Self-regulation difficulties in young children with cognitive, emotional and behavioural problems

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Summary of thesis

This thesis aimed to examine associations between self-regulation (SR) processes, such as executive functions (EFs), and emerging neurodevelopmental and mental health difficulties in children who were referred by teachers for a range of problems at school.

Chapter 2 investigated the prevalence of executive function (EF) problems in referred children and how EFs were associated with dimensions of attention deficit hyperactivity disorder (ADHD), oppositional defiant disorder (ODD), autism spectrum disorder (ASD) and anxiety. The sample demonstrated below-average performance on assessments of visuomotor control and attention (55%), cognitive inhibition (29%), cognitive flexibility (28%), and episodic memory (25%). ADHD and ODD symptoms were specifically associated with poor cognitive inhibition and flexibility, whereas ASD and anxiety were associated with better cognitive inhibition and flexibility.

Associations between specific symptom dimensions of ADHD (inattention, hyperactivity-impulsivity) and poor cognitive function were examined in Chapter 3, as well as how anxiety may impact these relationships. It was found that cognitive problems were predominantly associated with inattention, as opposed to hyperactivity-impulsivity. Separation anxiety moderated associations between inattention and inhibition; only children without separation anxiety showed significant correlations between inattention and poor performance.

Chapter 4 investigated processes involved in 'hot' cognitive control and found that low and high reward-seeking were associated with depression and ODD, respectively. We also extracted factors that corresponded to 'emotional impulsivity' and 'loss sensitivity', which were not independently associated with dimensional symptom severity measures.

In summary, findings from this thesis demonstrate that young children with emerging mental health difficulties exhibit difficulties in processes that are important for self-regulation.

Furthermore, the results highlight that using a dimensional and transdiagnostic approach may improve our understanding of how mental health difficulties emerge in children, and how self-regulation could be used as an intermediate process to detect those at-risk and develop tailored interventions (discussed in Chapter 5).

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List of abbreviations

ADHD = Attention Deficit Hyperactivity Disorder

ANT = Amsterdam Neuropsychological Tasks

ASD = Autism Spectrum Disorder

APA = American Psychiatric Association

AWMA = Automated Working Memory Assessment

BELT = Balloon Explosion Learning Task

CAMHS = Child and Adolescent Mental Health Services

CBCL = Child Behaviour Checklist

DAWBA = Developmental and Wellbeing Assessment

DCCS = Dimensional Change Card Sort

dlPFC = dorsolateral prefrontal cortex

DSM-5 = Diagnostic and Statistical Manual of Mental Disorders, fifth edition

EF = Executive Function

fMRI = functional Magnetic Resonance Imaging

HD = Hungry Donkey task

HPA = hypothalamic-pituitary-adrenal

NDDs = Neurodevelopmental Disorders

NICE = National Institute of Clinical Excellence

NIH = National Institute of Health

ODD = Oppositional Defiant Disorder

PSM = Picture Sequence Memory

RDoC = Research Domain Criteria

ROO = Response Organisation Objects

SR = Self-Regulation

PFC = Prefrontal Cortex

Chapter 1. General Introduction

1.1 Mental health difficulties in children and a case for earlier intervention

The worldwide prevalence of mental health difficulties in children and young people is estimated to be 13.4% (Polanczyk et al., 2015), with many more children experiencing symptoms that, while not reaching the threshold for a diagnosis, are a source of distress for the individuals and their families (Green et al., 2005). In the UK, demand for counselling services, hospital admissions for self-harm and referrals to specialist Child and Adolescent Mental Health Services (CAMHS) have all increased in the last decade, resulting in substantially longer wait times for diagnosis and treatment (Edbrooke-Childs & Deighton, 2020; Male et al., 2020). Furthermore, in the last three years, mental health problems have been exacerbated by increasing financial distress in families, COVID lockdowns and the consequent disruptions to children's schooling and social life (Adegboye et al., 2021; Peytrignet & Grimm, 2022).

Mental health difficulties in childhood are persistent; failure to address these problems early in life has a lasting and long-term impact on both the child and those around them (Kessler et al., 2005a; Meltzer et al., 2003; O'Shea & McHayle, 2021; Smith & Smith, 2010). Children with mental health problems face an increased risk of unemployment, substance abuse, lower academic achievement, greater criminal activity, poor physical health, and increased psychiatric difficulties in adulthood (Erskine et al., 2015), resulting in high costs across educational, healthcare, criminal justice, and welfare systems (Scott et al., 2001). In 2019, mental ill health was estimated to cost the UK £118 billion per year (McDaid et al., 2022). This high individual and societal cost of childhood mental health problems highlights a clear need for timely identification and intervention for children at risk of developing mental health problems to reduce societal costs as soon as symptoms emerge (e.g., Bachmann et al., 2022).

However, several service-level barriers prevent children from accessing services, such as extensive waiting lists, a lack of awareness and understanding of different pathways to appropriate care, financial restrictions, and insufficient resources (Anderson et al., 2017). The UK currently uses a tiers model, which defines the mental health system in terms of the level of need services can provide care for (e.g., Tier 4 services are for children with the most complex needs) (Wolpert et al., 2014). This tiered approach means that children who sit between tiers, such as those who are younger and exhibiting lower levels of problems, or those who do not have a formal diagnosis to confer eligibility for specific interventions, are being turned away or bounced between services (Batstra et al., 2014; Edbrooke-Childs & Deighton, 2020; Male et al., 2020; McShane & Rouse, 2015). On a more individual level, children who can mask and internalise symptoms are often overlooked, waiting longer, or do not access clinical services until a 'crisis point' is reached (Crenna-Jennings & Hutchinson, 2020; Department of Health and Social Care and Department for Education, 2017; Dvorsky et al., 2014). Furthermore, vulnerable groups of children, such as those who have experienced deprivation, trauma or parental mental health problems, are less likely to be referred to services because of these psychosocial factors (Doran, 2018). As a result, less than 25-35% of children with mental health difficulties are accessing support (McShane & Rouse, 2015), indicating high levels of unmet needs. Therefore, despite the strong economic case for improving children's mental health, individual and service-level barriers greatly limit children's access to the provision that is currently in place.

To increase access to services for children with emerging mental health problems, some have argued there is a need to shift away from tiered approaches, which are centred around providing help (or 'treatment') for children with more severe problems, to also consider 'risk support' for children with lower levels of difficulty (Farr et al., 2021; Wolpert et al., 2019). This has led to increased interest and investment in children's mental health services to widen access (Grimm et al., 2022). These efforts emphasise the promotion of mental health and well-being for all children and young people in the wider community, not only those who have a diagnosis or reach a specified severity threshold.

Accumulating evidence shows that children at risk of mental health problems show signs of difficulty early in life. For example, high and persistent irritability and emotional dysregulation, beginning at 12 months of age, is a robust predictor of Oppositional Defiant Disorder (ODD), depression and anxiety (Vidal-Ribas et al., 2016), and children who develop ADHD exhibit cognitive difficulties at age 3, which are predictive of poorer cognitive, emotional and social outcomes (Biederman et al., 2011; Cooper et al., 2014; O'Neil et al., 2017). Therefore, early indicators of mental health problems in children can be observed before the age that children are typically diagnosed (e.g., the average age for ADHD diagnosis is 6-10; Sainsbury et al., 2022).

These early indicators of mental health problems (e.g., irritability, cognitive difficulties) emerge at a time when the neural processes that underlie the skills that are crucial for healthy cognitive and socio-emotional functioning are still developing (Diamond, 2013; Skeem et al., 2014). Therefore, these early emerging problems that are precursors to mental health problems may be linked to the atypical development of important developmental processes in the brain. For example, ADHD is associated with delayed cortical maturation in prefrontal regions involved in the cognitive processes that are linked to educational under-achievement, difficulties with task adherence, and socio-emotional difficulties with peers (Shaw et al., 2007). Brain network abnormalities have also been found in anxiety and disruptive behaviour disorders (Fairchild et al., 2013; Raine, 2018; Tovote et al., 2015). These underlying neural processes associated with early emerging difficulties are more plastic and amenable to change earlier in development (Johnson, 2011; Uddin & Karlsgodt, 2018; Zelazo, 2015; Zelazo & Carlson, 2012). Therefore, improving our understanding of the underlying mechanisms which are associated with developing symptomatology may help us to identify children at risk of mental health problems earlier, and intervene at a time when children are most likely to benefit.

1.2 Self-regulation

1.2.1 Definitions and models of self-regulation

'Self-regulation' (SR) is the ability to monitor and regulate our cognition, emotions, and behaviour to move towards a goal (Bailey et al., 2019; Heatherton, 2011; Inzlicht et al., 2021; Sulik et al., 2016) and begins to emerge at the age of two (Kopp, 1982). Previous studies examining SR problems in children show substantial variation in the conceptualisation of SR; different definitions and levels of analysis have been adopted depending on the theoretical perspective being used (for review, see Inzlicht et al., 2021). SR has been studied as a bottom-up process, a dimension of temperament (Eisenberg et al., 2010a) and the physiological regulation of stress (Blair, 2010). It has also been studied as a top-down process encompassing the skills involved in cognitive control (Roebers, 2017). In recent years, researchers have attempted to integrate these different skills in models of SR by including both top-down and bottom-up processes, which contribute to the ongoing, dynamic, and adaptive modulation of one's internal state (e.g., Inzlicht et al., 2021; Nigg, 2017).

Because we are interested in understanding early emerging problems in children, Blair and Raver's (2015) model of children's developing self-regulation is relevant to this thesis. According to their developmental perspective, SR is a multi-allostatic system of feed-forward and feedback processes operating at biological, socio-emotional, behavioural and cognitive levels, which are triggered when prepotent responses are not adequate, such as in novel situations. Blair and Raver (2015) describe the neurobiology of SR as the give-and-take between emotion and attention. When arousal is registered in the attentional-cognitive and emotional-motivational systems of the brain, the stress response is activated. This response involves the production and release of corticotrophin-releasing hormone in the hypothalamus, the rapid sympathetic adrenal response, and the production of neurotransmitters (norepinephrine and dopamine). At the same time, activity in the hypothalamic-pituitary-adrenal (HPA) axis is stimulated, leading to the production of cortisol. Increases in these neurochemicals stimulate neural activity in areas of the prefrontal cortex (PFC). Finally, the activation of the PFC facilitates the top-down cognitive processes which are involved in modulating attention and controlling behaviour (Zelazo, 2015, 2020).

1.2.2 The development of SR

The PFC is responsible for top-down SR processes via its extensive connections with motor, motivational, reward, stress and affective systems (Macdonald et al., 2016). The development of SR throughout childhood is underpinned by changes in the PFC, which are dependent on experience (Johnson, 2011). Factors such as warm-sensitive parenting, opportunities to play games involving attention regulation, as well as family routines facilitate the development of adaptive SR skills (Hughes et al., 2009; Koopman-Verhoeff et al., 2019; Korucu et al., 2019) and coincide with maturational processes in the PFC, such as synaptic pruning and myelination (Huizinga et al., 2006; Luna et al., 2004; Tamnes et al., 2013).

The PFC has one of the longest periods of developmental maturation; thus, it is particularly vulnerable to the influence of environmental factors (Casey et al., 2010; Kolb & Gibb, 2011). For example, exposure to adverse childhood experiences and poverty are associated with high levels of chronic stress, which has toxic effects on the PFC and surrounding brain regions. These effects may explain difficulties in specific SR processes (Friedman et al., 2008; Hanson et al., 2012, 2013; Kolb et al., 2017; Liston et al., 2009). These environmental stressors, such as adverse childhood experiences, are also associated with a greater risk of mental health issues in childhood (Hoppen & Chalder, 2018;

Humphreys et al., 2019). Therefore, underpinned by neural processes within the PFC, SR can be seen as an intermediate mechanism linked to both specific factors that increase children's risk of mental health problems and developing psychopathology. Previous studies have provided support for the role of SR as a mediator linking familial factors (e.g., early childhood adversity) to engagement and learning in the classroom (Heaviside, 1993) and antisocial behaviour (van Goozen et al.., 2007). The importance and plasticity of SR and its neural underpinnings suggest top-down SR processes are an opportunity to identify areas of difficulty exhibited in young at-risk children that are linked to negative outcomes (Eisenberg et al., 2017).

1.2.3 SR processes

SR can be broken down into the processes that facilitate cognitive, emotional and behaviour regulation (e.g., Blair & Raver, 2015; Heatherton, 2011; Nigg, 2017). Cognitive regulation is the ability to manage cognitive processes (e.g., attention) and solve problems (Gioia et al., 2015). Emotion regulation is 'any process which influences the onset, offset, magnitude, duration, intensity or quality of one or more aspects of emotion response' (Gross, 2014; Nigg, 2017). Strategies of emotion regulation include cognitive reappraisal – reformulating the meaning of a situation – which effectively down-regulates emotional experience and behaviour; and expressive suppression, which inhibits emotional responding (e.g., facial expressions, verbal utterances) typically with little or no change in the ongoing internal emotional experience (Goldin et al., 2008). And finally, behaviour regulation is avoiding misbehaviours and demonstrating positive ones and involves inhibiting impulses and active choice-making, which can be seen in resisting intake of unhealthy substances and aggressive reactions (Vohs & Baumeister, 2004). All these types of SR involve distinct and overlapping PFC circuits (outlined in Macdonald et al., 2016). The dorsolateral portions of the PFC are heavily interconnected with sensory and motor cortices and play key roles in regulating cognition (e.g., attention and thought), whereas the ventromedial PFC is connected to the amygdala, playing a prominent role in regulating emotional responses. Finally, the orbitofrontal cortex integrates information from sensory and subcortical regions to guide reward-based decision-making to regulate behaviour.

Although these types of self-regulation can be broadly differentiated, there is also evidence that the capacity for all types of regulation relies on a general resource (Baumeister & Heatherton, 1996). Evidence from neuroimaging studies has shown that when participants are required to complete an attention-control task, they show poorer emotion regulation and reduced PFC activation (Wagner & Heatherton, 2010). Similarly, this reduction in PFC activation has been found following emotion regulation tasks, which also increases impulsive neural activations in the nucleus accumbens in response to food cues (Wagner et al., 2013). The idea of a general resource is consistent with neurobiological models of top-down emotional and behavioural regulation, whereby the activation of cognitive control in regions of the PFC contributes to the down-regulation of activity in areas associated with emotional responses (e.g., amygdala; Loos et al., 2020), and impulsive behaviour (e.g., nucleus accumbens, striatum; Behan et al., 2015). Although some emotional regulation strategies (e.g., expressive suppression, psychological distancing) are important components of self-regulation, executing the regulation of emotion/behaviour likely still involves some elements of processes primarily associated with cognitive regulation (Hofmann et al., 2012). Therefore, because cognitive regulation processes play an important part in multiple mechanisms of SR, this thesis will largely focus on the processes involved in top-down cognitive regulation.

1.2.4 SR and EFs

The skills involved in SR include those in the ‘Executive Function’ (EF) domain, which are the cognitive processes that are involved in the top-down control of goal-directed behaviour (Zelazo, 2020). Research on EF began with studies of patients with damage to the prefrontal cortex (PFC), who showed difficulty regulating skills in a goal-directed, contextually appropriate way, instead resorting to default, automatic responses (Luria, 1973). These studies led to the conceptualisation of brain function as hierarchical, with the PFC responsible for exerting top-down control over other brain regions, such as the striatum, amygdala, and other parts of the limbic system (Domasio, 1996; Luria, 1973). In support of these theories, patients with damage to their frontal lobe tend to ignore goals, struggle to inhibit learned automatic responses, ignore irrelevant information and shift strategies (Dimitrov et al., 2003; Kopp et al., 2013; Tsuchida & Fellows, 2013). At the same time, these patients exhibit dysfunction in behavioural control and self-regulation, such as aggression and excessive overeating (Grafman et al., 1996; Kelley et al., 2015; Woolley et al., 2007).

According to the iterative reprocessing model (Cunningham & Zelazo, 2007; Zelazo, 2015), in situations of novelty, conflict or uncertainty, automatic processing is replaced by deliberate and top-down cognitive control from the PFC using EFs. As a result, EF processes support the mechanisms that are necessary for self-regulation by modulating attention and consequently controlling behaviour by manipulating thoughts and actions, the ability to focus, inhibit predominant thinking and responding and switch between tasks (Blair & Raver, 2015; Garner, 2009; McCabe et al., 2010; Norman & Shallice, 1986; Rueda et al., 2005).

1.2.5 Defining and Measuring EF

Although there is general agreement on the broad concept of EF, theoretical models and the specific processes which may underpin EF have varied considerably between studies. There is general agreement that there are three core EFs: inhibition [inhibitory control, including self-control (behavioural inhibition) and interference control (selective attention and cognitive inhibition)], working memory, and cognitive flexibility (also called set shifting, mental flexibility, or attentional flexibility). (Diamond, 2013). In support of this model, Miyake et al. (2000) examined the structure of EF via latent variable analysis on multiple behavioural measures of these three skills. It was demonstrated that EF is comprised of separate factors that map onto each set of tasks measuring these three processes. However, there is also a ‘common factor’ that explains variance across tasks and is highly heritable (Friedman et al., 2008). Since this work, further research has shown EF develops hierarchically, from low-level processes (working memory, response inhibition), to higher-level EFs (cognitive flexibility), which facilitate more complex cognitive processes, such as reasoning and problem-solving (Collins & Koechlin, 2012; Diamond, 2013). However, in children, the structure of EF is less specialised (Lerner & Lonigan, 2014; McKenna et al., 2017) and shows greater overlap with other cognitive processes, such as episodic memory (Akshoomoff et al., 2014). Therefore, these lower-level cognitive processes may also be important to consider when examining EFs in young children with emerging SR difficulties.

Variation in the terminology used to describe EFs coincides with differences in how EFs are measured – including neuroimaging, behavioural tasks, and observer report – each reflecting different research disciplines. This thesis will measure EFs using objective, lab-based assessment tasks with a view to identifying problems early in life. On the other hand, neuroimaging is not feasible for children who cannot sit still for longer periods or who find it an unpleasant and frightening experience; thus making it more difficult to study SR-related processes in children. Parental reports of their child’s EFs are less able to predict academic achievement, interpersonal behaviours, and mental and physical health than lab-based tasks (Allan et al., 2014; Robson et al., 2020). Furthermore, lab-based tasks have high construct validity, whereas parent reports are influenced by other factors, such as parental mental health and social desirability and show poor correlations with children’s self-reports of EFs (Podsakoff et al., 2012; Sudikoff et al., 2015).

Not only are EFs crucial for maintaining focus on a task, as in cognitive regulation, but they are also involved in regulating behavioural and emotional responses. For example, memory is used to represent self-regulatory goals; attention is used to direct focus towards goal-relevant information and away from distressing emotional stimuli; and one must inhibit one's automatic response to override a habit (Hofmann et al., 2012; Hunt et al., 2013). To differentiate the way in which EFs can be used in 'cognitive' regulation from 'behaviour' regulation, researchers have used the term 'cool' to describe abstract, unemotional conditions and 'hot' to describe situations in which there are rewards and punishments (Inzlicht et al., 2021; Nigg, 2017). Thus, EFs vary on a dimension from 'cool' (emotionally neutral) to 'hot' (involving emotion and motivation) (Zelazo, 2020; Zelazo & Carlson., 2012), where the latter requires greater top-down control over bottom-up reactive processes (e.g., to rewards and losses). The differentiation of 'cool' and 'hot' EFs can be seen at the neurobiological level, whereby top-down regulation in 'cool' conditions involves top-down regulation from the dorsolateral PFC to the motor and sensory cortices, whereas under 'hot' conditions, projections are additionally made from the ventromedial and orbitofrontal PFC to the regions associated with processing rewarding and emotional stimuli, to down-regulate the positive reward-seeking and negative emotional responses (Johnstone et al., 2007; Macdonald et al., 2016).

To isolate 'cool' cognitive processes, we will use tasks where children recruit EF processes to complete tasks which involve abstract, unemotional stimuli (National Advisory Mental Health Council Workgroup, 2016). 'Hot' tasks will be used to measure top-down control over responses to loss and rewards as indicators of poor emotion and behaviour regulation (Fernandez et al., 2016; Schoorl et al., 2016) because losses and rewards on these tasks activate the same regions of the brain as when negative and positive emotions are experienced (Crone & van der Molen, 2007; Sanfey et al., 2003).

