EP and maladaptive regulation of behaviour within the social, problem-solving and strategizing milieu, consistent with prior research (Hughes et al., 1998; Utendale & Hastings, 2011). Both boys and girls appeared to respond similarly on both tasks for correct responding.

Results were not consistent between the two tasks for how the EP of boys and girls were related to measures of latency to respond, however. As expected, shorter latencies were associated with higher ratings of EP on the stroop-like Day/Night (D/N) task (Diamond & Taylor, 1996; Diamond et al., 2002) confirming the role of impulsivity (reduced ability to inhibit prepotent responding) in EP over the early childhood period. The opposite association was observed on the Tapping task for boys, though, in that longer latencies were characteristic of high levels of EP. This finding might support the differential nature of the tasks in terms of variability in processing requirements between verbal and motoric performance.

For these boys, longer processing may reflect inherent inefficiencies (or rather disorganization; perhaps too much processing) in attempting to provide the right answer, rather than an inherent lack of processing (impulsivity). Given that time limits were not imposed for children's responses, boys with poor PFC development might be demonstrating inefficient, continuous mental processing during the task. This might be due to developmental delay of this more motorically-based performance task for boys compared to girls, suggesting this subset of boys would not necessarily continue to manifest EP as the PFC develops and "catches up" to similar developmental levels at a later time. Perhaps longer latencies and the relation to EP would be observed in girls younger than 4, at earlier PFC development.

Although boys tend to have more EP than girls (Hinshaw, 2003) and perform more poorly than girls on measures of IC (Raaijmakers et al., 2008), I only found the one significant sex difference just described for the Tapping task. Generally, relations were similar for boys and girls in this study, and both girls and boys with poor IC were likely to show increased levels of EP. From age 4 the PFC appears to be associated with behaviour regulation and manifestation of EP, independent of IQ and WM. These findings were consistent with findings from Study 1.

Study 3

Dynamic RSA regulation was examined for the sample from Study 2, in relation to IC and EP. Reduction in SA node activity via vagal down-regulation was expected to be associated with poorer IC and higher levels of EP. Further, the relation between RSA and IC was expected to be moderated by EP such that the association between RSA suppression and IC would be weaker for children with higher levels of EP. I also expected to find that RSA and IC relations would be more robust for older children.

For children with low levels of EP, there was some evidence for the expected relation between RSA suppression and IC. Orienting and responding to environmental stimulation are typically associated with RSA suppression (Calkins et al., 2007; Porges, 2007). Children with few EP demonstrated less RSA suppression during IC task performance compared to their counterparts with more EP, and this reduced level of suppression was significantly associated with faster response latencies, which is typically regarded as an index of better IC performance. However, children with more EP had greater RSA suppression, which suggested that RSA suppression during cognitive challenge did not necessarily reflect improved self-regulation. Children who were older showed lower RSA suppression during IC, further suggesting that greater suppression was not necessarily reflective of improved regulatory capacity or greater maturity or integration of autonomic physiology with prefontostriatal structures.

Most tellingly, children with more EP made more errors on the IC tasks, and their poor performance was associated with higher levels of RSA suppression. Thus, children who manifested fairly serious externalizing and aggressive behaviours appeared to show evidence for deficiencies in their underlying neurophysiology through compromised integration of the vagal-PFC network (central autonomic network; CAN).

Integrated neural circuits, in particular interconnections among the vagal and prefrontostriatal structures, provide for great flexibility in engaging with a changing, unpredictable environment. The need to focus attention and engage behavioural responding quickly and appropriately requires high control of physiological energy reallocation systems. The PFC, in regulating behaviours associated with inhibition, problem-solving, strategizing and goal acquisition is intricately associated with metabolic control systems such as the autonomic nervous system (ANS; Bennarroch, 1993, 1997: Thayer, 2007; Thayer & Friedman, 1997). Disorganized and/or immature development of the integration of these systems (uncoupling) may result in poor and inefficient responding via inappropriate physiological adaptation during stress or taxing cognitive challenges. Ultimately, without the physiological regulation necessary to efficiently support responding, behaviour may not be as functionally efficient (appropriate) during periods of stress. Cognitive functioning may suffer, as might behaviour, without appropriate physiological support.

For children with high levels of EP, this poor coupling between neuroregulatory structures may be the defining element underlying their behavioural problems and poor IC. The prefrontal structures inhibit vagal outflow during periods of stress, providing for appropriate orienting and responding. Children with high levels of EP might experience excessive inhibition of the vagal structures (see Ter Horst & Postema, 1997). As this would potentiate fight-or-flight responses (Porges, 2007), these children's behaviour may appear chronically defensive in nature, and be generally inappropriate under most normal situations of mild or moderate challenge, such as cognitive tasks in safe, controlled settings.

The IC tasks used in this study, as well as most normal social interaction within the environment, may in fact be perceived differently, as less versus more stressful, by children with different levels of EP. Children with low levels of EP may react to situations of cognitive challenge, or similar demands by parents or teachers, as relatively innocuous, predictable and manageable, and hence lower levels of RSA suppression are observed. For children with more EP, similar situations may be perceived as more threatening and elicit significantly more stress, and hence dynamic physiological adaptation that is inappropriate for normative cognitive or behavioural performance would occur. The greater RSA suppression observed in these children during IC tasks might represent over-arousal that is not conducive to performance in concert with what is generally considered relatively benign levels of stress or challenge.

Moderate levels of RSA suppression are indeed related to good performance on cognitive tasks, and can represent appropriate, normative parasympathetic response during such periods (Diamond & Kirkham, 2005; Leon-Carrion, García-Orza, & Pérez-SantaMaría, 2004; Marcovitch et al., 2010). For children with few EP, IC tasks might not be perceived as anything other than engaging and mildly cognitively challenging, as opposed to particularly worrisome, stressful or threatening. Conversely, their counterparts with more EP might respond in a maladaptive physiological manner to these same situations, as if they were unsafe and threatening, and their consequent behavioural responses would be likely associated with negative reactions from peers, parent and teachers.