Children's poor performance on cool and hot EF tasks is predictive of a broad range of negative outcomes, including lack of school readiness, low academic achievement, worse professional success, health, drug use and criminality in adulthood, beyond that of intelligence and socioeconomic status (Blair & Raver, 2015; Bull & Scerif, 2001; Kim et al., 2012; Moffitt et al., 2011). At the same time, EF problems have also been found in children with various cognitive, emotional and behavioural disorders (O'Hearn et al., 2008; Petrovic & Castellanos, 2016; Rubia, 2011; Shi et al., 2019; Snyder et al., 2015; Zelazo, 2020). Therefore, understanding how EFs are associated with the development of SR problems has transdiagnostic relevance for early detection and intervention efforts.

1.3 Attention Deficit Hyperactivity Disorder (ADHD)

This thesis will examine SR processes in young children with emerging clinical symptoms of ADHD, ODD, ASD, anxiety and depression, but with a specific focus on ADHD. This is for several reasons. First, ADHD is currently the most prevalent psychiatric condition in children (Polanczyk et al., 2014; Visser et al., 2014). Second, ADHD has traditionally been considered a disorder of self-regulation: inattention and hyperactivity-impulsivity can be considered manifestations of cognitive and behavioural regulation difficulties, respectively (Barkley, 2011). Finally, because ADHD is a neurodevelopmental disorder, the cognitive problems associated with ADHD emerge early in life. Thus, understanding the development of ADHD may help us to detect problems in the processes that contribute to poor SR in young children, which may be useful in early detection and intervention for children at risk (Robson et al., 2020; Sullivan et al., 2015).

1.4 What is Attention-Deficit/Hyperactivity Disorder (ADHD)?

The most recent diagnostic manual used in psychology (The Diagnostic and Statistical Manual – 5th edition [DSM-5]; American Psychiatric Association [APA], 2013) includes ADHD as a neurodevelopmental disorder (NDD), the core features of which are inattention, hyperactivity and impulsivity. To meet the DSM-5 diagnostic criteria, a child must show six or more of the nine listed inattention symptoms (e.g., “Often fails to give close attention to details or makes careless mistakes in schoolwork, at work, or during other activities”) and 6 of the 9 listed hyperactive-impulsive symptoms (e.g., “Often fidgets with or taps hands or feet or squirms in seat”). In addition, symptoms must be present before age 12 and for at least 6 months, occur in 2 or more settings, and interfere with functioning (e.g., classroom learning, making and keeping friends).

ADHD has a worldwide prevalence of 7.8 to 11% (Polanczyk et al., 2014). Children with ADHD are more likely to have poor outcomes at school, such as educational underachievement. At the same time, teachers report experiencing stress and negative feelings towards teaching students with ADHD (Mulholland et al., 2015). Moreover, research has found that children with ADHD are more likely to experience a range of serious negative outcomes later in life, including drug abuse, school dropout, criminality, antisocial behaviour and psychiatric hospitalisations (Molina et al., 2009; Shaw et al., 2012). Despite the high prevalence and negative outcomes that are linked to ADHD, children referred to mental health services with inattention and hyperactivity problems are likely to be rejected (Smith et al., 2018), and ADHD is still relatively under-recognised and under-diagnosed in most countries (Sayal et al., 2018). Even children receiving medication management and/or behavioural therapy have a more negative developmental trajectory than typically developing children (Molina et al., 2009). Thus, our current understanding of how to identify and provide effective interventions for children with ADHD is limited.

Previous research has shown that both genetic and environmental factors increase one’s vulnerability to ADHD (Sonuga-Barke et al., 2022). For example, studies which have examined specific genetic factors have implicated the dopaminergic system, which is involved in processing rewards and feeling motivated (Cubillo et al., 2011). Individuals with

ADHD exhibit reduced dopamine receptor density, which may be linked to difficulties with sustaining attention and motivation, as well as greater impulsive behaviour (Cabana-Domínguez et al., 2020; Faraone et al., 2015). However, the genetic variants which have been identified as potentially contributing to the disorder are not yet sufficiently predictive of cases to be clinically useful (Sonuga-Barke et al., 2022). To illustrate, ADHD has a heritability of 74% (Faraone & Larsson, 2019), yet genome-wide association studies (GWAS), which look at the specific genes which increase risk, have thus far only provided heritability estimates of 20-30% (Demontis et al., 2022). This mismatch between twin and GWAS studies may indicate that many genes of small effect size, which are not only the common variants used in GWAS, could contribute to the diverse symptomatology exhibited in children with ADHD. At the same time, environmental familial factors, such as early adversity, socioeconomic status, and maternal depression, are associated with a greater likelihood of children developing ADHD (Gómez-Cano et al., 2023), and these factors may interact with genetic predispositions to increase risk (Chen et al., 2020). Therefore, it is not yet clear how exactly genetic and environmental factors contribute to symptomatology, and there may be multiple aetiological pathways to the disorder, which vary between individuals (Faraone & Larsson, 2019).

1.4.1 Theories of SR difficulties in ADHD

Although there may be heterogeneity in how symptoms of ADHD develop, both genetic and environmental factors that increase the risk of ADHD have effects on the neurological processes which facilitate SR, implicating the prefrontal cortex (PFC) (Mackes et al., 2020; Rutter et al., 2007; Surman et al., 2011). Therefore, whilst previous research has shown that the aetiology of ADHD is complex and heterogeneous, it has also shown that there is overlap in the systems to which these factors contribute towards. Because the PFC is responsible for EF, these findings may indicate that EF skills may play a central role in the development of SR difficulties that are associated with ADHD, which has led to several EF-based theories of ADHD.

1.4.1.1 Core deficit models

Traditional theoretical accounts of ADHD have viewed the disorder from a categorical perspective, whereby poor SR skills, such as EF, are central to the disorder and play a key role in the aetiology of symptoms. For example, Barkley. (1997) argued for the presence of a ‘core deficit’ in inhibition, which leads to secondary problems in other self-regulatory processes, such as sustained attention. It is proposed that inhibition is the single core dysregulated process within the individual, which results in more general and broader cognitive difficulties and symptoms of hyperactivity-impulsivity and inattention.

1.4.1.2 Cognitive energetic model

The ‘Cognitive Energetic Model’ (CEM) (Sergeant, 2000) suggests ADHD is associated with general state-regulation dysfunction, which disrupts the individual’s ability to allocate attention and engage general, basic cognitive processes (e.g., encoding in memory, central processing, response organisation). Unlike Barkley’s model of ADHD, CEM implies that basic cognitive processes, the building blocks for EF, are the main underlying difficulty in ADHD and that other cognitive difficulties manifest as a result of problems in these basic skills.

1.4.1.3 More pathways to disorder; dual/triple pathway models

In 2003, Sonuga-Barke proposed a dual-pathway theory of ADHD. In this model, problems in the cognitive systems domain, such as working memory, inhibition, and attention, are only one mechanism of the disorder. The second pathway implicates problems in ‘hot’ EF, suggesting that ADHD can alternatively involve difficulties in motivational processes. As such, this model implies that individuals with ADHD may exhibit difficulties in regulating cognition during abstract and non-emotional tasks but may also have problems in exerting top-down cognitive control over behaviour under motivational conditions, where rewards are involved. For example, children with ADHD may struggle to control their impulses in response to rewarding stimuli, which carry positive valence. In 2010, this model was expanded to include a third pathway, ‘timing deficits’, because children with ADHD demonstrate difficulties when initiating motor movement on tasks (Sonuga-Barke et al., 2010). This timing pathway encapsulates basic cognitive processes, such as those in the CEM model (Sergeant, 2000).

1.5 Research examining EF problems in ADHD

1.5.1 Behavioural evidence

The large proportion of research which has examined EF problems in ADHD used a case-control design, comparing children with a clinical diagnosis to typically developing children on measures of single processes. Some of these studies revealed that children with ADHD show relative difficulty on inhibition tasks (Berlin et al., 2004; Geurts et al., 2005; Schoemaker et al., 2012; Wodka et al., 2007) which has been interpreted as support for ‘core deficit’ theories of ADHD (e.g., Barkley, 1997). However, other researchers have failed to find inhibition problems in ADHD samples (e.g., Bioulac et al., 2014) and have found that other EF difficulties can occur independently of inhibition problems (e.g., working memory; Brocki et al., 2008).

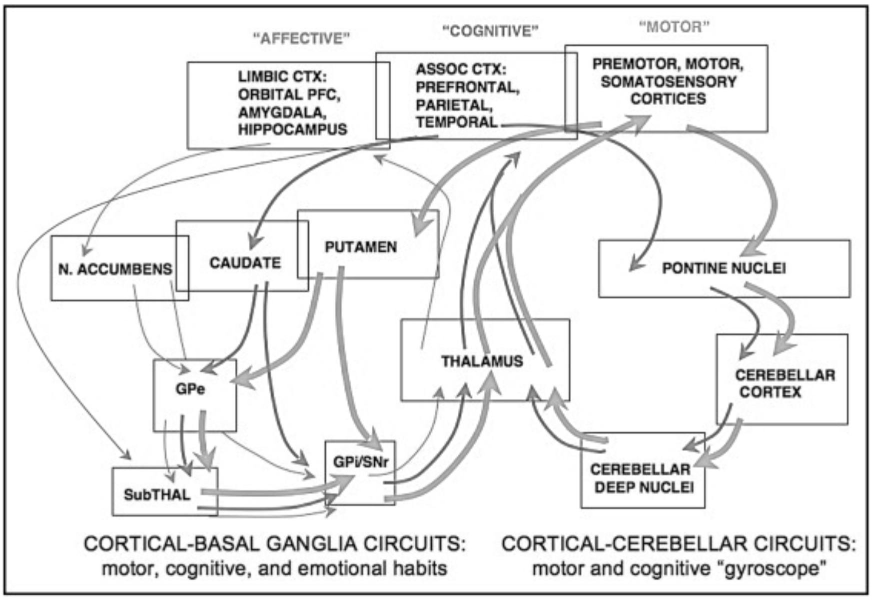
More recently, studies using a broad assessment approach have shown that presentations of cognitive difficulty vary between individuals with ADHD, despite having the same diagnosis (e.g., Coghill et al., 2014b; Kofler et al., 2019). Estimates of the prevalence of EF difficulty in ADHD vary considerably; some studies have suggested that EF problems only occur in 35% of children with the disorder (e.g., Biederman et al., 2004), whereas other studies have much higher estimations (e.g., 89%; Kofler et al., 2019). Some studies have further shown that children with ADHD also exhibit difficulties in basic non-EF processes, showing greater RT variability on inhibition tasks and poorer episodic memory than typically developing children (Alderson et al., 2015; Cai et al., 2019). Thus, although it may be consistently found that children with ADHD are more likely to exhibit cognitive problems than typically developing children, these problems are heterogeneous, and inhibition problems are not the most prevalent.

1.5.2 Neurological evidence

Individuals with ADHD exhibit altered structural and functional differences in the regions of the brain which mediate cognitive control, attention, motivation and timing (see Figure 1; Arnsten & Rubia, 2012). fMRI studies have observed hypoactivation in the dlPFC while individuals with ADHD are carrying out ‘cool’ EF tasks, which is linked to poorer cognitive performance (Christakou et al., 2012; Cortese et al., 2012; Smith et al., 2008; Vloet et al., 2010). At the same time, some brain regions demonstrate greater activation, such as the default mode network, which is associated with mind wandering and is anti-correlated with performance on cognitive tasks (Bozhilova et al., 2018). Structurally, individuals with ADHD have smaller volumes in the basal ganglia (Gallo & Posner, 2016), which may explain altered reward responsiveness and poor performance on hot EF tasks. Therefore, neurological studies suggest individuals with ADHD show abnormalities in the structure and function of the brain regions involved in timing and cool EF, which mediate top-down cognitive control in neutral contexts (Kouneiher et al., 2009), and those involved in hot EF, which process rewards and losses (Schultz, 2016).

Figure 1.1.

The neural networks associated with poor motivational, cognitive and motor (timing) regulation problems in ADHD (Arnsten & Rubia, 2012).



Together, findings from behavioural and neuroimaging studies suggest ADHD is associated with difficulties in multiple cognitive processes that are involved in SR. ADHD is associated with heterogeneity in problems at different levels of cognitive complexity, which includes basic, low-level processes which contribute to EF tasks (e.g., encoding in memory, central processing, response organisation); 'cool' EF processes, such as working memory and inhibition; and finally, problems with 'hot' EF (e.g., reward processing) (Coghill et al., 2014b; Kofler et al., 2019; Willcutt et al., 2005). As a result, there is substantial variation in the prevalence rates of EF problems found between studies where different cognitive and EF measures have been used (e.g., 35-89%; Biederman et al., 2004; Kofler et al., 2019). These findings collectively support the theoretical models which incorporate multiple pathways to ADHD because not all children with ADHD exhibit the same cognitive problems (Nigg, 2013; Sonuga-Barke et al., 2010).

1.5.3 EF as an intervention for children with ADHD

Upon diagnosis, psychostimulant medications are generally the first line of treatment for reducing the symptoms of ADHD (National Institute for Health and Care Excellence [NICE], 2018). However, for some individuals, medication is associated with adverse side effects such as sleep problems, loss of appetite and headaches (Graham & Coghill, 2008; Newcorn et al., 2010). These negative side effects are a greater issue in younger children (aged 3-5), where pharmacological treatment is also less effective (Greenhill et al., 2006). Therefore, psychiatric guidelines recommend that non-pharmaceutical interventions should also be considered, yet it is not very clear what these interventions should involve (Sadock et al., 2009). Some examples which have been found to be effective include dietary interventions (e.g., Cooper et al., 2016), mindfulness meditation (Evans et al., 2018), parenting interventions for behaviour management (Pelham et al., 2016), physical exercise (Neudecker et al., 2015), and neurofeedback (Alegria et al., 2017).

Interpreting the reported impact of these interventions is complex because of the lack of objective cognitive measures used across studies. For example, most interventions have not been evaluated using a double-blind randomised-control trial, which means that assessors of outcomes (e.g., teacher- or parent- reports of symptom improvement) may over-estimate treatment effects because of expecting a positive outcome (Coghill et al., 2021). Alternatively, intervention studies using objective tasks to indicate changes in underlying processes provide an objective measure of the problems, which occur in individuals with ADHD which interventions can be tailored towards (Gloster & Karekla, 2020).

Converging evidence from behavioural and neurological studies has shown that difficulties in EF processes are prominent in ADHD. At the same time, the well-established validity of EF tasks means that the effectiveness of EF interventions can be objectively measured before and after training without relying purely on parent- or teacher-report.

Therefore, if processes such as EF are involved in some of the symptoms of ADHD, training these skills may be an effective intervention for children with emerging symptoms (Shaw et al., 2005).

Most cognitive training programs to improve EFs in ADHD have focused on a single process, such as working memory (e.g., “Cogmed”; Klingberg et al., 2005). Others include “Braingame Brian” (Dovis et al., 2015; van Houdt et al., 2019), which is a gamified training for multiple processes, including visuospatial working memory, inhibition, and cognitive flexibility, through tasks embedded in a game-like world. Studies which have evaluated these interventions have looked at ‘near transfer’ and ‘far transfer’ effects (Melby-Lervåg & Hulme, 2013). Significant effects of training on the targeted skill are ‘near transfer’, whereas ‘far transfer’ is when the training improvements correspond to outcomes which were not directly trained, such as disorder symptoms and other EFs which were not directly targeted. In general, there is some evidence that cognitive training can lead to near-transfer effects (e.g., Jones et al., 2019; van Houdt et al., 2019). However, most studies have found that far transfer to other EFs and symptoms are not maintained at follow-up assessments (e.g., Dovis et al., 2015; Jones et al., 2019). Where studies have found significant effects on far transfer measures, sample sizes are smaller, there is an absence of an active control group, or raters are not blinded to whom received the intervention (Rapport et al., 2013). Therefore, although there is a strong evidence base implicating EF problems in ADHD, the lack of far-transfer effects found in cognitive training studies calls into question whether our current understanding of these problems is sufficient to recommend intervention in this area.

1.6 Limitations of prior work examining cognitive processes in ADHD

The following section will now consider several issues in research examining cognitive processes in ADHD, which are maintained by our reliance on traditional classification and core-deficit informed thinking.

1.6.1 Classification systems

Most clinical research and practice in child mental health is guided by The Diagnostic and Statistical Manual of Mental Disorders (DSM-5), currently in its 5th edition (DSM-5; American Psychiatric Association [APA], 2013). The DSM was created to advance a common language whereby manifestations of psychopathology are consistently referred to by diagnostic label, and each mental disorder is defined by a set of symptom criteria. However, whilst this phenotype-driven approach is useful for improving the reliability of clinical and research work, it does not aid our understanding of the mechanisms which underpin specific symptoms. The binary classification system (i.e., present or not present) in the DSM and the separation of overlapping symptoms into individual categories implies that each disorder has a core problem (i.e., a 'core deficit') and has traditionally led to the development of disorder-specific, 'one size fits all' treatments, corresponding to each classification (Caspi & Moffitt, 2018; Roy-Byrne, 2017). However, as demonstrated above with the case of ADHD, the underlying mechanisms associated with each disorder in the DSM are complex, and difficulties in psychological processes may vary within these diagnostic classifications (Astle et al., 2019; Coghill et al., 2014b; Kofler et al., 2019; Zdorovtsova et al., 2023).

To improve our understanding of SR difficulties in children at-risk of various cognitive, emotional and behavioural problems and to develop effective early interventions, it is important for research to move beyond 'core deficit' thinking and account for (1) the dimensional nature of symptoms, (2) heterogeneity within diagnostic categories, and (3) comorbidity and overlap.

1.6.2 The dimensional nature of symptoms

Previous studies have shown that EF difficulties and SR problems can be detected in young, pre-diagnosed children (e.g., Kalff et al., 2003; O'Neil et al., 2017; Vidal-Ribas et al., 2016) and older children with clinical symptoms, who do not reach the threshold for a diagnosis, still perform at below age-expected levels on measures of EF (e.g., Gathercole et al., 2008; Holmes et al., 2014). Indeed, it is becoming increasingly recognised that disorders such as ADHD do not qualitatively differ at the clinical boundary (Arildskov et al., 2022; Caspi & Moffitt, 2018), and cognitive difficulties, symptoms, and functional problems are linearly associated (Salum et al., 2014b). Therefore, considering SR processes and clinical symptoms as varying on a continuum may be more accurate than a categorical approach. Furthermore, a dimensional approach to assessment and intervention ensures that subthreshold children who may exhibit EF difficulties and clinical symptoms and who could benefit from intervention are not overlooked. To improve our understanding of these relationships between EF and dimensional measures of clinical symptoms, studies that use community sampling of children identified as at-risk rather than relying on a formal clinical diagnosis for inclusion are needed (e.g., Howe-Davies et al., 2022; Simpson-Kent et al., 2021; Wells et al., 2019).

1.6.3 Within-disorder heterogeneity

A large proportion of intervention studies for children with ADHD have used inclusion criteria which is solely focused on diagnosis, as opposed to the specific difficulties which interventions are aiming to target, and most interventions have focused on training working memory (Lambez et al., 2020). However, this ‘one size fits all’ approach is inconsistent with the high heterogeneity in how EF problems manifest (Vanden Bussche et al., 2017). Instead, interventions should be tailored to processes which are impaired, and associated with developing symptomatology for the individual (Rapport et al., 2013).

Not only may children with mental health difficulties exhibit heterogeneity in the cognitive processes associated with poor SR, but there is also substantial heterogeneity in children’s symptom profiles. Although two people may have the same diagnosis, this does not mean that they have identical symptom profiles and co-occurring difficulties. For example, two individuals could both meet the criteria for major depression but share no common symptoms (Fried & Nesse, 2015). In ADHD, some children may be predominantly inattentive, whereas others may demonstrate a higher proportion of hyperactive-impulsive symptoms (APA, 2013). Some studies have shown that these different symptoms are associated with different underlying neuropsychological processes (e.g., Castagna et al., 2019; Toplak et al., 2005), thus using a categorical approach and not accounting for varying symptom severity may add to inconsistencies between studies looking at EF problems.

1.6.4 Widespread comorbidity and overlap

Traditionally, exclusion criteria were used to diagnose conditions (e.g., ADHD not diagnosed if ASD present), whereas now there is increased recognition that 'pure' conditions are the exception rather than the rule (Jensen et al., 2001), and this is reflected in the current DSM revision (i.e., according to the DSM-5, ASD and ADHD can be diagnosed as co-occurring conditions; APA, 2013). Comorbidity between disorders is an important consideration for EF research because comorbid disorders may be independently associated with problems in EF, thus might inflate estimates of EF problems in specific disorders. Alternatively, shared EF difficulties may point to overlapping underlying mechanisms between disorders (Rommelse et al., 2011). ADHD is associated with high rates of comorbidity (Grzadzinski et al., 2016; Oerbeck et al., 2017; Schatz & Rostain, 2006); thus, the sections below will briefly summarise research into EF problems in disorders which frequently co-occur with ADHD. A more detailed exploration of previous research looking at these disorders is presented in subsequent chapters.

1.6.4.1 ASD

In research and clinical settings, ASD is typically separated from ADHD and other mental health problems (Male et al., 2020). In recent years, the concept of ASD has expanded to mean that many people on the spectrum are intellectually and emotionally able and that ‘impairment’ primarily relates to stigmatisation within society (Donaldson et al., 2017). Nevertheless, the conditions and cognitive/socio-emotional difficulties that frequently co-occur with ASD may give rise to additional problems such as anxiety and ADHD; thus, ASD is still very relevant in the study of mental health (Young et al., 2020). Therefore, this thesis considers symptoms of ASD alongside emerging mental health problems in children because a transdiagnostic approach is a more realistic way to fully capture how symptoms of ASD, ADHD and other mental health problems emerge (Astle & Fletcher-Watson, 2020; Male et al., 2020; Mohammadi et al., 2021; Simonoff et al., 2008).

ASD is characterised by challenges in social communication and restricted/repetitive behaviour patterns (APA, 2013) and affects approximately 1% of children worldwide (Simonoff et al., 2008). Traditional theories of ASD have focused on a range of processes, including ‘theory of mind’ (being able to switch perspectives and represent others’ beliefs) and ‘weak central coherence’ (processing information in a detail-oriented way, at the expense of global meaning) (Baron-Cohen, 1997; Frith, 1989; Rajendran & Mitchell, 2007). In terms of specific processes that are linked to SR, such as EF, some have proposed that cognitive flexibility problems (i.e., shifting attention and switching perspectives) may explain the difficulties that individuals with ASD have in adapting to changing events (Yeung et al., 2016). Therefore, because of the potential link between ASD and cognitive flexibility, which may lead to inflated estimates of cognitive flexibility problems in studies of other disorders (e.g., Coghill et al., 2014b), it may be necessary to dimensionally account for ASD when examining this specific EF. However, the evidence for EF problems in ASD is mixed, and effect sizes between studies vary considerably (Demetriou et al., 2018).

1.6.4.2 Anxiety

Anxiety disorders are the most prevalent mental health problems in children and have a significant negative impact on children’s educational and social functioning (Copeland et al., 2014). The prevalence of anxiety in children has increased substantially in recent years, occurring in over 6.5% of children (Sadler et al., 2018), is frequently comorbid with NDDs, such as ASD (40%; Simonoff et al., 2008) and ADHD (33%; Jensen et al., 2001), yet very few children with anxiety disorders access evidence-based treatments (Reardon et al., 2019). Access to support is limited by the highly costly nature of traditional treatments (e.g., cognitive behaviour therapy; CBT) and the lack of lower-level interventions.

Whereas SR processes are central to theories of ADHD (e.g., Barkley, 1997; Sonuga-Barke et al., 2010), models of anxiety have largely focused on understanding developmental risk factors rather than the processes which might maintain symptoms (e.g., Spence & Rapee, 2016). However, emerging evidence suggests that similar processes may occur in children as to those described in adult cognitive models, such as difficulties with cognitive flexibility and a rise in negatively valenced affect (Crocker et al., 2013; Sharp et al., 2015; Snyder et al., 2015).

Some studies have indicated that heightened arousal in anxiety reduces problems with EF in children with ADHD (Castagna et al., 2019). The Attentional Control Theory (ACT; Eysenck et al., 2007) proposes that anxiety and worry may deplete working memory resources under conditions of high working memory demand but may increase alertness and improve performance under low-demand conditions (Arnsten, 2009). These potentially interacting processes associated with ADHD and anxiety are an important area for further investigation, to understand variation in the cognitive problems that children with different combinations of symptoms may exhibit.

1.6.4.3 ODD/CD

Children with disruptive behaviour disorders, such as oppositional defiant disorder (ODD) and conduct disorder (CD) are characterised by persistent antisocial and aggressive behaviours (APA, 2013), increasing risk of a range of serious negative outcomes, such as delinquency, unemployment and additional psychiatric problems (Fergusson et al., 2005). Usually, ODD precedes CD, such that the age of onset for ODD is 7-15, whereas, for CD, this is 9-14 (Kessler et al., 2007); however, whether ODD is a precursor to CD is subject to debate (e.g., Burke et al., 2005; Diamantopoulou et al., 2011). Because this thesis is interested in the emergence of clinical symptoms in young, pre-diagnosed children, measures of disruptive behaviour will focus on ODD; however, many studies have examined both disorders together (Matthys et al., 2012).

Like ADHD, prior research suggests there are multiple pathways to disruptive behaviour disorders, including genetic and environmental factors, but SR processes may play an important mediatory role (van Goozen et al., 2022). Processes within the positive/negative valence systems, assessed by tasks which involve regulating responses under ‘hot’ conditions, are often compromised in children with ODD/CD. For example, reduced sensitivity to threats of punishment is associated with difficulties in learning to refrain from inappropriate behaviours, whereas greater risk-seeking is associated with dysfunctional reward processing (Matthys et al., 2012). Moreover, some studies have found that individuals with ODD/CD demonstrate problems with ‘cool’ EF processes, indicating poor cognitive control (e.g., Hobson et al., 2011). However, this evidence is more mixed (e.g., Woltering et al., 2016). Furthermore, ODD and CD co-occur with ADHD in approximately 50% of cases (APA, 2013). Therefore, because the comorbidity rate between ADHD and disruptive behaviour is so high, there is a need for research examining the development of these disorders to differentiate whether the cool-hot EF distinction distinguishes between ADHD from disruptive behaviour or whether there is overlap in these underlying difficulties (Rubia, 2011).

1.6.4.4 Depression

Clinically significant depression typically onsets from adolescence onwards; however, the first episode is often preceded by subthreshold symptoms and clinical antecedents, such as ODD (Burke et al., 2010; Thapar et al., 2022). Depression is associated with reduced reward sensitivity, which can be assessed using hot EF tasks, and may underlie anhedonia and blunted positive affect (Foti et al., 2014; Foti & Hajcak, 2009). Reduced reward sensitivity is also associated with ODD (Bjork & Pardini, 2015). Therefore, although this thesis is generally concerned with clinical disorders that emerge in childhood, symptoms of depression will need to be examined regarding 'hot' EFs because it is unclear whether reward-related processes are specifically associated with ODD, depression, or both these disorders together.

The findings described in the above sections indicate that there may be overlapping difficulties in specific EF processes between diagnostic categories, such as cool EF problems in both ADHD and ODD/CD. This overlap may indicate that there are shared underlying problems that contribute to multiple forms of symptomatology. In response, some researchers have argued that there are transdiagnostic mechanisms associated with increased psychopathology (Rommelse et al., 2011). For example, poor EF may be a mechanism for poor self-regulation, which is involved in multiple disorders (e.g., ADHD, ODD/CD, anxiety, and depression; van Goozen et al., 2022).

However, the large proportion of research which has identified EF problems in these different disorders has used a group-level approach, and comorbidities have been inconsistently controlled. Furthermore, when comorbidities have been accounted for, studies have used exclusionary criteria, which reduces the generalisability of findings, and fails to consider whether co-occurring clinical symptoms have effects at a subthreshold level (Carter

Leno et al., 2018). If individual EFs are associated with specific disorder dimensions in different ways (e.g., inhibition problems – inattention, better inhibition – anxiety), failure to control for comorbidities may mask independent disorder-specific associations. Therefore, it remains to be seen whether difficulties in processes which were thought to be disorder-specific can be exhibited among other groups (e.g., 'cool' EF difficulties in ODD/CD, independent of ADHD) or whether these findings can be explained by inconsistent control of comorbid symptomatology. If the latter, breaking down SR processes into disorder-specific domains may be useful. For example, if cool EF problems are unique to ADHD, assessing these skills in young at-risk children may be a useful screening tool to indicate risk for attentional difficulties. Overall, research looking at EFs in disorders which frequently co-occur with ADHD that improving our understanding of SR problems in at-risk children requires us to adopt a transdiagnostic approach and dimensionally control for co-occurring symptomatology.

1.7 A different lens: the RDoC approach and SR as a transdiagnostic process

Whilst there is a large evidence base that challenges 'core deficit' theories, implicit 'core deficit' thinking persists through the way in which developmental and intervention studies are constructed (Astle & Fletcher-Watson, 2020). For example, adopting a case-control design, examining a single cognitive process, and using group-level data analyses, assumes that all participants in the 'case' group share an underlying problem and will benefit from training this process.

To be consistent with the reality of how clinical symptoms are exhibited in children, it is important that research accommodates the dimensional nature of symptom heterogeneity within diagnoses and comorbidity. This led to the development of the NIMH Research Domain Criteria initiative (RDoC; Insel et al., 2010). The goal of RDoC is to characterise clinical disorders by varying degrees of dysfunction in psychological/biological systems by linking measurable neuropsychological domains to dysfunctions in thought and behaviour. The processes are considered to vary on a continuum. Thus, RDoC uses a dimensional, as opposed to categorical, approach to neuropsychological processes and disorder symptoms.

By providing data about basic processes related to mental health, the RDoC enables us to understand specific difficulties young children are presenting with and tailor interventions in line with specific needs to prevent and treat psychopathology. Furthermore, where symptoms and cognitive problems cluster together, we can develop transdiagnostic interventions which are suitable for children with a wide range of difficulties and those who show comorbid disorders with overlapping underlying processes (e.g., Cuthbert & Morris, 2021).

Therefore, RDoC can help us to overcome these core issues in previous SR research. RDoC considers psychopathology on a dimension, rather than using arbitrary cut-offs, and examines transdiagnostic processes and symptom dimensions, allowing comorbidity and overlap, as well as heterogeneity. Although RDoC is not yet able to replace current diagnostic systems, the shift in focus from diagnoses to dimensional assessments of symptoms and processes is more consistent with the realistic nature of how developmental disorders manifest in children, thus, can be used in combination with our current understanding of the dimensions of symptoms that children can present with.

This thesis aims to position SR within the RDoC framework to examine associations between specific SR processes and dimensions of NDDs and clinical symptoms. There are currently six key domains in the RDoC framework: positive valence, negative valence, arousal/regulatory, sensorimotor, social processes and cognitive systems. Each domain includes specific psychological/biological constructs which can be represented on a dimension of functioning from normal to abnormal. This thesis will focus on the three RDoC domains that are relevant to SR, which can be assessed using cool and hot EF tasks. The "cognitive systems domain" is responsible for cognitive processes such as cool EFs and memory and can be assessed using 'cool' EF tasks. 'Hot' EF tasks tap into processes within the "positive valence systems" and "negative valence systems" domains. "Positive valence" processes include those involved in responding to positive motivational situations or contexts, such as reward-seeking. Finally, the "negative valence" includes responses to aversive situations or contexts, such as loss or fear.

1.8 The NDAU

The Neurodevelopment Assessment Unit (NDAU) is an ongoing study at Cardiff University with a dual purpose: to collect broad assessment data on primary school children and to provide feedback on children's strengths and difficulties to referrers (i.e., classroom teachers), with strategies for intervention (see website: https://www.cardiff.ac.uk/neurodevelopment-assessment-unit). The NDAU adopts a transdiagnostic approach by assessing children aged 4-7 who are referred by teachers and Special Educational Needs Co-ordinators (SENCOs) due to concerns about varying cognitive, emotional and behavioural problems. The NDAU aims to provide early identification and intervention for children at risk of developing mental health problems in schools and families. The unit is supported by a clinical psychologist and an educational psychologist who inform the recommended support based on the data collected from the assessment.

Children visit the NDAU with a primary caregiver (usually the mother) and complete the assessment over two sessions; one in the morning (9:30-12:30) and the second in the afternoon of the following week (1:30-4). Before the session starts, a waiting room-style stranger-approach procedure is carried out. The child is then required to complete a range of tasks, which assess cognitive and socio-emotional processes which correspond to systems within the RDoC framework (Appendix A). These tasks are administered and completed on computers, tablets and using books/toys. The session is recorded by 8 cameras which are in the assessment room. This is carried out by a trained placement student, who sits in an observation unit and makes notes on the session. Trained researchers (PhD students and post-doctoral researchers) run the child assessment, working with the child to ensure they are motivated and trying their best on tasks. Each time one or two tasks are completed the child is rewarded by moving their picture up a chart towards an end goal (rainbow/planet). After reaching the top of the chart, they receive a prize as a thank-you for their participation.

At the same time, the child's caregiver is asked to complete an interview to understand their perspective of their child's difficulties. During this, carers also complete a series of questionnaires to measure the quality of the parent-child relationship and the child's symptoms of NDDs and psychopathology (Appendix B).

Following the assessment, a detailed report is fed back to the child's school, identifying areas of strength and need. In addition, in line with the educational psychologist's recommendations, the report details how the child's specific difficulties can be targeted through different interventions (e.g., online training to support children in recognising different facial expressions).

The unit has received ethical approval from Cardiff University (ethics number: EC.16.10.11.4592GRA5) and is funded by The Waterloo Foundation [grant number 511633 & 520678] and awarded to Stephanie van Goozen.

1.8.1 The Sample

The participants in each Chapter of this thesis are primary school children aged 4-8, referred to the NDAU from schools in and around Cardiff. The children's classroom teachers or SENCOs completed the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) to assess cognitive, emotional and/or behavioural problems in the past 6 months as part of the referral process.

The SDQ is a clinically useful screening measure for cognitive, emotional and behavioural difficulties in children and is comprised of five subscales: conduct problems, hyperactivity problems, emotion problems, peer problems and prosocial problems. For all subscales except for prosocial problems, higher scores indicate more severe difficulties, whereas, for the prosocial problems scale, lower scores indicate lower prosocial behaviour and greater difficulties. Each subscale, as well as the total difficulty scores, is categorised into "close to average," "slightly raised/slightly lowered," "high/low," and "very high/very low," according to the four-band categorisation of the scoring system (Green et al., 2005). In all Chapters, SDQ classifications indicating different degrees of raised behaviour issues (e.g., "Slightly Raised or Lowered," "High/Low", or "Very High/Low") were collapsed into a "Raised" category (Murphy & Risser, 2022).

Investigation of the teacher SDQ total scores suggests 80% (n = 351) of the children in the NDAU thesis sample (n = 443) were rated as at-risk of future psychopathology, scoring in the top 20% of the population. According to the Child Behaviour Checklist (CBCL; Achenbach et al., 2003) and Autism Quotient (Auyeung et al., 2008), children in the sample showed clinically significant symptoms of ADHD (n = 173, 47%), anxiety (n = 123, 33%), depression (n = 124, 34%), ODD (n = 135, 37%) and ASD (n = 191, 50%). According to the Developmental and Well-being Assessment (Goodman, 1997), which was administered to children's primary caregivers in the form of a diagnostic interview, 36% (n = 153) of the sample met diagnostic criteria for ADHD, 24% (n = 100) met diagnostic criteria for ODD, 24% (n=107) met diagnostic criteria for an anxiety disorder, and 4% (n = 17) met criteria for depression. Despite showing substantial difficulties in school and prompting referral, not all children in the sample exceeded these diagnostic thresholds, highlighting the importance of using a dimensional approach to study the processes associated with emerging symptoms.

Sample sizes vary between each Chapter because different inclusion criteria were used, and data collection in the NDAU continued throughout the undertaking of this research (after each Chapter was written).

1.8.2 Role and Responsibilities

My responsibilities as a PhD student included deciding the area of research to focus on, the rationale, the selection of tasks to use and the analyses to perform. I chose to conduct my PhD project on SR problems in children referred to the NDAU, looking at comorbidity and heterogeneity. Children in the sample were recruited from 2017 to 2022. I contributed to data collection because I carried out child assessments and interviewed caregivers in the NDAU from September 2019 until July 2023. Therefore, I administered the ‘cool’ and ‘hot’ EF assessments, verbal ability tasks and parent-reported measures, which are used in this thesis. I also contributed to data checking, data managing and data cleaning by supervising undergraduate placement students who were responsible for entering data into databases and into reports for schools, checking that the quality of the data was good by monitoring how engaged children were with these tasks throughout the sessions. I was involved in training new researchers (post-doctoral researchers, PhD students) who joined the NDAU and became child testers, as well as the undergraduate placement students who carried out some of the parent interviews. I will contribute further with publications of the main project aims. Finally, I was responsible for the data analysis, result interpretation, discussion and writing up of this thesis.

1.9 Thesis aims and objectives

SR difficulties are associated with a range of clinical disorders and may be useful in the identification of at-risk children and the tailoring of interventions. However, previous research has not yet considered how problems in the cognitive processes associated with SR manifest in pre-diagnosed children with emerging difficulties whilst also accounting for high heterogeneity in cognitive problems and co-occurring clinical symptoms.

The overarching objective of this thesis is to examine the role of SR processes in children referred from schools for varying cognitive, emotional and behavioural problems to (1) examine to what extent at-risk children exhibit problems in the cognitive processes that are important for SR (e.g., basic cognitive processes, cool and hot EFs), (2) investigate how these processes relate to specific disorder dimensions of ADHD, ASD, anxiety, ODD and depression, and (3) find out whether SR processes can be broken down into disorder-specific domains.

While Chapters 2, 3 and 4 will investigate these aims simultaneously and adopt a transdiagnostic and broad assessment approach, each Chapter will focus on a different set of executive functions and disorder-process associations.

Chapter 2 will examine how referred children perform on assessments of memory, cognitive inhibition, cognitive flexibility, visuomotor control and attention on the one hand, and associations between these processes and symptom severity of ADHD, ASD, ODD and anxiety, on the other, whilst controlling for co-occurring conditions. It is hypothesised that ADHD symptoms would be associated with cognitive inhibition, memory and visuomotor difficulties, whereas ASD will be associated with cognitive flexibility. Because limited research has examined how ODD and anxiety symptoms are independently associated with EF whilst controlling for ASD and ADHD symptoms, our examination of associations between these disorders and EF is exploratory.

Chapter 3 will investigate basic cognitive processes and response inhibition in children with emerging ADHD symptoms, unique associations between the core ADHD symptom dimensions of inattention and hyperactivity-impulsivity and specific cognitive processes, and whether anxiety moderates these associations. It is hypothesised that: the sample will show below-average performance on cognitive tasks relative to norms and standard scores; that inattention symptoms will be more strongly associated with poor cognitive function, except for response inhibition, relative to hyperactivity-impulsivity symptoms; and that anxiety will moderate relations between inattention and poor cognitive function by worsening working memory and improving response inhibition and attentional control.

Finally, in Chapter 4, we will expand our assessment measures to also include 'hot' EF tasks to measure the cognitive processes that are associated with behavioural and emotional regulation. This Chapter will examine to what extent children at-risk of cognitive, emotional and behavioural problems perform more poorly on 'hot' EF assessments than children with no problems. Furthermore, this Chapter will investigate the RDoC constructs extracted from cognitive control (cool EF) and decision-making (hot EF) tasks and how these constructs are dimensionally associated with the severity of ADHD, ODD, depression and anxiety while controlling for co-occurring symptoms. It is predicted that poor cognitive control will be associated with ADHD severity, that higher risk-seeking will be associated with ODD severity and greater loss sensitivity with depression severity.