Implications and Future Directions

These data demonstrate the dynamic nature of the early childhood period in children's development of IC and regulation of behaviour. Considering that poor development of the PFC and inappropriate regulatory physiology appear to contribute to EP, early identification of children at risk, as well as early intervention strategies, would be prudent. Psychoeducational strategies focusing on children's perceptions of stress, as well as methods to enhance adaptive self-regulation during periods of focused attention could enhance the ability of children with EP to interact appropriately with parents, teachers and peers, as well their ability to stay on task and perform better academically. Minimizing these children's misperceptions of normative, benign situations as fear-inducing could improve relations between RSA and neurocognitive functioning, with consequently better performance in numerous social and academic areas.

Given the increasing regulation of behaviour by the PFC with maturation of these frontal structures, targeting those children who appear to be delayed in PFC development and remediating associated IC deficits with cognitively-based training regimens could also serve to reduce development of EP. Further, supplementing such an intervention with integrated early social skills training, during periods of rapid PFC development, might mitigate advancement of refractory externalizing behaviours.

As shown in study 1, increases in IC over time are associated with reductions in EP. Granted the direction of causality cannot be inferred given the nature of focal variables in that study; however, it seems intuitive that better IC would result directly in more adaptive, age-appropriate and socially appropriate behaviour, as part of better, more efficient and effective strategizing to accomplish tasks or goals. In light of these findings, research investigating early identification and targeted intervention strategies might produce reductions in risk of developing EP, and better outcomes given earlier treatment. The current data may contribute to evidenced-based treatments that are efficacious as well as externally valid, and reduce the burden of this very problematic constellation of maladaptive behaviours.

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APPENDICES

Appendix A
Source:

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Developmental Changes in the Relations Between Inhibitory Control and Externalizing Problems During Early Childhood

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Deficits in executive function, and in particular, reduced capacity to inhibit a dominant action, are a risk factor for externalizing problems (EP). Inhibitory control (IC) develops in the later preschool and early childhood periods, such that IC might not regulate EP in toddlers and younger preschoolers. Aggression was observed during peer play for 66 girls and 49 boys, from 2.75 to 6.00 years ($M = 4.14$, S.D. = 0.78). Mothers reported on children's IC and EP concurrently and 12 months later, and concurrent teacher reports of EP were also collected. Factor analysis supported aggregation of mother and teacher-reported EP and observed physical aggression into one measure of externalizing difficulties. Mothers reported lower IC for children with more externalizing difficulties, and the inverse relation between IC and externalizing difficulties strengthened over the toddler, preschool and kindergarten periods. Similar relations between IC and EP were observed 12 months later, and increases in IC also predicted reductions in EP over 1 year. These data demonstrate that the preschool years are a dynamic period of developmental change in the relations between IC and EP. Copyright © 2010 John Wiley & Sons, Ltd.

Key words: executive function; inhibitory control; aggression; externalizing problems; preschool; prefrontal cortex

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Appendix B
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Neurocognitive Development and Externalizing Problems: The Role of Inhibitory Control Deficits From 4 to 6 Years

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Executive processes have been posited as important regulators of externalizing problems (EP), but there has been little research on the relation between executive dysfunction and EP in early childhood. During the preschool period, maturation of the prefrontostriatal circuitry parallels increases in inhibitory control (IC). Poor IC development could result in elevated levels of aggressive, disruptive, and impulsive behavior. In this investigation, the development of the relation between IC and EP was examined in preschool and early elementary school children using the Day/Night and Tapping tasks. Children with more EP made more incorrect responses on both IC tasks, consistently across age and sex. The associations between EP and response latencies differed across children, however, with longer latencies on the Tapping task being most characteristic for boys with high levels of EP. This association was not apparent for girls. Two prominent aspects of early EP, aggressive and inattentive behavior, showed only weak unique associations with IC performance. These findings imply that diminished IC accompanies elevated EP as early as the preschool years, and that this decrement persists into the elementary school-age years for both girls and boys, and that accuracy and response latency may confer different information about the development of IC. Aggr. Behav. 37:1–13, 2011. © 2011 Wiley-Liss, Inc.

Keywords: externalizing problems; inhibitory control; executive function; early childhood; neurocognitive development

Deficits in executive control may underlie the symptomatology observed in children with externalizing problems [EP; Oosterlaan et al., 2005; Séguin and Zelazo, 2005; Séguin et al., 2004]. Executive control processes refer to a broad category of cognitive capacities subserved by the prefrontal cortex (PFC) and subcortical system [Diamond, 2002; Luria, 1973, 1980; Miller and Cummings, 1999; Welsh et al., 1991]. These capacities are necessary for the execution of goal-directed behaviors [Brocki et al., 2007] and include maintenance of information in working memory (WM), attentional allocation in formulating and executing goal-directed action, and inhibition of prepotent responding [Blair et al., 2005; Pennington, 1997; Stuss, 1992]. This latter capacity of inhibitory control (IC) is defined as "the deliberate suppression of a salient, prepotent cognition or response" [Ciairano et al., 2007; p 336]. Diminished IC, meaning a reduced capacity to inhibit a prepotent dominant action, seems to be particularly characteristic of children at risk for aggressive, disruptive, and dysregulated trajectories of development [Avila et al., 2004; Brophy et al., 2002]. Questions remain, however, regarding the age at which IC begins to regulate EP. This investigation was conducted to examine the relations between IC and EP in preschool- and early elementary school-aged children, a period of rapid growth in IC capacity.

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