The three empirical Chapters of this thesis are based on work which is currently under review (Chapter 4; under review in *European Child & Adolescent Psychiatry*), has already been published (Chapter 3; published in *Child Neuropsychology*) or is accepted a paper (Chapter 2; accepted for publication in *Cortex*). As a result, there may be some repetition in the Introductions or Discussion sections of the Chapters; however, the hypotheses, Methods and Results of each Chapter are unique.

Chapter 2. Dimensional associations between executive function processes and symptoms of ADHD, ASD, oppositional defiance and anxiety in young school-referred children[1]

2.1 Introduction

Neurodevelopmental disorders (NDDs), such as Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) affect approximately 7% and 1% of children worldwide, respectively (Polanczyk et al., 2007; Simonoff et al., 2008). ADHD is characterised by levels of inattention and/or hyperactivity and impulsivity that are developmentally inappropriate. ASD is associated with challenges in social communication and often with restricted / repetitive behaviour patterns (American Psychiatric Association, 2013). Both NDDs are associated with significant difficulties in cognitive and socioemotional functioning (Magiati et al., 2014; Rabiner et al., 2016b). Because symptoms and cognitive problems associated with NDDs typically develop early in life, research investigating these processes is important for the development of early interventions. In the current study, we adopted a transdiagnostic and dimensional approach to examine the role of executive function (EF) and memory problems in young children referred by schools for varying cognitive, emotional and behavioural difficulties with the aim of identifying unique associations between EF and memory processes and individual symptom dimensions.

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[1] The study described in this chapter has been published as an original article: Anning, K., Langley, K., Hobson, C., & van Goozen, S. (2023). Dimensional associations between executive function processes and symptoms of ADHD, ASD, oppositional defiance and anxiety in young school-referred children. *Cortex*. https://doi.org/10.1016/j.cortex.2023.06.005

EF comprises the cognitive processes that enable self-regulation and self-directed behaviour towards a goal (Welsh & Pennington, 1988). Subcomponents of EF include inhibitory control (interference control, response inhibition), cognitive flexibility (switching between mental sets), and working memory (retaining/manipulating information) (Diamond, 2013). Difficulties in using EF skills are associated not only with poorer academic performance but also with mental and physical health (Moffitt et al., 2011). Previous research has identified EF problems in children with ADHD and ASD. For example, it has been proposed that poor self-regulation and increased impulsivity in ADHD are attributable to problems with inhibitory control (Barkley, 1997; Wodka et al., 2007), whereas individuals with ASD have difficulty adapting to changing events because of problems with cognitive flexibility (Yeung et al., 2016). The assessment of specific EFs in young pre-diagnostic children should be useful for early detection and the development of interventions to reduce severity of EF difficulties and associated adverse psychosocial outcomes later in life (Glahn et al., 2014).

However, whilst some specific EF difficulties have traditionally been linked to ADHD or ASD, research has also found heterogeneity in prevalence and specificity of EF problems in both disorders (Demetriou et al., 2018; Kofler et al., 2019). For example, poor sustained attention and working memory can occur in ADHD without poor response inhibition (Willcutt et al., 2005); cognitive flexibility difficulties have been identified in ADHD (Coghill et al., 2014b); and response inhibition problems have been observed in ASD (O'Hearn et al., 2008). These findings challenge the notion that identifiable EF problems are central to the development of specific disorders (e.g., Barkley, 1997; Pennington & Ozonoff, 1996; Rapport et al., 2001).

One factor that might contribute to this inconsistency is that NDDs are highly comorbid. One third of children with ADHD show elevated ASD symptoms and 40-70% of children with ASD have comorbid ADHD (Grzadzinski et al., 2016). Because ASD is typically assessed and diagnosed via a separate pathway to ADHD and other mental health conditions, ADHD symptoms have been inconsistently controlled for in case-control studies that included children with an ASD diagnosis (Male et al., 2020). If ADHD is associated with poor memory and inhibition, studies that do not control for ADHD may thus overestimate the prevalence of EF difficulties in children with ASD.

ADHD is frequently comorbid with disruptive behaviour disorders such as ODD (26%; Mohammadi et al., 2021), whereas anxiety disorders are highly prevalent in ASD (40%; Simonoff et al., 2008). However, anxiety can occur in ADHD (e.g., 14%; Jensen et al., 2001) and ODD can occur in ASD (around 30%; Simonoff et al., 2008). Recent research has found that comorbidity increases the variation in EF skills associated with NDDs. For example, ODD was found to be independently associated with inhibition, attention and working memory difficulties, such that children with ADHD+ODD or ASD+ODD had more severe EF problems (Crawford et al., 2006; Griffith et al., 2019; Lawson et al., 2015).

Research has also found that comorbid anxiety may mitigate some EF problems by increasing cortical arousal and alertness (Arnsten, 2009), but can worsen performance on more complex EF tasks (e.g., Castagna et al., 2019; Lawson et al., 2015). Attentional Control Theory (ACT; Eysenck et al., 2007) tries to explain these mixed findings by proposing that the effects of anxiety are moderated by the working memory demands of the task, arguing that worry affects task performance by pre-empting some processing and storage capacity of the working memory system. As a result, anxiety is detrimental under conditions of high working memory demand. Previous studies have shown that children with ADHD+ASD are at increased risk of both comorbid anxiety and ODD, which may coincide with more severe

EF problems in a cumulative way (i.e., children with more comorbidities will have poorer EF abilities; Cooper et al., 2014; Haywood et al., 2021).

Because of the potential for cumulative and counteracting EF mechanisms in children with varying comorbid diagnoses, commonly used case-control studies are unable to detect specific associations between EF and individual symptoms of NDDs, ODD and anxiety. Further, the presence of co-occurring symptomatology may also alter cognitive processes at a sub-threshold level (e.g., Carter Leno et al., 2018; de la Osa et al., 2019). The high co-occurrence between NDDs and additional clinical symptoms, as well as increasing evidence that clinical symptoms and co-occurring cognitive problems are dimensional traits which show no sudden change at the diagnostic boundary (Arildskov et al., 2022; Kim et al., 2019; Krueger et al., 2018), has encouraged the adoption of a transdiagnostic and dimensional approach in studying NDDs and EF in young children (e.g., Astle & Fletcher-Watson, 2020; Griffith et al., 2019; Landis et al., 2021; Neely et al., 2016). A shift in focus from disorder categories to dimensional measures of important domains of functioning aligns with the Research Domain Criteria (RDoC) initiative, launched by the National Institute of Mental Health (NIMH), to help identify the underlying neuropsychological and biological mechanisms that are associated with clinical outcomes (Insel et al., 2010). In the study of EF, using an RDoC approach to assessment and analysis will enable us to dimensionally account for co-occurring subthreshold symptoms and disentangle specific associations between EF processes and symptoms of NDDs, anxiety and ODD.

Previous research that has adopted a dimensional approach has linked greater EF difficulties to increased severity of ADHD symptom expression (Castellanos et al., 2006). Specifically, poorer memory and inhibition have been found to be correlated with greater inattention severity (Castagna et al., 2019). However, other studies found that ADHD symptoms showed no associations with more complex EF processes, such as cognitive flexibility (Coghill et al., 2014a). This suggests that associations between EF and symptoms of ADHD might be domain specific. In addition, longitudinal studies have found that improvements in visuospatial memory are linked to reductions in ADHD symptoms (Karalunas et al., 2017), suggesting that it is important to consider cognitive processes that are linked to performance on EF tasks, such visuospatial memory, to improve our understanding of areas of cognitive difficulty linked to symptoms of this disorder.

In the ASD literature, studies have found associations between cognitive flexibility problems and both socio-communication symptoms and restrictive and repetitive behaviour (Hill & Bird, 2006; South et al., 2007), but results on associations with performance on other EF tasks are inconsistent (e.g., Cantio et al., 2016; Geurts et al., 2014; Iversen & Lewis, 2021). For example, correlations between ASD symptoms and performance on inhibition tasks have been found by some (e.g., Van Eylen et al., 2015), but not others (e.g., Happé et al., 2006). This inconsistency in findings may indicate that EF problems in ASD are specifically linked to higher-level cognitive problems, such as theory of mind (switching perspectives), rather than ASD symptom expression directly (Jones et al., 2018). There is also some evidence to suggest that individuals with ‘pure’ ASD without intellectual disability (IQ > = 70) may exhibit strengths in some EFs (inhibition, memory) but difficulties in others (cognitive inflexibility, poor planning; Lopez et al., 2005). Therefore, further research is needed to clarify the role of EF strengths and difficulties in ASD, while controlling for co-occurring symptoms of other disorders associated with cognitive problems, such as ADHD.

Most research studies examining associations between EF and symptoms of NDDs have used clinically diagnosed children, with the result that we currently have limited knowledge of how EF difficulties and symptoms emerge in young children who have not yet been diagnosed. Furthermore, many children who have NDD symptoms, but who do not reach the threshold for a diagnostic label, struggle in classroom environments, are at risk of developing additional emotional and behavioural difficulties and perform at below age-expected levels on assessments of EF (e.g., de la Osa et al., 2019; Holmes et al., 2014). Further research using community samples of children, identified by teachers as struggling at school, is therefore needed to improve our understanding of the cognitive difficulties and symptoms exhibited in this group. In combination with dimensional analyses to investigate how specific EF processes are associated with measures of NDD, ODD and anxiety symptoms, this transdiagnostic and broad assessment approach should be useful in helping schools to direct and tailor their support for a wider population of children who would benefit from early intervention, and by reducing the need for children to have a diagnosis in order to receive support (Department of Health and Social Care and Department for Education, 2017).

The current study aimed to investigate (1) the mental health difficulties and cognitive problems in young pre-diagnostic children who were referred to a university-based neurodevelopment assessment unit because of school-based cognitive, emotional and behavioural problems, and (2) associations between dimensional measures of NDDs and their comorbid conditions and specific executive function processes. When controlling for co-occurring symptom dimensions, we hypothesised that ADHD symptoms would be associated with cognitive inhibition, memory and visuomotor difficulties, and that ASD symptoms would be associated with poorer cognitive flexibility. Because limited research has examined how ODD and anxiety symptoms are independently associated with EF, our examination of associations between these disorders and EF, whilst controlling for ASD and ADHD symptoms, was of an exploratory nature.

2.2 Method

2.2.1 Participants

The participants were 438 children (aged 4-8, mean age = 6.31, 313 boys, 125 girls) who were referred to Cardiff University's Neurodevelopment Assessment Unit (NDAU) (https://www.cardiff.ac.uk/neurodevelopment-assessment-unit) by classroom teachers or Special Educational Needs Co-ordinators (SENCOs). Schools in South Wales can refer children for an assessment to the NDAU if they demonstrate problems in one or more of the following areas: attention, behaviour, emotion, communication/social interaction, memory, and self-regulation, and if they have not yet received a diagnosis. The classroom teachers or SENCOs complete an expression of interest form, which includes information on the child's presenting needs, school-based assessment data and any external agency involvement.

2.2.2 Background Information

Parents provided child and family background information by completing questionnaires. This included details such as household income and ethnic background. Children in the study sample were 85% White British (15% other race/ethnicity; including 5% not specified, 3% British/European, 1% British/Caribbean), which is broadly representative of the population in England and Wales (Coates, 2021). Over a third of children came from families living in poverty, with an income of below £20,000 per annum.

2.2.3 Measures

2.2.3.1 Emotional and behavioural problems

As part of the referral process, teachers/SENCOs completed the Strengths and Difficulties Questionnaire (SDQ), which is a validated and widely used measure of behaviour, to dimensionally measure and screen for mental health problems in children aged 2-17 (Goodman, 1997, 1999). There are five subscales: emotional symptoms, conduct problems, hyperactivity, peer problems and prosocial behaviour, assessed through 25 items scored on a 3-point Likert scale (not true, somewhat true, or certainly true). In the case of missing scores, scale means were calculated from the remaining valid items for each individual subscale. Each scale has categorisation bands which were used to examine the mental health problems in the sample, and to identify children with raised emotional/behaviour issues. These bandings were based on a large UK community sample (Green et al., 2005). For all subscales except for prosocial problems, higher scores indicate more severe difficulties, whereas for the prosocial problems scale lower scores indicate greater difficulties (i.e., low prosocial behaviour). When we examined the prevalence of mental health problems in the sample, prosocial scores were reversed so that higher scores indicated greater prosocial difficulties. The ‘slightly raised’, ‘high’ or ‘very high’ subscale categorisation bands were collapsed into a ‘Moderate to High Risk’ group (n = 405; boys = 297, girls = 108, mean age = 6.28, SD =1.09) (Murphy & Risser, 2022). The majority of children in this group (n = 366, 90%) scored in the ‘high’ or ‘very high’ range for at-least one subscale. Despite being referred to the NDAU for an assessment, a small proportion of children (n = 49; 10%) had a ‘Close to Average’ classification on all subscales (hereafter referred to as 'Low Risk') (n = 33, boys = 16, girls = 17, mean age = 6.60, SD = 1.07). We included all children in our dimensional analyses (correlations, regressions) because we wanted to capture the full spectrum of EF and disorder symptomatology; these inclusion criteria were established prior to data analysis.

2.2.3.2 Symptoms of ADHD, ODD and anxiety

The Child Behaviour Checklist (Achenbach et al., 2003) was used to assess symptoms of ADHD, ODD and Anxiety. Both the preschool (1.5-5) and child (6-18) versions were used, to accommodate the age range of the sample. The CBCL consists of a series of items that describe children’s behaviour. Parents rated each item on a 3-point scale ranging from – 0 (not true) to 2 (very true). Raw scores were converted to standardised T scores, based on the child’s age and sex. The reliability and validity of the CBCL has been demonstrated in many studies (e.g., Nakamura et al., 2009). The subscales used in the current study were the anxiety scale, oppositional defiance scale, and the attention problems scale. We focused on anxiety and ODD as these disorders have been found to most frequently co-occur with ASD and ADHD in children of this age (Biederman et al., 2007; Salazar et al., 2015). The attention problems scale was used to assess ADHD symptoms (as opposed to the specific DSM-5 scales), because this scale has been shown to be the more accurate at identifying children with ADHD (Schmeck et al., 2001; Spencer et al., 2018). T scores were used as dimensional measures of symptom severity, where scores of > 69 are classified as clinically relevant (Achenbach & Rescorla, 2001).

2.2.3.3 Autism Spectrum Disorder (ASD) Symptoms

To measure autistic symptoms, the child's version of the Autism Spectrum Quotient (AQ-Child; Auyeung et al., 2008) was used. This 50-item measure assesses social-communication, as well as repetitive, stereotyped behaviour symptoms. Parents rate each item on a 4-point scale (definitely disagree, slightly disagree, slightly agree, definitely agree), which is summed to create a dimensional measure of autism traits. In the case of missing scores, means were calculated from the remaining valid items in each subscale (social skills, attention switching, attention to detail, communication, imagination) before the total AQ score was computed. Previous studies have validated the AQ as a highly sensitive and specific screening tool using a cut-off of 76 (Auyeung et al., 2008).

2.2.3.4 Executive function

The NIH Toolbox (Akshoomoff et al., 2014) taps key functions in the cognitive domain, including important executive function processes. In the current study, we utilised the tasks which assess cognitive flexibility, cognitive inhibition, and episodic memory. All tasks were administered on a tablet. Each test includes of practice blocks which children must successfully pass to proceed to the test blocks. The NIH Toolbox software produces raw, computed, uncorrected- and age-corrected standardised scores for each assessment. Age-corrected scores are calculated using the child's raw score and their age band, broken down into one year, and are comparable to normative data from over 2500 participants. We used these standardised scores to establish the proportion of children in the sample with age standardised scores in the 'below average' range; at-least 1 SD below the norm mean (standardised mean = 100, SD = 15). Computed scores were used in all other data analyses, and we controlled for age (in months) in all regression models.

2.2.3.5 Cognitive flexibility

Cognitive flexibility was assessed using the Dimensional Change Card Sort (DCCS). During the task, children are shown pictorial stimuli on the screen and are instructed to match the central test stimuli with one of two stimuli on the basis of either shape or colour. Computed scores reflect combined accuracy and response time, which are calculated using a 2-vector scoring method (see Akshoomoff et al., 2014 for more details).

2.2.3.6 Cognitive inhibition

The NIH toolbox version of the Flanker task asks children to match a target stimuli while inhibiting attention to its flanking stimuli. Children below the age of 8 were shown fish stimuli, whereas children aged 8 were shown arrows. Cognitive inhibition is required to ignore the surrounding stimuli and focus on the central stimuli on incongruent trials - where the target stimuli points in the opposite direction to the surrounding flanks. Computed scores reflect the response times and accuracy of performance and are calculated using a two-vector scoring method.

2.2.3.7 Visuomotor control

The ANT-Pursuit task taken from the Amsterdam Neuropsychological Tasks (ANT; De Sonneville, 1999) requires the participant to use a mouse cursor to track a moving target for 60 seconds. The total mean distance from the target, and the within-subject variability of the mean distance are used as dependent measures for the accuracy and stability of movement, respectively. The ANT software converts raw test scores into Z-scores using a nonlinear regression function derived from data of 2340 typical controls (De Sonneville, 2014). A higher Z-score of above 1 reflects greater distance from the target and indicates below average performance (1 SD below the mean) whereas a score below -1 indicates a more accurate and above average performance (1 SD above the mean). Although a visuomotor task, the ANT-Pursuit also requires a high level of attentional control and monitoring of movement, because the trajectory of the target is unpredictable and the required movements are always new (Huijbregts et al., 2003).

2.2.3.8 Other cognitive processes influencing executive function

Episodic memory

Episodic memory helps individuals to maintain goals and follow task rules. We examined episodic memory in our sample of referred children with the aim to establish whether this process was associated with disorder symptom severity. Visuospatial episodic memory was assessed using the Picture Sequence Memory task (PSM). During the PSM, children are presented with a series of objects and activities. Children must remember the specific order of the sequence and then reproduce this by touching each of the pictures on the iPad and placing them in the correct order. The participant’s score is derived from the cumulative number of adjacent pairs of pictures correctly recalled over two test trials, where computed scores represent the outcome of an item response theory calculation.

Verbal IQ

Verbal IQ was assessed using the Lucid Ability test (Version 5.15; GL Assessment, 2014) because aspects of language processing may affect the ability to conceptualise tasks and follow directions (Norbury et al., 2010). In children aged 4-6 years, a picture vocabulary task is used; older children aged 7-16 complete a conceptual similarities task. A standardised score is calculated based on the child’s age (mean average = 100, SD = 15). Age-standardised scores were used in data analyses including regression analyses to ensure relations between symptom scores and EF were independent of co-varying relations with verbal IQ (e.g., Hughes & Ensor, 2008).

2.2.4 Procedure

Children participating in the study visited the NDAU with a parent (usually the mother) or caregiver for two 3 hour sessions. Children completed executive function, memory and verbal IQ tasks in a separate room with a trained researcher, whilst the child's parent completed questionnaires on child and family background, child mental health, ASD and ADHD. The cognitive assessments in the current study were administered in the following order: verbal IQ (LUCID), visuomotor control (ANT-ROO), episodic memory (picture sequence), cognitive flexibility (DCCS), cognitive inhibition (Flanker); these tasks were interspersed with other tasks to measure other domains of functioning (e.g., theory of mind, emotion recognition; see NDAU website for more information; https://www.cardiff.ac.uk/neurodevelopment-assessment-unit/refer-a-child/our-assessments). Informed consent was obtained from the child's caregiver before the assessment took place. All experimental procedures were approved by the relevant institutional ethics committee (EC.16.10.11.4592GR).

2.2.5 Data Analysis

Data analyses were conducted using IBM SPSS Statistical version 27. All variables were normally distributed except for performance on the ANT-Pursuit. Therefore, where this variable was concerned, non-parametric tests were additionally conducted to confirm results. T-tests and correlations were conducted to assess whether age, sex and verbal IQ were associated with performance on cognitive tasks and symptom severity scores, and needed to be controlled for. We examined correlations between variables to ensure that the assumption of no multicollinearity was met in regression analyses.

To capture the mental health difficulties associated with being referred to the NDAU and to better understand the overlap between them, the SDQ categorisation bands were used to establish the type of difficulties that children were referred for, and whether these occurred independently or showed morbidity with other problems. We looked at the prevalence of children with scores which fell into the 'slightly raised', 'high' or 'very high' range within and across subscale problem areas. Subsequently, we looked at the prevalence of specific neurodevelopmental disorders using the CBCL and AQ cut-offs.

To examine type and extent of EF problems in our sample we used age-standardised scores from the NIH Toolbox and ANT-Pursuit to look at the proportion of children who scored 1 SD below the average.

We used correlation and regression analyses to examine dimensional associations between parent-rated symptoms of ADHD, ASD, ODD, anxiety, EF, and memory, and conducted a series of regression models to examine how individual cognitive processes predicted pure symptoms of each disorder. In each model, the symptom dimension being examined (e.g., ADHD) was entered as the dependent variable. Age (in months), sex and verbal IQ were entered in Step 1; the other symptom dimensions were controlled for and entered in Step 2. EF variables and episodic memory scores were entered in Step 3.

2.3 Results

2.3.1 Missing values

Some children did not have a full set of EF data because they refused to do certain tasks, were not engaged, or did not follow the instructions. We examined whether children with some missing task data (n = 174) differed in symptom severity, age, sex or verbal IQ scores from children who completed all EF tasks. There were no differences on any of these variables except for age; children who had missing data on at-least one task were younger ($t(436) = 3.463$, $p < .001$).

2.3.2 Preliminary analysis

We examined associations between potential covariates (age, sex, verbal IQ) and symptom scores and EF variables. Verbal IQ was positively associated with performance on the DCCS and the Flanker. Girls performed better on the DCCS $t(337) = -2.344$, $p = .020$. Age was positively correlated with performance on all EF tasks as well as with severity of ADHD and anxiety symptoms. Girls were rated as having fewer ASD symptoms, $t(353) = 2.516$, $p = .012$. Because age was associated with ADHD and EF performance, age was controlled for when examining correlational associations between ADHD, anxiety, and EF. Sex was controlled for when examining correlational associations between autism symptom severity and cognitive flexibility. Age, sex and verbal IQ were controlled in all regression analyses.

2.3.3 Prevalence and overlap of teacher-reported mental health problems (SDQ) in the sample

Table 2.1 shows the prevalence of teacher-reported problems; the most commonly reported problem was hyperactivity and inattention (86%), followed by prosocial problems (73%), peer problems (68%), conduct problems (61%) and emotional problems (43%). These difficulties rarely occurred independently; children who had moderate to high risk scores in one category (‘slightly raised’, ‘high’ or ‘very high’) demonstrated moderate to high risk scores in three other areas, on average (median = 3, range = 0 - 4). Figure 2.1 illustrates the overlap in problems that teachers reported. The proportion of children with ‘pure’ problems (only showing raised scores in one category) was very low (1-7% for each problem subscale), particularly for conduct problems (< 1% of children with raised conduct problems had scores in the ‘close to average’ range for every other subscale).

Table 2.1.

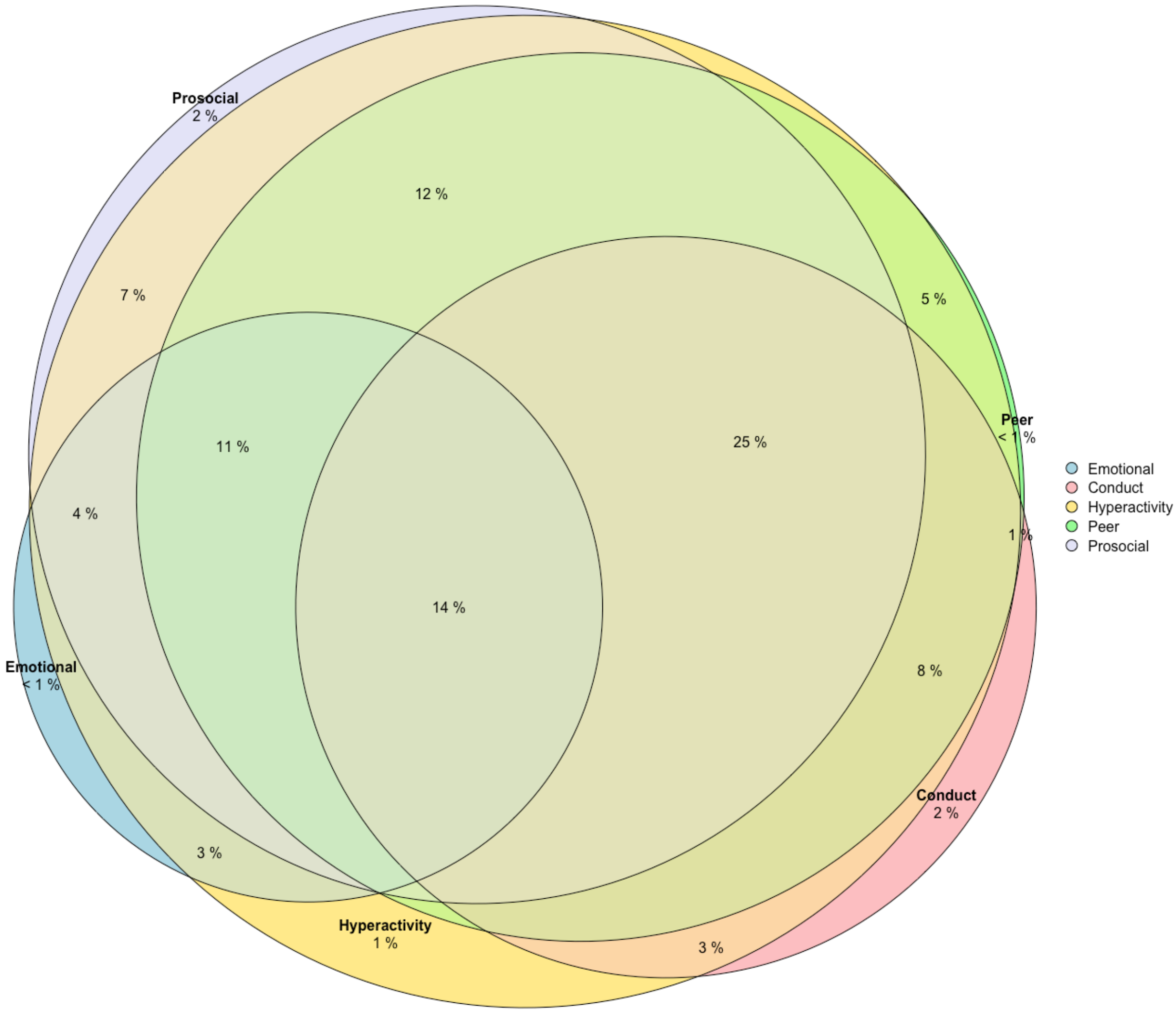
Prevalence of teacher reported SDQ problems in children with a moderate to high SDQ score (n = 405).

SDQ subscale	N (%) with moderate to high difficulties in each problem domain[a]	N (%) of children with a raised score in an additional area, within each subscale group[b]					
		No raised score in other category	Emotional	Conduct	Hyperactivity	Peer	Prosocial
Emotional problems	172 (43)	10 (6)		110 (64)	136 (79)	129 (75)	120 (70)
Conduct problems	248 (61)	2 (<1)	110 (44)		231 (93)	198 (80)	213 (86)
Hyperactivity problems	347 (86)	24 (7)	136 (39)	231 (67)		245 (71)	269 (78)
Peer problems	277 (68)	6 (2)	129 (47)	198 (72)	245 (88)		222 (80)
Prosocial behaviour	294 (73)	6 (2)	120 (41)	213 (72)	269 (92)	222 (76)	

Note. [a] Moderate to high SDQ scores included those in the ‘slightly raised’, ‘high’ or ‘very high’ categorisation bands. [b] Comorbidity was defined as having a score in the ‘slightly raised’, ‘high’ or ‘very high’ categorisation band in more than one SDQ problem domain (Green et al., 2005). For the prosocial SDQ scale a higher score reflects more prosocial behaviour, thus these were reversed. Therefore, for all subscales ‘slightly raised’, ‘high’ or ‘very high’ indicates more difficulty.

Figure 2.1.

Overlap in raised SDQ problems reported by teachers in children with moderate-high problems in at-least one domain (n = 405)



2.3.4 Prevalence and overlap of NDD symptoms in children identified by teachers as showing moderate to high emotional and/or behavioural difficulties

Children who were identified by teachers as being at moderate to high risk of emotional and/or behavioural difficulties (*n* = 405) had more NDD symptoms, with over half (n = 211, 52%) exceeding clinical cut-off scores on the questionnaires; ADHD (*n* = 56, 14%), ASD (*n* = 62, 15%) and ADHD+ASD (*n* = 93, 24%). ODD and Anxiety most frequently co-occurred with ADHD (ODD; n = 26, 6%) and ASD (Anxiety; n = 27, 7%), and rarely occurred independent of NDDs (2% and 4%, respectively). EF problems in the sample

2.3.4.1 EF difficulties in children with moderate to high risk of mental health problems

Table 2.2 shows how children in the moderate to high risk group performed on our range of EF measures. We examined the proportion of children in each group who showed below average EF and memory performance relative to age-standardised norms. Our sample demonstrated difficulties across cognitive domains, with the greatest prevalence of below average performance found for visuomotor control (55%). To examine which dimensions of symptom severity were specifically associated with these EF and memory difficulties, further analyses were conducted using a dimensional approach.

Table 2.2.

Prevalence of moderate to high risk (teacher SDQ) children who performed in the below average range on each EF assessment.

	n [a]	Mean computed score (SD)	Mean standard score (SD)	N (%) below average	N (%) within average range	N (%) above average
Episodic memory	353	406.28 (96.28)	96.96 (21.82)	89 (25)	196 (55)	71 (20)
Cognitive flexibility	339	3.46 (2.18)	92.72 (14.49)	95 (28)	230 (68)	13 (4)
Cognitive inhibition	330	4.27 (2.04)	91.08 (14.69)	94 (29)	228 (69)	8 (2)
Visuomotor control	298	2.96 (5.13)	2.96 (5.13)	164 (55)	122 (41)	12 (4)

Note. [a] = n varies by task because some children were not paying attention or refused to complete assessments, and standardised scores were not computed for some children because of a processing error. * $p < .05$, ** $p < .01$. Variances were not equal for analyses of cognitive inhibition and visuomotor control, so results of adjusted analyses are shown.

2.3.5 Dimensional associations between EF performance and disorder symptom severity scores

Table 2.3 shows the correlations between EF performance and symptom severity scores for the full sample of children (n = 438). ADHD symptoms were significantly negatively associated with episodic memory and cognitive inhibition; anxiety was significantly positively associated with cognitive flexibility and visuomotor control.

Table 2.3.

Bivariate Pearson correlations between symptom severity scores, executive function (EF) and memory assessments.

	1	2	3	4	5	6	7
1. ADHD							
2. ASD	.398**						
3. Anxiety	.235**	.538**					
4. ODD	.471**	.395**	.368**	--			
5. Episodic memory	[a]-.140**	.061	-.003	-.060	--		
6. Cognitive flexibility	[a]-.028	[b].084	.169**	-.076	.327**	--	
7. Cognitive inhibition	[a]-.122*	.075	.069	-.049	.409**	.462**	--
8. Visuomotor control	[a].004	-.066	-.132*	-.110	-.124*	-.238**	-.363**

Note. ADHD = Attention Deficit Hyperactivity Disorder. ASD = Autism Spectrum Disorder. ODD = Oppositional Defiant Disorder. [a] Correlations between ADHD/anxiety and EF reflect partial correlations controlling for age. [b] Partial correlation between AQ and cognitive flexibility controlling for sex. * $p < .05$, ** $p < .01$.

The different symptom severity scores were all significantly positively correlated (with r values ranging between .2 and .6, $p <. 001$), reflecting high co-occurrence between different symptoms dimensions in the sample. However, ODD was clearly more strongly associated with ADHD, whereas anxiety was more strongly associated with ASD.

Finally, multiple regression analyses examined to what extent different cognitive processes can predict severity of discrete clinical symptom dimensions (ADHD, ODD, ASD, Anxiety; see Table 2.4), whilst controlling for potential covariates (age, sex, verbal IQ), and the presence of other symptoms. Difficulties with episodic memory ($\Delta F(1,298) = 6.271$, p =

.013) and cognitive inhibition ($\Delta F(1,280) = 3.900$, $p = .049$) were significant predictors of ADHD symptoms. Severity of anxiety symptoms was predicted by better cognitive flexibility ($\Delta F(1,289) = 7.992$, $p = .005$), better cognitive inhibition predicted ASD severity ($\Delta F(1,280) = 4.402$, $p = .037$), and poorer cognitive flexibility predicted ODD severity ($\Delta F(1,289) = 7.006$, $p = .009$).

Table 2.4.

Summary of final step multiple regression analyses examining EF and memory assessments as predictors of disorder symptom severity, controlling for the presence of other symptoms, age, sex and verbal IQ.

EF variables	Symptom dimension				
	Statistic	ADHD	ASD	Anxiety	ODD
Episodic memory	ΔR^2	.013*	.004	.006	<.001
	ß	-.128*	.072	-.082	.001
Cognitive flexibility	ΔR^2	<.001	<.001	.018**	.016**
	ß	.007	.016	.154**	-.144**
Cognitive inhibition	ΔR^2	.009*	.009*	<.001	<.001
	ß	-.114*	.116*	-.019	-.022
Visuomotor control	ΔR^2	.003	<.001	.002	.008
	ß	.058	-.005	-.051	-.094

Note. ADHD = Attention Deficit Hyperactivity Disorder. ASD = Autism Spectrum Disorder. ODD = Oppositional Defiant Disorder. * $p < .05$, ** $p < .01$.

2.4 Discussion

This study examined specific associations between different executive function (EF) processes and symptoms of NDDs, anxiety and ODD, in young children referred by their teachers for a range of cognitive and socio-emotional problems. We examined the proportion of children scoring in the below-average range on EF and episodic memory assessments, and the extent to which these cognitive processes predict variation in symptoms of ASD, ADHD, ODD and anxiety.

Previous research using a categorical approach has shown that there is substantial heterogeneity in the nature and severity of EF difficulties within diagnostic groups, suggesting that claims of 'disorder-specific' problems in EF processes are oversimplified (Astle & Fletcher-Watson, 2020; Dajani et al., 2016). Adopting a dimensional approach and controlling for co-occurring symptomatology in a large sample of teacher-referred children, the current study found dimensional associations between different cognitive processes and symptoms of specific disorders, showing that the assessment of diverse cognitive processes can help to identify and understand specific symptoms. In line with our predictions, we found that when controlling for co-occurring symptom dimensions, ADHD symptoms were associated with poorer cognitive inhibition and memory; however, we found no association between ASD traits and poorer cognitive flexibility.

2.4.1 EF, Memory and ADHD

ADHD symptoms were specifically associated with poorer performance on assessments of episodic memory and cognitive inhibition, in line with our hypotheses and previous research linking EF and memory problems to more severe symptoms of inattention in children with ADHD (e.g., Karalunas et al., 2017). Although a high proportion of children in our sample (55%) showed poor visuomotor control, this was not dimensionally associated with ADHD symptom severity, suggesting that problems with visuomotor control are not independently associated with symptoms of ADHD. However, because the majority of our sample (86%) was reported to have elevated ('slightly raised', 'high', or 'very high') hyperactivity problems, and over half the sample showed difficulty on the visuomotor task (55%), the limited variation on these two measures may have prevented detection of a relationship. Alternatively, poor visuomotor control may reflect a transdiagnostic process associated with multiple neurodevelopmental difficulties and additional clinical symptoms, rather than ADHD specifically.

2.4.2 EF and ODD

We found that cognitive flexibility was uniquely negatively associated with severity of ODD symptoms. Evidence of EF difficulty in disruptive behaviours is mixed (Schoemaker et al., 2013; van Goozen et al., 2022), and most studies in older children with ODD that controlled for ADHD found no relationship with poor cognitive flexibility (e.g., Hobson et al., 2011). Previous studies have found that parents report more defiance in older children and more negative affective symptoms in younger children (i.e., irritability, anger; Leadbeater & Homel, 2015). Negative affect is more strongly associated with EF than defiance (Griffith et al., 2019), and the regulation of negative emotions involves cognitive flexibility (Davis et al., 2010). Because our study involved a young, pre-diagnostic sample, the findings suggest that poor cognitive flexibility is associated with developing symptoms of ODD, especially the type of symptoms that occur in young children. Some have argued that ODD can be conceptualised as an emotional regulation disorder rather than a disruptive behaviour disorder (Cavanagh et al., 2017). Therefore, poor cognitive flexibility may be a transdiagnostic risk factor for emotion regulation difficulties (e.g., tantrums, reactive and impulsive aggression), which are common in children with ADHD, ODD and ASD, as opposed to more proactive and deliberate antisocial behaviour (England-Mason, 2020).

2.4.3 EF and ASD

Previous research has indicated that cognitive flexibility is the most commonly identified EF problem in individuals with ASD (Leung & Zakzanis, 2014); it is also linked to disorder-specific symptoms (Hill & Bird, 2006; South et al., 2007) and challenges (e.g., theory of mind; Jones et al., 2018). However, we did not find the predicted a negative association between ASD traits and cognitive flexibility performance, which suggests that difficulties with cognitive flexibility may be associated with expressed symptoms of co-occurring ODD, such as negative affect, rather than socio-communication challenges and restricted repetitive behaviour. However, there are some alternative explanations for the absence of the predicted relationship between ASD and cognitive flexibility, which we will now consider.

First, our assessment of ASD symptoms included both socio-communication and restricted repetitive behaviour difficulties. If difficulties with the cognitive flexibility are specifically related to restricted repetitive behaviours (Schmitt et al., 2019), this may have dampened any associations between our ASD symptom scores and performance on the cognitive flexibility task. Research using specific assessments of ASD dimensions may be helpful in revealing a possible relationship. Second, the children in our sample were referred from mainstream schools and are therefore less likely to represent those with lower IQ and more severe EF problems (Charman et al., 2011). Third, it may be that EF in everyday life situations, where social demands are higher, is associated with ASD traits as opposed to EF performance assessed using lab-based tasks (Albein-Urios et al., 2018); this would explain why most studies using self-report questionnaires or ecologically adapted tasks (e.g., Hill & Bird, 2006) observed these associations and reported larger effect sizes than studies using performance-based measures (Demetriou et al., 2018; Geurts et al., 2009; Kenworthy et al., 2008; White, 2013).

Although most research examining EF in ASD has focused on EF difficulties, some studies have found that a more complex model including both strengths and difficulties is better able to account for variation in symptoms. For example, Lopez et al. (2005) found that restricted, repetitive behaviour was best explained by a model consisting of strengths in working memory and inhibition, and difficulties with cognitive flexibility, planning and fluency. ASD is also associated with better performance on tasks involving visuospatial skills such as discrimination and visual search (Kuschner et al., 2009). Therefore, under the controlled conditions of our study, specific strengths associated with ASD – visuospatial abilities, attention to detail – may have helped our children to discriminate between target and flanking stimuli and to inhibit incorrect responses.

ASD often co-occurs with externalising disorders, such as ADHD and ODD (Grzadzinski et al., 2016; Simonoff et al., 2008) and previous research has shown that even sub-threshold externalising symptoms are associated with poor EF performance (e.g., Carter Leno et al., 2018; de la Osa et al., 2019). Although previous studies excluded children with comorbidities (e.g., ASD+ADHD; Van Eylen et al., 2015), sub-threshold symptoms might nevertheless moderate associations between EF and ASD symptoms when they are not controlled for. Using a dimensional approach to examine EF and different clinical symptoms, we found that cognitive flexibility and inhibition difficulties were better able to explain co-occurring ODD or ADHD symptoms in ASD, rather than socio-communication or restrictive repetitive behaviour. Using longitudinal data, Ameis et al. (2022) found that EF mediated associations between early childhood ASD symptoms and adolescent externalising but not internalising symptoms, suggesting that the presence of EF difficulties in ASD is associated with sub-threshold attentional difficulties and externalising behaviours (e.g., Brunsdon & Happé, 2014). Therefore, while most models of psychopathology suggest that greater comorbidities coincides with more severe EF problems (e.g., Caspi et al., 2014), our findings suggest that co-occurrence of ASD and ADHD may be associated with fewer inhibition problems. If ASD is indeed associated with specific strengths in visuospatial ability and greater attention to detail, presence of ASD traits may compensate for some attentional difficulties and distractibility associated with cognitive inhibition problems in children with ADHD.

2.4.4 EF and Anxiety

While some studies found that anxiety is associated with poorer cognitive flexibility (e.g., Godoy et al., 2021), we found a positive association between anxiety and performance on the cognitive flexibility task. This finding is broadly in line with research demonstrating that comorbid anxiety may reduce some EF difficulties in young children with ADHD symptoms by enhancing stimulus-focused attention, which compensates for the under-arousal associated with ADHD symptoms (Arnsten, 2009). We found no associations between anxiety and other EF processes. These discrepancies may reflect the age of our sample: in contrast to NDDs, anxiety disorders typically emerge later in development, and are most likely to be expressed as fears about separation, as opposed to generalised or social anxiety disorder (Beesdo et al., 2009). Our non-specific assessment of anxiety may therefore reflect milder symptoms, which could be somewhat beneficial at this level of EF performance. Few of our children (6%) were referred by their teachers for "pure" emotional problems and most who exhibited anxiety symptoms had difficulties in other areas (including ASD, ADHD), so our study may well have been underpowered to detect associations between "pure" anxiety and EF. Finally, any effect of anxiety on cognitive functioning may become more prominent when a task involves multiple EF processes working simultaneously, placing greater demands on working memory systems (Eysenck et al., 2007).

2.4.5 Implications

We found that children identified by teachers as showing moderate to high risk of mental health difficulties showed high levels of ADHD and ASD symptoms, and heterogeneous types of EF problems. This shows that designing and delivering interventions should be tailored to the specific problems and needs of the individual child (van Goozen et al., 2022). Currently, non-pharmacological school-based interventions for NDDs like ADHD have limited transfer effects to clinical symptoms (e.g., inattentiveness; Cortese et al., 2015). Most school-based interventions are complex and target multiple components, regardless of individual child's strengths and difficulties (Richardson et al., 2015). This lack of personalisation is also reflected in research studies of interventions; limited attention is given to the individual's neuropsychological profile before intervention, focusing instead on diagnostic status (Rapport et al., 2013). Our study indicates that children's needs and difficulties are complex and heterogeneous and that an individualised approach to assessment involving multiple symptom dimensions and EF processes is needed before tailored interventions to address these difficulties can be offered. In terms of classroom interventions, a good example of this approach is the ADHD Flex Toolkit (Russell et al., 2023); here, strategies are tailored to individual children with traits of ADHD, irrespective of diagnosis, based on their needs and abilities. Future research that adopts a personalised needs-focused and early intervention approach may be in a better position to develop a wider range of cognitive training programs to target specific EF problems and to deliver more effective strategies to support a wide range of children at school.

We also found that some EF problems were more widespread than others. Over half of the children in our full sample showed below average performance in visuomotor control (ANT-Pursuit task; Huijbregts et al., 2003). This suggests that visuomotor control places a demand on general executive processes and is implicated in multiple disorders. In addition to visuomotor control, the ANT-Pursuit task also requires a high level of attentional control and processing. Given the importance of attention in the development of cognitive skills and our finding that a high proportion of our sample scored in the below-average range on this task, children showing signs of ADHD, ASD and comorbid conditions may benefit from interventions specifically designed to target attention and motor problems using attention-directing and visuomotor control strategies (e.g., Nekar et al., 2022; Pauli-Pott et al., 2021). The close coupling of motor, cognitive and attentional processes further indicates that targeting these skills might have downstream benefits for other higher order cognitive processes that are associated with difficulties in inhibition and self-control in ADHD (Stöckel & Hughes, 2016) and in theory of mind in ASD (Jones et al., 2018). By examining a range of EFs in young children with symptoms of ASD and ADHD, the current study shows how EF assessment could be used in clinical practice to identify and target underlying cognitive problems. Furthermore, because young children show more plasticity in EF-related neural systems than older children, training EF skills in younger samples at risk of cognitive and/or socio-emotional problems may therefore be more effective than waiting until problems have become severe enough for children to receive a clinical diagnosis (van Goozen et al., 2022; Zelazo & Carlson, 2012).

2.4.6 Strengths and Limitations

A strength of the current study was the recruitment of children with emerging mental health difficulties from the community through educational professionals, which means that our sample is more representative of the children who raise concern in classroom teachers than volunteer sampling (e.g., via parents).

Turning to limitations, the current study did not examine how some clinical dimensions might moderate associations between NDD symptoms and EF. Previous research has indicated that comorbid additional clinical symptoms are associated with more severe cognitive problems, as is the case when attention problems are combined with emotional dysregulation and aggression symptoms (Blok et al., 2022). Because we found that ODD symptoms were independently associated with cognitive flexibility problems, our results suggests that ODD might strengthen the ADHD - EF association. However, while ODD may exacerbate EF difficulties in NDDs, the opposite may be true for anxiety, which was associated with less difficulty. Therefore, although some comorbidities might have enhancing moderating effects because they are associated with greater executive dysfunction, anxiety symptoms may diminish specific EF difficulties in NDDs (e.g., Castagna et al., 2019); however, examining these complex interactive and potential counteracting EF mechanisms was beyond the scope of our study.

While the current study considered heterogeneity in symptoms across clinical categories, our measures did not discriminate between disorder-specific heterogeneity. Symptom dimensions can be broken down into more specific domains which may be differentially associated with EF difficulties (e.g., ADHD into inattention and hyperactivity – Castagna et al., 2019; ASD into social communication and restricted, repetitive behaviour – Schmitt et al., 2019). Future studies may want to discriminate between various components involved in the manifestations of different disorders to further understand sources of heterogeneity in profiles of EF problems.

Because we used a correlational design, we are unable to infer whether cognitive difficulties caused clinical symptoms, or vice versa. Indeed, there are limited conclusions that can be drawn regarding the causal relation between EF and NDDs (Astle & Fletcher-Watson, 2020; Pellicano, 2012), given that previous longitudinal research found no associations between NDD symptom improvement and change in EF processes (Coghill et al., 2014a), and given the substantial heterogeneity in the cognitive problems implicated in ASD and ADHD. Nevertheless, the current results support the existence of an association between performance on executive tasks and emerging clinical symptoms.

Another limitation is that we focussed on specific EF and did not examine the shared variance between the tasks attributable to general cognitive processes. Previous factor analytic studies (e.g., Akshoomoff et al., 2014; Willoughby et al., 2012) have demonstrated that in young children there is less differentiation between EF processes and other cognitive skills (e.g., episodic memory), and that EF has shared and separable factors (Miyake et al., 2000). Because IQ assessments measure aptitude and potential rather than specific processes and because previous research has demonstrated only weak relations between IQ and the neuropsychological tasks in the ANT (Cohen's d < .25; Brunnekreef et al., 2007), we did not consider it to be beneficial to include IQ as a covariate (Dennis et al., 2009). However, future research using bifactor models of EF (e.g., Bloemen et al., 2018), which identify shared and specific cognitive processes elicited by lab-based tasks, may help to establish how general cognitive processes and domain-specific EF-symptom associations are associated with NDD, ODD and anxiety symptoms. Because we found that ADHD symptoms were associated with both higher level (cognitive inhibition) and lower level cognitive processes (episodic memory), and given that there was a high prevalence of poor performance on the visuomotor control task in our sample, the possibility exists that ADHD symptoms are associated with general processes that contribute to performance on EF tasks (Coghill et al., 2014a), rather than with domain-specific EF processes. Conversely, associations between ODD and EF may uniquely and specifically relate to cognitive flexibility.

In line with studies examining rates of disruptive behaviour disorders, ASD and ADHD in primary school-aged children (Ogundele, 2018), we found that considerably more boys than girls were referred for an assessment (28% of the sample was female). Research indicates that girls are more likely than boys to mask symptoms and present with internalising behaviours (Dean et al., 2017; Levy et al., 2005). We also found that few children were referred for 'emotional' problems. It is therefore possible that the sex bias in our sample reflects higher rates of overt and externalising behaviours in boys, which are more easily recognised and less tolerated by educational practitioners, and increase the likelihood of referral for additional educational support (Dhuey & Lipscomb, 2010; Gaub & Carlson, 1997). However, because we found no sex difference in our EF assessments (with the exception of cognitive flexibility, on which girls performed better), the current study suggests that it is important to raise awareness of how cognitive difficulties manifest in girls with a range of mental health problems, because they are still at risk of EF problems and associated negative outcomes (e.g., poorer academic achievement; Diamond, 2013). Increasing teachers' recognition of how psychosocial difficulties and EF problems are exhibited in female pupils, and by using more routine administration of cognitive assessments in schools, could be beneficial in ensuring that girls with emerging needs are not overlooked.

2.4.7 Conclusions

The current study demonstrates that children with emerging neurodevelopmental problems identified by their classroom teachers show EF strengths and difficulties that are associated with NDDs and mental health symptoms. ADHD and ODD-type problems were among the most common reasons for a child to be referred, and these were associated with specific EF processes and memory problems. None of our EF performance measures were negatively correlated with ASD symptoms, suggesting that any relation between EF and ASD traits is not a direct one but may reflect subthreshold symptom levels of ADHD and ODD. Further research is needed to explore the underlying cognitive processes associated with ASD and anxiety, but our findings of relative EF strengths in children with elevated ASD or anxiety suggest that targeting the EF processes elicited by lab-based tasks is unlikely to alleviate the clinical symptoms associated with these disorders.

Our research highlights the importance of an integrated approach to diagnostic assessment to inform subsequent intervention. By assessing multiple EFs and different disorders, as well as using a dimensional approach to analysis, we were able to identify specific processes which are associated with developing symptoms of NDDs and other mental health problems in young children. Because of the complex and heterogeneous nature of these symptoms and their high comorbidity, this approach was more useful than a categorical examination of EF because we were able to control for sub-threshold symptom levels. Disentangling associations between EF and clinical symptoms should help to explain inconsistent findings from previous research and will also enhance our understanding of the processes associated with developing ASD, ADHD, anxiety and ODD in children.

Chapter 3. Inattention symptom severity and cognitive processes in children at risk of ADHD: The moderating role of separation anxiety[2]

3.1 Introduction

The findings of Chapter 2 demonstrated that the large proportion of children who raised concern in classroom teachers (86%) were referred for ADHD-related problems and that many children who were referred demonstrated below-average performance on EF tasks (25-55%). Chapter 3 will build on these findings by examining the role of within-disorder heterogeneity, separating the ADHD dimensions of 'inattention' and 'hyperactive-impulsivity', because these clusters of symptoms may be associated with distinct cognitive problems (de la Peña et al., 2020; Milich et al., 2001). Chapter 2 also demonstrated that anxiety may be associated with better performance on specific cognitive tasks, thus Chapter 3 will also examine the potential moderating role of anxiety in associations between ADHD symptoms and cognitive processes. Finally, in addition to looking at cool EFs, Chapter 3 will examine basic cognitive processes, such as inhibition response time variability, to build a more detailed picture of the cognitive regulation difficulties that may be associated with developing symptoms of ADHD (Butzbach et al., 2019).

Previous studies have demonstrated that children with ADHD exhibit difficulties in EF processes (e.g., 30-37% of children have memory problems [Coghill et al., 2014b]; 21-46% have response inhibition problems [Kofler et al., 2019]), which are associated with greater

[2] The study described in this chapter has been published as an original article: Anning, K. L., Langley, K., Hobson, C., De Sonneville, L., & Van Goozen, S. H. (2023). Inattention symptom severity and cognitive processes in children at risk of ADHD: The moderating role of separation anxiety. *Child Neuropsychology*. https://doi.org/10.1080/09297049.2023.2190964

severity of ADHD symptoms, and more problems in daily life such as controlling attention and staying on task in the classroom (Antonini et al., 2013; Karalunas et al., 2017). Weaker performance on measures EF is also observed in young children at risk of ADHD (Coghill & Sonuga-Barke, 2012; Kalff et al., 2003, 2005; Slaats-Willemse et al., 2007), who may benefit from early intervention in this domain (Gau & Shang, 2010). Furthermore, there is some evidence to suggest that training programs can improve these cognitive processes and even alleviate symptoms of ADHD (e.g., Kofler et al., 2020), although the evidence that cognitive training can reduce symptoms of the disorder is mixed (Cortese et al., 2015).

However, despite the consensus that EF problems are highly prevalent in children with symptoms of ADHD, there is substantial variation between studies with respect to the type and severity of cognitive problems found (e.g., Coghill et al., 2014b; Kofler et al., 2019; Willcutt et al., 2005). Individuals with ADHD also differ from typically developing children on measures of cognitive processes that are closely related to performance on EF tasks, such as episodic memory and RT variability (Alderson et al., 2015; Cai et al., 2019). In addition, because factor analytic studies (e.g., Akshoomoff et al., 2014) have shown that EF are less clearly differentiated and overlap with other cognitive skills in young children (e.g., 3- to 6-year-olds), it may be beneficial for research in pre-diagnosed samples not to limit assessments to EF in order to improve our understanding of the cognitive processes that may be associated with developing ADHD symptoms. A further issue is that the comorbidity of ADHD with other conditions influences the prevalence and type of cognitive problems observed (Castagna et al., 2019). To improve understanding and inform a more targeted approach to intervention, it is important to examine associations between different cognitive problems and ADHD symptoms, and to clarify the role of comorbid symptoms in children at risk.

Response inhibition, working memory, and sustaining attention, are the most studied and identified cognitive difficulties in ADHD (e.g., Kofler et al., 2019; Willcutt et al., 2005). Most studies identifying these cognitive problems have compared children with and without a diagnosis in middle childhood when diagnoses are more common. However, in order to identify children pre-diagnosis, who might benefit from pre-emptive interventions, it is worth examining whether young children with sub-threshold ADHD symptoms also exhibit difficulties in cognitive processes. Adopting a dimensional perspective to investigate these associations might be an effective way of identifying such children. Previous research using a dimensional perspective has shown that the ADHD symptom dimensions of inattention and hyperactivity-impulsivity may be differentially associated with cognitive processes (Kuntsi et al., 2014). Inattention has been found to be associated with specific problems in visuospatial memory, RT variability and response inhibition (Cai et al., 2019; Loo et al., 2009), whereas impulsivity/hyperactivity is associated with withholding prepotent responses (commission errors) on response inhibition tasks (Kuntsi et al., 2014). Thus different symptom clusters (predominantly inattentive, predominantly hyperactive, or a combination) might be associated with different profiles of cognitive problems, which could explain some of the inconsistencies observed in case-control studies. It is unclear whether similar associations can be observed in young children with emerging symptoms of ADHD.

Comorbidity is a key issue when examining cognitive problems in those with ADHD. Jensen et al. (2001) identified three clinical profiles in a large sample of children aged 7-10 with ADHD: ADHD with co-occurring anxiety and without any disruptive disorder; ADHD and disruptive disorders without anxiety; and ADHD with both anxiety and disruptive disorders, where "pure" ADHD was the exception rather than the rule. Because ADHD is most frequently comorbid with externalising symptoms of disruptive behaviour disorders

(Jensen et al., 2001; Larson et al., 2011), comorbid anxiety has received less attention, despite estimates of comorbidity being as high as 40% (MTA Cooperative Group, 1999).

Previous studies suggest that anxiety moderates the association between cognitive problems and ADHD. For some specific cognitive processes, anxiety may strengthen the relation between worse performance and inattention symptom severity, by disrupting the process of maintaining and rehearsing information, particularly on working memory tasks (Eysenck & Derakshan, 2011; Owens et al., 2012). Castagna et al. (2019) found increased symptoms of inattention in those with high levels of anxiety, and that these were associated with worse performance. There is also some evidence to suggest that anxiety reduces the prevalence of certain cognitive deficits, such as response inhibition. Anxiety may inhibit impulsive responding by increasing behavioural control and monitoring, resulting in fewer commission errors (Kuntsi et al., 2014; Newcorn et al., 2001; White et al., 2011; Yurtbaşı et al., 2018). There are also more general mechanisms via which anxiety may reduce cognitive deficits in ADHD, such as by increasing cortical arousal, stimulus-focused attention, or motivation to perform well on tasks (Arnsten, 2009; Vance et al., 2013; Vloet et al., 2010). Consistent with this, Ruf et al. (2017) showed that adolescents with ADHD and anxiety had faster RTs and less variability than an ADHD-alone group. Thus anxiety may have different moderating effects on associations between cognitive processes and ADHD.

Anxiety may enhance associations between ADHD symptoms and poorer working memory by increasing cognitive demand. Alternatively, if children with high anxiety show increased behavioural and/or attentional control, or have greater motivation not to fail, associations between ADHD symptomatology and performance on other cognitive tasks may be undetectable in children with raised anxiety levels. Understanding these moderations is crucial in developing early interventions for ADHD, where cognitive training may be broadly beneficial, but may need to be adjusted in the light of comorbidity.

The present study examined different cognitive processes in children with emerging ADHD symptoms. Our goal was to identify unique associations between symptom dimensions of ADHD and different cognitive processes, and to take into account the potential role of anxiety in moderating these relationships.

The sample consisted of young children (4-8 years) who had been referred by their schoolteachers for a range of emotional, cognitive and behavioural problems, including hyperactivity, impulsivity and inattention. Our analyses focused on the prevalence of cognitive problems in these children, on the associations between cognitive processes and ADHD symptom dimensions, and on the way in which anxiety moderated these associations. It was hypothesised: 1) that the sample would show below-average performance on assessments of cognitive processes, relative to norms and standard scores; 2) that inattention symptoms of ADHD would be more strongly associated with poor cognitive function, with the exception of response inhibition, relative to hyperactivity-impulsivity symptoms; and 3) that anxiety would moderate relations between inattention and poor cognitive functioning by worsening working memory and improving response inhibition and attentional control.

3.2 Method

3.2.1 Participants

The sample consisted of 116 children (girls = 37; aged 4-8, M = 6.15 years, SD = 1.00) who were referred to the Neurodevelopment Assessment Unit (https://www.cardiff.ac.uk/neurodevelopment-assessment-unit) at Cardiff University. The NDAU uses a transdiagnostic approach to research and intervention, and recruits children through schools based on neurodevelopmental difficulties or needs rather than conventional categorical classifications. To be considered at risk of ADHD and included in the sample the teacher-reported hyperactivity problem scores from the Strength and Difficulties Questionnaire (SDQ; Goodman, 1997) had to be slightly raised, high or very high (i.e., scores above 5). This 4-band classification has been validated in a large UK community sample (Green et al., 2005).

3.2.2 Background information

Parents provided child and family background information, including details of household income and ethnic background. One-third of the sample had a household income below £20,000 per annum, which is considered to be living in poverty according to the UK household income poverty definition (https://commonslibrary.parliament.uk/ research-briefings/sn07096/). A large proportion of the parents (47%) had no post-16 educational qualifications. The vast majority of the families identified as white British. Because early familial adversity and low socioeconomic status increase risk of ADHD (Russell et al., 2015), a relatively high proportion of financial difficulties may reflect underlying factors which have contributed to the development of ADHD in our sample.

3.2.3 Measures

3.2.3.1 ADHD Symptom Severity

Symptoms of child psychopathology were measured using the web-based form of the Developmental and Well-being Assessment (DAWBA) available at http://www.dawba.net (Goodman et al., 2000). This was administered to caregivers of each child as a structured interview by trained researchers. The DAWBA is a widely used, reliable and valid measure for assessing childhood psychiatric disorders (Aebi et al., 2012; Angold et al., 2012). Dimensional symptom severity scores were derived using an SPSS syntax, which utilised the clinical symptoms from the DAWBA questions which match DSM-5 criteria (symptoms, substantial difficulties in important areas of functioning) (APA, 2013). Symptoms of inattention and hyperactivity-impulsivity were taken from the attention and overactivity section of the DAWBA. The scoring system was based on whether the child was rated as showing the symptom: 'No more than others' (score = 0), or 'A lot more than others' (score = 1). There were 9 items for each dimension, resulting in a range of scores from 0-9.

3.2.3.2 Anxiety

The DAWBA was also used to assess anxiety, using responses to questions in sections relating to social anxiety, separation anxiety and generalised anxiety disorders. Dimensional scores for each anxiety disorder were produced based on whether children showed symptoms: 'No more than others' (score = 0), or 'A lot more than others' (score = 1). For separation, social and generalised anxiety, there were 10, 12 and 17 items, resulting in possible dimensional scores of 0-10, 0-12, 0-17, for each disorder, respectively. The presence of clinical anxiety (generalised, social, separation) was established using the DSM-5 diagnostic criteria, which assesses whether symptoms are present and associated with distress or substantial difficulties in important areas of functioning (e.g., education, social relationships). We used this to identify which anxiety disorder was most prevalent and associated with clinically significant functional difficulties in the sample, which informed subsequent analyses.

3.2.3.3 Working and Episodic Memory

Verbal working memory was assessed using the backwards digit assessment from the Automated Working Memory Assessment (AWMA; Alloway, 2007), a validated assessment battery administered via the computer. The child is required to immediately recall a sequence of spoken digits in the reverse order. The sequence of digits increases in length when the child has answered over 4 out of 6 sequences correctly. Some digit span tasks have been criticised for invoking short term, rather than working memory processes (e.g., Kofler et al., 2020; Rapport et al., 2008). However, previous studies have demonstrated that differences in the way in which the backwards digit is administered can facilitate the engagement of working memory by providing more opportunity for children to recall sequences of greater list length (Wells et al., 2018). Because the AWMA provides up to six trials at each list length and does not discontinue unless the child is unable to recall four correct trials at a particular block), the AWMA overcomes some of the limitations of standardised backwards-digit tasks, and is regarded as a robust assessment of verbal working memory (Conway et al., 2005). Age-corrected standardised scores were used in further analyses.

Children completed the Picture Sequence Memory (PSM) task from the NIH Toolbox Cognition Battery, which measures nonverbal episodic memory (Zelazo et al., 2013) on an electronic tablet. In the task, participants are shown sequences of objects and activities with corresponding audio-recorded phrases. They are asked to reproduce the sequence by touching each of the pictures on the touchscreen and placing them in the correct order. The software uses the number of adjacent pairs placed correctly to calculate computed scores and age-equivalent standardised scores. Computed scores represent the outcome of an item response theory calculation utilizing the number of correct adjacent pairings of pictures, and are not adjusted for age. Age-corrected standardised scores were used to examine the prevalence of below-average performance as used in previous studies (Paine et al., 2021). For more information on how scores are calculated, see the scoring and interpretation guide (National Institutes of Health, 2016).

3.2.3.4 Response Inhibition

Inhibition was measured using the Response Organisation Objects task taken from the Amsterdam Neuropsychological Tasks battery (ANT-ROO; De Sonneville, 1999). In Part 1, participants are presented with randomly generated red circles, which appear either side of a fixation cross. Participants have to click on the button which corresponds to the side on which the dot was presented. RTs (in ms) and errors are measured. In Part 2, participants are required to click the button which corresponds to the opposite side to the one on which a white circle is presented. The percentage of errors and mean reaction time in Part 2 were used as measures of response inhibition. Measures of performance in part 1 (mean response time, percentage of errors), were utilised as a measure of baseline performance (Ólafsdóttir et al., 2019), and were entered as covariates in moderation analyses of response time/accuracy. The ANT software also produces Z-scores based on the age of the participant, using a nonlinear regression function derived from data of 1640 typical controls (De Sonneville, 2014). These were used to indicate the prevalence of below-average inhibition (slow RT or high errors) in the current sample, compared to age-equivalent norms.

We also examined inconsistent and premature response style associated with ADHD (Rubia et al., 2007), utilising measures of premature responding and within-subject variability on the ANT tasks. Premature errors on Part 2 of the ANT-ROO were calculated (Hobson et al., 2011). Within-subject variability in reaction time was calculated as the coefficient of variability (CV) (standard deviation of RT/mean RT) on Part 2 of the task (Stuss et al., 2003; Vaurio et al., 2009).

3.2.3.5 Visuomotor and Attentional Control

The Pursuit task from the Amsterdam Neuropsychological Tasks (ANT) was used to measure executive motor control and attention. During the ANT-Pursuit, the child is asked to follow a randomly moving star around a screen for 5 minutes using a mouse cursor. Accuracy is calculated using the mean distance (mm) between the cursor and target. The ANT-Pursuit also requires a high level of attentional control to monitor movement, as the trajectory of the target is unpredictable and the required movements are always new (Huijbregts et al., 2003). To profile visuomotor and attentional control, raw test scores were converted into age-standardised Z-scores using a nonlinear regression function derived from the data of 2340 typical controls (De Sonneville, 2014). A higher Z-score reflects greater distance from the target and indicates below average performance. Within-subject variability on the Pursuit task was measured using the standard deviation of the distance scores over the first 60 seconds.

3.2.3.6 Sustained Attention

The ANT-Pursuit task is also a measure of sustained attention (Lambregts et al., 2018), because children are required to focus attention and remain vigilant over the 5-minute duration of the task. The difference between the mean distance (in mm) from the star in the first minute was subtracted from the mean in the last minute, with larger scores indicating worse sustained attention by showing a greater decrease in accuracy.

3.2.3.7 Vocabulary

To assess receptive vocabulary, the British Picture Vocabulary Scale (BPVS) was administered (Dunn et al., 1982). In each trial, children were presented with four pictures, and asked to select the picture which best goes with a word spoken by the researcher. Raw scores were used in data analyses to control for vocabulary. This task was not completed by 2 participants, meaning the final sample for this task was smaller (n = 114).

3.2.4 Procedure

Whilst the child completed the tasks, the parent/caregiver completed an interview and questionnaires in a separate room. Informed consent was obtained from the caregiver for each child before the assessment took place. All experimental procedures were approved by the relevant institutional ethics committee (EC.16.10.11.4592GR).

3.2.5 Data Analysis

All analyses were conducted using SPSS 26. Correlations and t-tests were used to examine whether age, sex and vocabulary were associated with dependent variables. The assumptions for parametric tests and multiple regression were assessed. Where age-standardised scores violated these assumptions (dependent variables were not normally distributed, data showed heteroskedasticity) and raw/computed scores were acceptable, raw/computed scores were used instead. As a result, for episodic memory (picture sequence memory) we used computed scores (both skewness and kurtosis <|1|, plots in SPSS revealed heteroskedasticity). For the inhibition task (ANT-ROO), standardised scores were more skewed than raw scores, and showed heteroskedasticity, so square root transformations were applied to raw scores to reduce skew (baseline and inhibition errors, response times). Transformations for measures of visuomotor control and sustained attention (ANT-Pursuit) failed to reduce skew, so were not used. Therefore, we used age-standardised scores and carried out non-parametric equivalent tests (Spearman's Rho) to confirm correlational associations.

Data analyses were split into three parts to examine 1) the proportion of children at risk of ADHD who showed below-average cognitive functioning, 2) associations between cognitive processes and ADHD symptom dimensions, and 3) interactions between anxiety and ADHD symptom severity as predictors of performance on cognitive tasks. The total valid N for data analysis was 114 (i.e., the number of children who completed all cognitive tasks and the vocabulary assessment). To profile the sample's performance on assessments of working and episodic memory, we used age-corrected standard scores, for which the normative mean is 100 and standard deviation is 15 (Alloway, 2007; Zelazo et al., 2013). A score between 85 and 115 indicates that a child's performance is within 1 SD above or below the national average compared with like-aged participants. Scores of below 85 and above 115 indicate below or above average performance, respectively. To profile performance on the ANT tasks, we used norm values produced by the software (De Sonneville, 1999), which are the values associated with the norm sample of the same age as the participant. A score of -1 to 1 indicates a child's performance is within 1 SD above or below the norm sample. Because this is calculated using errors, reaction times, and distance from the target, a score of above +1 indicates weaker performance (i.e., below the norm), whereas a score of below -1 is considered above the norm.

1) A whole group correlational analysis was used to examine associations between ADHD symptom dimensions and cognitive processes. We also conducted a sensitivity analysis by excluding children meeting full diagnostic criteria for anxiety. Consistent with previous studies, this was carried out to ensure comorbidity was not masking correlations between symptom scores and cognitive processes (Barnett et al., 2009).
2) Where dimensional relationships between cognitive processes and ADHD symptoms were significant, multiple and moderated hierarchical regression analyses were conducted to examine associations between ADHD dimensions and cognitive processes, and the potential moderating role of anxiety on these associations. Performance on each cognitive task was the dependent variable for each model. Sex and verbal ability were entered as predictors in Step 1, to control for potential confounding effects. Where age-standardised scores were not used, age was additionally entered in Step 1.
3) For analyses of response inhibition, we also entered baseline measures of response time and errors into Step 1 of each model to control for baseline processing speed (Salum et al., 2014a). ADHD and anxiety symptoms scores were entered in Step 2, and the interaction between these scores was entered in Step 3. All predictor variables were centred. To ensure that the assumption of no multicollinearity was not violated, cognitive processes which were associated with both ADHD symptom dimensions were examined in two separate models (i.e., one with inattention as a predictor, and one with hyperactivity-impulsivity as a predictor). To explore moderating effects further, the pick-a-point approach (Rogosa, 1980) was used to compare associations between ADHD and cognitive processes in children with low, mean and high anxiety scores. The Johnson-Neyman (J-N) technique was applied to derive regions of significance for the moderating effect of anxiety on associations between ADHD and

cognitive processes (Preacher et al., 2007). This technique enabled us to define the ranges of values of anxiety which produce a statistically significant moderation effect. To apply this method, moderated regression analyses were repeated without mean centring of symptoms of inattention or anxiety. Previous studies have shown that the variance in cognitive processes accounted for by the interaction between ADHD and anxiety is small. For example, Castagna et al., (2019) found the interaction between inattention x anxiety accounted for a small proportion of variance in working memory ($\Delta R^2 = .05$, $p < .05$; Castagna et al., 2019). Therefore, interactions that were either significant ($p <. 05$) or marginal ($p <. 10$) were followed up with further analysis.

3.3 Results

3.3.1 Preliminary Analyses

Table 3.1 shows the DAWBA symptom scores for the sample. Forty-three children (37%) met the diagnostic criteria for ADHD (predominantly inattentive: $n = 7$, predominantly hyperactive-impulsivity: $n = 4$, combined: $n = 32$).

Table 3.1.

Descriptive information for children meeting diagnostic criteria for ADHD and anxiety, and the full sample.

	ADHD (n = 43) Mean (SD)	Separation Anxiety (n = 23) Mean (SD)	Full Sample (n = 116) Mean (SD)
Age	6.28 (.98)	6.13 (.92)	6.15 (1.00)
Vocabulary scores [a]	86.81 (15.62)	86.95 (17.88)	88.48 (17.11)
Teacher-rated ADHD Symptoms (SDQ)	9.33 (1.04)	8.61 (1.41)	8.59 (1.43)
Inattention	7.63 (1.40)	5.70 (3.02)	4.82 (3.33)
Hyperactivity-impulsivity	7.70 (2.03)	6.04 (3.02)	5.17 (3.39)
Separation Anxiety	1.58 (2.05)	4.74 (1.66)	1.44 (2.05)

Note. [a] Two children did not complete the BPVS task so *n* varies (ADHD: *n* = 43, Separation Anxiety: *n* = 22, full sample: *n* = 114). SDQ = Strengths and Difficulties Questionnaire. DAWBA = Developmental and Well-being Assessment.

Seventy percent of the children in the sample had zero symptoms of social anxiety and 85% had zero symptoms of generalised anxiety. In contrast, symptoms of separation anxiety were exhibited in 54% of the sample and 23 children (20%) met DSM-5 diagnostic criteria (APA, 2013). The number of children meeting criteria for other anxiety disorders was low and very rarely occurred independently of separation anxiety (social anxiety: *n* = 1; generalised anxiety: *n* = 5). Because separation anxiety is the most prevalent form of anxiety disorder in children of this age (Beesdo et al., 2009) and is associated with developing a variety of anxiety disorders later in life (Aschenbrand et al., 2003), we used separation anxiety scores to investigate interactions between ADHD symptom dimensions and anxiety on cognitive processes.

3.3.2 Prevalence of cognitive problems in children at risk of ADHD

Table 3.2 shows the prevalence of children performing in the below-average range on each cognitive task. Overall, 72% of the sample demonstrated poor performance in at least one cognitive domain.

Table 3.2.

Cognitive task performance in the sample compared to norms and standard scores.

EF	Task	Standard score Mean (SD)	N (%) < 1 SD below average	N (%) within 1 SD range of average	N (%) > 1 SD above average
Memory	PSM	101.05 (23.02)	27 (23.3)	65 (56.0)	24 (20.7)
	AWMA	99.21 (16.02)	17 (14.7)	83 (71.6)	16 (13.8)
Inhibition	ANT-ROO	.85 (1.54)	43 (37.1)	71 (61.2)	2(1.7)
Visuomotor control	Pursuit	2.04 (4.40)	55 (47.4)	54 (46.6)	7 (6.0)

Note. WM = Working Memory. AWMA= Automated Working memory Assessment - Backwards Digit Recall. PSM = Picture Sequence Memory. RT = response time.

Associations between age, vocabulary scores and cognitive processes are shown in Table 3.3. Age was associated with higher picture sequence memory scores, faster and more accurate inhibition, better sustained attention, and lower within-subject variability (ANT-ROO inhibition response times and ANT-Pursuit distance from target). Independent samples t-tests showed that there were no sex differences in ADHD or separation anxiety symptom scores. Girls demonstrated significantly slower response inhibition ($t(114) = -2.50$, $p = .01$). Vocabulary scores were associated with faster and more accurate response inhibition and lower within-subject variability (ANT-ROO and ANT-Pursuit)

Table 3.3.

Bivariate Pearson correlations between age, vocabulary scores, ADHD and anxiety symptom scores and cognitive processes in the full sample.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age												
2. BPVS	.556**											
3. Inatt	.118	-.018										
4. Hyp-Imp	.059	-.086	.823**									
5. Anxiety	-.057	-.161	.196*	.239**								
6. AWMA	-.166	.076	-.106	.020	-.170							
7. PSM	.225*	.179	-.188*	-.078	.045	.191*						
8. RI RT	-.268**	-.372**	.103	.022	.026	-.133	-.122					
9. RI % errors	-.253**	-.256**	.143	.087	.152	-.333**	-.291**	.432**				
10. RI Var	-.243**	-.317**	.232*	.203*	.094	-.178	-.197*	.531**	.414**			
11. VM	.065	-.050	.164	.090	-.038	-.225*	-.039	.288**	.370**	.103		
12. SA	-.158	-.161	.241**	.174	.189*	-.055	-.285**	.182	.167	.228*	.421**	
13. VM Var	-.219*	-.228*	.202*	.146	.120	-.153	-.266**	.337**	.318**	.324**	.554**	.816**

Note. *$p < .05$, **$p < .01$. Inatt = inattention. Hyp-Imp = Hyperactivity-Impulsivity. AWMA = Automated Working Memory Assessment. PSM = Picture Sequence Memory. RI = Response Inhibition. RT = Response Time. Var = Variability. VM = Visuomotor control. SA = Sustained Attention. VM Var = visuomotor control variability. Inhibition response times and errors were square root transformed. Significant associations between ANT-Pursuit variables and symptom scores were confirmed using Spearman's Rho correlations.

3.3.3 Associations between cognitive processes and specific ADHD symptom dimensions

As shown in Table 3.4, in the whole-group correlational analysis, inattention was correlated with poor visuospatial episodic memory, more variable inhibition (response times) and visuomotor control, and worse sustained attention. Hyperactivity-impulsivity was correlated with higher inhibition variability. Our sensitivity analysis showed that, when children with separation anxiety were removed from correlational analyses, inattention was additionally associated with worse response inhibition (slower, more errors) (Table 3.4).

Table 3.4.

Sensitivity analysis correlations with children with anxiety removed from the sample (n = 93).

	1	2	3	4	5	6	7	8	9	10	11
1. Age	--										
2. BPVS	.560**	--									
3. Inatt	.036	-.066	--								
4. Hyp-Imp	.002	-.109	.817**	--							
5. AWMA	-.142	.114	-.063	.090	--						
6. PSM	.227*	.181	-.263*	-.147	.189	--					
7. RI RT	-.232*	-.391**	.211*	.089	-.131	-.134	--				
8. RI % errors	-.257*	-.292**	.206*	.108	-.362**	-.269**	.489**	--			
9. RI Var	-.261*	-.332**	.330**	.256*	-.167	-.173	.579**	.390**	--		
10. VM	.081	-.032	.186	.087	-.224*	-.055	.310**	.463**	.125	--	
11. SA	-.191	-.129	.243*	.154	-.051	-.363**	.214*	.241*	.194	.536**	--
12. VM Var	-.232*	-.204	.233*	.155	-.157	-.287**	.380**	.399**	.299**	.589**	.830**

Note. * p <. 05, ** p <. 01. Inatt = inattention. Hyp-Imp = Hyperactivity-Impulsivity. AWMA = Automated Working Memory Assessment. PSM= Picture Sequence Memory. RI = Response Inhibition. RT = Response Time. Var = Variability. VM = Visuomotor control. VM Var = visuomotor control variability. SA=Sustained Attention.

3.3.4 Interactions between separation anxiety and ADHD symptom severity in predicting performance on cognitive tasks

Our sensitivity analysis (Table 3.4) s indicated that removing children with separation anxiety strengthened correlations between ADHD symptoms and poor performance on cognitive tasks. To examine the potential moderating effect of anxiety, we looked at whether adding interactions between ADHD symptoms and separation anxiety in the third step of moderated hierarchical regression models improved model fit.

3.3.4.1 Episodic and Working Memory

No significant associations were found between performance on the AWMA backwards digit task and ADHD symptom dimensions. Associations between greater separation anxiety and poor working memory were not significant (b = -.17, p = .07). On the picture sequence task, greater inattention was associated with poorer episodic memory. As shown in Table 3.5, the addition of individual symptom severity scores in Step 2 resulted in a significant increase in R^2 (ΔR^2 = .06, p = .04), where greater inattention was a significant predictor of worse performance (b = -.24, p = .01). We examined whether separation anxiety moderated this relationship by entering the interaction term between separation anxiety and inattention in Step 3 of the hierarchical regression model. When this term was added, the increase in $R^{2.}$ was marginal (ΔR^2 = .03, b = .43, p = .06). This interaction was probed further by exploring the association between inattention and episodic memory at different levels of separation anxiety, and by calculating the region of significance (Hayes et al., 2017). The region of significance suggested that the association between inattention and episodic memory shifted from significant to non-significant as separation anxiety scores increased beyond a score of 1.50. Inattention was significantly associated with poorer episodic memory for children with the lowest separation anxiety scores[3], b = -10.05,

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[3] One SD below the mean was below the minimum observed in the data for separation anxiety scores, so the minimum measurement (a score of 0) was used for conditioning instead.

SE = 3.19, *t* = -3.15, *p* <.01, and mean levels of separation anxiety, *b* = -5.96, *SE* = 2.79, *t* = -2.14, *p* = .03, but not for children with high separation anxiety scores (+1 SD), *b* = -.12, *SE* = 4.51, *t* = -.03, *p* = .98 (see Figure 3.1). Together, these results indicate that children with high inattention and high separation anxiety performed better on this assessment of visuospatial episodic memory than children with high inattention and low separation anxiety symptoms.

Table 3.5.

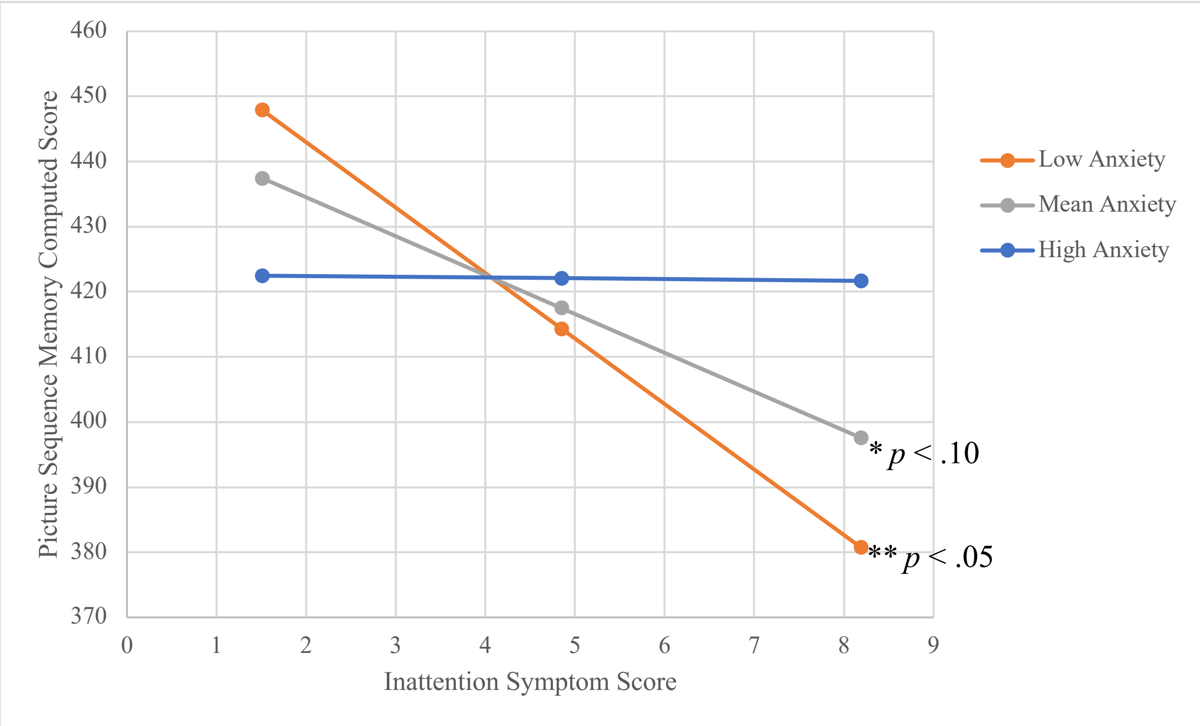
Hierarchical Regressions Estimating Performance on Cognitive Tasks.

Measure	Step/Variable	R^2	ΔR^2	B	SE B	β	t	95% CI
PSM	Step 1	.058	.058⁺					
	Age			18.26	10.83	.189⁺	1.686	[-3.209, 39.732]
	Sex			-5.53	9.06	-.057	-.611	[-23.479, 12.419]
	BPVS			6.87	10.94	.070	.628	[-14.808, 28.546]
	Step 2	.113	.055*					
	Inattention			-23.16	9.25	-.238*	-2.504	[-41.496, -4.831]
	Anxiety			11.54	9.41	.116	1.227	[-7.101, 30.190]
	Step 3	.142	.029⁺					
	Inattention x Anxiety			41.82	21.91	.431⁺	1.909	[-1.616, 85.246]
RT	Step 1	.541	.541**					
	Age			.011	.683	.001	.016	[-1.343, 1.365]
	Sex			1.265	.568	.147*	2.228	[.140, 2.391]
	BPVS			-1.297	.695	-.150⁺	-1.866	[-2.674, .081]
	Baseline RT			5.778	.633	.640**	9.129	[4.524, 7.033]
	Step 2	.543	.002					
	Inattention			-.009	.601	-.001	-.014	[-1.199, 1.182]
	Anxiety			-.399	.602	-.045	-.662	[-1.593, .796]
	Step 3	.563	.019*					
	Inattention x Anxiety			-3.043	1.408	-.354*	-2.162	[-5.835, -.252]
Sustained Attention	Step 1	.034	.034					
	Age			-2.730	3.004	-.103	-.909	[-8.684, 3.224]
	Sex			.724	2.511	.027	.288	[-4.253, 5.701]
	BPVS			-2.728	3.033	-.102	-.899	[-8.739, 3.283]
	Step 2	.112	.079*					
	Inattention			6.306	2.533	.237*	2.489	[1.285, 11.328]
	Anxiety			3.097	2.576	.114	1.202	[-2.010, 8.204]
	Step 3	.129	.017					
	Inattention x Anxiety			8.770	6.043	.330	1.451	[-3.209, 20.749]

Note. Significant *p* values corresponding to increases in R^2 and beta values are indicated as follows: ^+p <. 10,* = *p* <.05, ** = *p* <.01.

Figure 3.1.

Correlations between inattention and episodic memory at different levels of separation anxiety.



Note: Low anxiety = separation anxiety score of 0, n = 65 (56%). Mean separation anxiety = separation anxiety score within 1 SD of the mean, a score of 1-3 (n = 30, 26%). High separation anxiety = separation anxiety score of more than 1 SD above the mean (score of 4-10, n = 21, 18%).

3.3.4.2 Inhibition

Our correlational analyses showed that associations between inattention and poor response inhibition (greater RT variability, more errors and slower response times) shifted from non-significant to significant when children with separation anxiety were removed from the sample (Tables 3.3-3.4). We examined this potential interaction between separation anxiety and inattention using a moderated hierarchical regression analysis (see Table 3.5). This showed that the interaction between inattention and separation anxiety accounted for a significant proportion of variance in response times ($\Delta R^2 = .02$, $b = -3.043$, $p = .03$). Examination of the significance region showed that this association shifted from non-significant to a significant negative association for children with higher separation anxiety symptom scores; above 5.14, indicating that separation anxiety was associated with faster inhibition response times in children with high inattention. We found that the association between inattention and inhibition was not significant at low and mean levels of separation anxiety. Children with high separation anxiety (+ 1 SD) showed a marginal association between inattention and faster inhibition ($b = -.51$, $SE = .29$, $t = -1.73$, $p = .09$).

3.3.4.3 Attention and within-subject variability

Hierarchical regression models predicting sustained attention and within-subject variability (inhibition response times, tracking performance on the ANT-Pursuit), showed that inattention was the only significant symptom predictor of variance in these domains (Table 3.6). The addition of inattention symptom severity resulted in a significant change in R^2 in the following models predicting poorer performance on cognitive tasks: inhibition response time variability ($\Delta R^2 = .08$, $B = .30$, $p < .01$); variability in tracking distance on the ANT-Pursuit task ($\Delta R^2 = .05$, $B = .22$, $p = .03$), and sustained attention ($\Delta R^2 = .08$, $B. = .24$, $p = .01$).

Table 3.6.

*Hierarchical Regressions Estimating Within-subject variability***.**

Measure	Step/Variable	R^2	ΔR^2	B	SE B	β	t	95% CI
ANT-ROO	Step 1	.110	.110**					
	Age			-.016	.018	-.097	-.892	[-.052, .020]
	Sex			-.016	.032	-.044	-.486	[-.037, .023]
	BPVS			-.003	.001	-.266*	-2.444	[-.081, -.008]
	Step 2	.194	.084**					
	Inattention			.015	.005	.304**	3.359	[.021, .081]
	Anxiety			-.005	.007	-.060	-.663	[-.041, .020]
	Step 3	.197	.002					
	Inattention x Anxiety			-.020	.036	-.123	-.575	[-.093, .052]
ANT-ROO	Step 1	.110	.110**					
	Age			-.016	.018	-.097	-.892	[-.052, .020]
	Sex			-.007	-.044	-.044	-.486	[-.037, .023]
	BPVS			-.045	-.266	-.266*	-2.444	[-.081, -.008]
	Step 2	.160	.050*					
	Hyperactivity			.039	.015	.235*	2.526	[.008, .070]
	Anxiety			-.008	.016	-.048	-.514	[-.039, .023]
	Step 3	.165	.006					
	Hyperactivity x Anxiety			-.033	.039	-.198	-.854	[-.110, .044]
ANT-Pursuit	Step 1	.071	.071*					
	Age			-3.077	2.361	-.145	-1.304	[-7.756, 1.601]
	Sex			1.705	1.974	.080	.868	[-2.206, 5.616]
	BPVS			-3.050	2.383	-.142	-1.280	[-7.773, 1.674]
	Step 2	.120	.049+					
	Inattention			4.598	.215	.215*	2.274	[.590, 8.605]
	Anxiety			.714	.033	.033	.347	[-3.362, 4.789]
	Step 3	.124	.004					
	Inattention x Anxiety			3.586	.169	.169	.738	[-6.043, 13.215]

Note. Significant *p* values corresponding to increases in R^2 and beta values are indicated as follows: * = p <.05, ** = p <.01.

3.4 Discussion

There is a wealth of research showing that ADHD is associated with difficulties in cognitive processes, and this has influenced the development of theories and interventions to improve outcomes for those who live with this disorder (e.g., Kasper et al., 2012; Kofler et al., 2019; Schreiber et al., 2014; Willcutt et al., 2005). However, limited research has examined associations with dimensional measures of ADHD and cognitive processes in young children without a diagnosis. Because ADHD symptoms emerge at an early age, our understanding of how cognitive problems and ADHD symptoms develop in young children may be useful in the development of tailored interventions to reduce the negative outcomes associated with cognitive difficulties and ADHD. Further, despite the high co-occurrence of anxiety and ADHD, the effect of comorbid anxiety on these underlying processes has received limited attention. In the present study we aimed to address these issues by assessing a range of cognitive processes in children exhibiting early and clear symptoms of ADHD. The sample varied in severity of separation anxiety symptoms, enabling us to examine whether separation anxiety moderated associations between ADHD dimensions and cognitive functioning.

3.4.1 Prevalence of cognitive problems in the sample

Almost three-quarters of our sample showed below-average performance on a cognitive task, suggesting that children showing symptoms of ADHD are at risk of cognitive problems, irrespective of diagnostic status. The cognitive problems found were heterogeneous; children exhibited below-average performance across a range of tasks, with similar prevalence rates to those in studies of children with a diagnosis of ADHD (e.g., 30-37% memory problems [Coghill et al., 2014b], 21-46% response inhibition problems [Kofler et al., 2019], 30-50% visuomotor control problems [Fliers et al., 2008]). We found that the Pursuit task, which measures visuomotor control, captured the largest proportion of difficulty in the sample, with the mean score falling in the 'below-average' range (with 47% being 1 SD below the average). In addition to requiring visuomotor control, the Pursuit requires attentional control by having to monitor movement, track unpredictable movements of the target, and sustain focus throughout (Huijbregts et al., 2003). This suggests that maintenance of task motor and attentional control was the most common difficulty in our sample.

3.4.2 Dimensional associations between ADHD symptoms and cognitive processes

Consistent with predictions, poor performance on assessments of visuospatial episodic memory, visuomotor control and sustained attention was associated with inattention symptom severity, but not with hyperactivity-impulsivity severity. This suggests that these specific cognitive problems are predominantly associated with difficulties controlling and focusing attention in young children at risk of ADHD, as opposed to hyperactive and impulsive behaviour (Cai et al., 2019; Loo et al., 2009; Toplak et al., 2005). The hypothesised association between inhibition errors and hyperactive-impulsive symptoms was not found. Instead, measures of poor inhibition performance (slow response times, errors) correlated with inattention. Our study is not the first to find that inhibition is associated with inattention rather than hyperactive-impulsive symptoms, which highlights the need to distinguish between cognitive inhibition, associated with performance on neuropsychological tasks, and behavioural disinhibition problems (i.e., difficulty regulating gross motor activity) (Chhabildas et al., 2001). The only variable that was significantly associated with hyperactive-impulsive symptoms was variability in response times, which was associated with both dimensions of ADHD symptomatology. Previous research has shown that children at risk of ADHD show higher gross motor activity during cognitively demanding tasks (Burley et al., 2021). Instead of being directly related to weaker cognitive function, it may be that hyperactivity reflects a compensatory behaviour to up-regulate arousal and sustain neural activity (Rapport et al., 2009). Because RT variability is associated with lapses of attention, this association between parental ratings of hyperactivity and RT variability may reflect how children increase movement to up-regulate arousal when they are losing focus (Sarver et al., 2015). This may explain why hyperactivity was not directly associated with poor performance but was associated with more frequent lapses of attention on the task.

3.4.3 Separation anxiety as a moderator of relations between ADHD and cognitive processes

The moderating effects of separation anxiety on associations between ADHD dimensions and problems in cognitive processes was broadly in line with predictions. In contrast to children in groups with low and mean anxiety scores, children in the high separation anxiety group (4-10 symptoms), did not show a significant association between inattention and episodic memory. For response inhibition, associations between inattention and response inhibition were not significant within each anxiety group. Our moderation analysis indicated that children with very high separation anxiety (6-10 symptoms) showed a significant association between high inattention and faster inhibition response times. Our sensitivity analysis showed that when children with clinically significant separation anxiety were removed from the sample, inattention was associated with more inhibition errors. This association was not significant in the full sample. Together, this indicates that the faster response times associated with comorbid separation anxiety did not compromise accuracy. The finding that separation anxiety dampened associations between inattention and poor inhibition, and between inattention and poor visuospatial episodic memory, suggests that in children with high inattention symptoms, separation anxiety was associated with better performance on these cognitive assessments. Therefore, comorbid separation anxiety may mitigate these specific cognitive problems in ADHD. There are several proposed ways in which comorbid anxiety could influence cognitive processes, such as increasing inhibition or reducing impulsivity (Bloemsma et al., 2013; Newcorn et al., 2001). We found that the moderating effect of separation anxiety was not restricted to inhibition and our findings are therefore more consistent with a general mechanism, with separation anxiety increasing aspects of attention, motivation and/or arousal (Vance et al., 2013; Vloet et al., 2010). This may compensate for the under-activation of brain regions associated with poor EF in ADHD and improve performance across multiple domains of cognitive functioning (Bellgrove et al., 2004; Loo et al., 2009; Rubia, 2018).

However, the moderating effect of separation anxiety was only associated with tasks that involved lower cognitive demand (picture sequence memory, ANT-ROO), suggesting that comorbid separation anxiety may be insufficient to improve performance on cognitive tasks when more complex cognitive processing is involved. For example, our results suggest anxiety was associated with better performance on the picture sequence task, but not on the backwards digit recall task where symptoms of separation anxiety showed a marginal association with poorer performance. This is consistent with previous research showing that anxiety has a negative effect on the 'central executive component' in working memory (Eysenck & Derakshan, 2011). The working components of working memory (continuous updating, reordering) facilitate performance on the backwards digit task, but these are disrupted by worrisome thoughts (Baddeley, 1996; Eysenck & Derakshan, 2011). The picture sequence task recruits the 'visuospatial sketchpad' subcomponent within working memory, which is less likely to be affected by anxiety (Owens et al., 2012). Thus while comorbid separation anxiety in ADHD may improve visuospatial processes within working memory, it may worsen performance on tasks that place greater demands on the 'central executive' (Castagna et al., 2019; Owens et al., 2012; Ruf et al., 2017).

We found that separation anxiety did not moderate performance on the Pursuit task. It seems unlikely that this is purely due to the visuomotor demands of this task, because separation anxiety was associated with better control of motor function on the ANT-ROO. The Pursuit task requires a high level of attentional control in working memory to continuously update and monitor the unpredictable movements of the target (Kalff et al., 2003) and we found that separation anxiety was correlated with poorer sustained attention. Thus, although anxiety-related increases in attention, arousal or motivation may improve some cognitive processes, this does not appear to be the case on tasks requiring a greater and more enduring level of attentional processing.

3.4.4 Implications

The results demonstrate associations between specific cognitive processes and parent-reported inattention difficulties, which can be used to identify and support children at risk of ADHD and cognitive problems. While the design of the current study does not allow causal inferences to be made, i.e., whether cognitive problems caused inattention or whether increased inattention led to poorer cognitive performance, longitudinal studies have shown that improvements in specific cognitive processes are associated with reductions in ADHD symptoms of inattention (Karalunas et al., 2017). If targeting cognitive processes has the potential to alleviate symptoms of ADHD, taking into account comorbid anxiety disorders (such as separation anxiety) may to help to tailor interventions to underlying cognitive problems.

It may be beneficial for intervention efforts to focus on the cognitive problems that are most prevalent and less influenced by comorbidity (Rapport et al., 2013). Whilst our sample showed heterogeneity in cognitive problems, a high proportion of the sample demonstrated poor performance on the ANT-Pursuit task, which was associated with ADHD symptoms in children with and without anxiety. This suggests that targeting visuomotor control and attention through early intervention may be more beneficial than training other cognitive processes, because this problem can be identified in a larger proportion of children showing symptoms of ADHD. Further, previous research has shown that children with anxiety have difficulty disengaging from threatening thoughts and events, which may be exacerbated by poor attentional control (Bar-Haim et al., 2007). Thus, training attentional processes may reduce anxious symptoms and improve neuropsychological processes in children at risk of both ADHD and anxiety (Taylor et al., 2016).

Consistent with previous research on early childhood, we found that separation anxiety was the most prevalent anxiety disorder in our sample (Beesdo et al., 2009; Masi et al., 2012). The risk of developing separation anxiety, as well as ADHD, is increased by early familial adversity, low socioeconomic status, and poorer parental mental health (Jensen et al., 2001; Mulraney et al., 2018). In our sample, a relatively high proportion of the children live in poverty (33% had a household income below £20,000 per annum), suggesting that our findings are most generalisable to children with high environmental risk for ADHD and anxiety. Future research should examine how environmental factors interact in the development of ADHD, anxiety and cognitive difficulties, as a pathway to disorder.

3.4.5 Limitations

Age-related differences in the prevalence of anxiety disorders are well-documented in the anxiety literature; separation anxiety has an earlier age of onset and is more common than social and generalised anxiety in preadolescence (Kessler et al., 2005b; Lijster et al., 2017). Therefore, our focus on separation anxiety is consistent with previous research on how anxiety is most likely to present itself in children in our age range. However, the low prevalence of generalised and social anxiety in our sample limited our ability to investigate whether symptoms of types of anxiety other than separation anxiety moderate associations between ADHD symptoms and cognitive problems in the same way. Our findings are broadly consistent with previous research that included symptoms of other anxiety disorders (e.g., Castagna et al., 2019; Ruf et al., 2017), and our study highlights that studying generalised/social anxiety in children of this age range is likely to be more challenging, because symptoms of these disorders are less common and less severe in young samples.

To the best of our knowledge, there are no previous studies that have examined the moderating role of separation anxiety on associations between cognitive processes and developing symptoms of ADHD in young children. The sample size of our study is similar to previous research on anxiety, executive function and ADHD in older children (e.g., Castagna et al., 2019), and is larger than some studies which have used clinical samples (Maric et al., 2018). However, our findings relating to separation anxiety require replication, particularly the interactive effect of separation anxiety and inattention on episodic memory, which was marginal. Nonetheless, the results of the current study suggest that it is important for future research to consider this anxiety disorder when examining cognitive processes in young children at risk of ADHD.

The sample largely performed in the lower range or below average across the selection of tasks. However, performance was not always poor enough to be considered ‘below-average’. Prevalence estimates were slightly lower than those reported in other studies. This may reflect our use of stricter criteria than other studies. For example., Kofler et al. (2019), defined ‘impairment’ as a score that is significantly worse than the non-ADHD mean. By contrast, we used norms and standard scores to differentiate children who were more than 1 SD below average. Compared to other studies with typically developing comparison groups, the current sample exhibited a lower average performance (e.g., Casaletto et al., 2015; Nicolaou et al., 2018). We also examined the profiles of children who missed the below-average cut-off. Nearly half the sample (48%) had scores just missing the cut-off (between 0.5 and 1 SD below the standard score) on only one or two tasks, and only 18 (16%) children did not perform within or below this range on at least one cognitive task.

It should also be noted that our sample did not have a diagnosis of ADHD; symptom severity ranged from ‘slightly raised’ to ‘very high’. Our inclusion of children with slightly raised ADHD problems was based on evidence that associations between ADHD symptoms and functional difficulties are linear (Arildskov et al., 2022; Salum et al., 2014b), and ensure that we did not miss children high in one dimension and low in another (Ullebø et al., 2011). We found that associations between ADHD symptom severity and weaknesses in cognitive processes can be identified in young children with emerging symptoms who are below the threshold for a clinical diagnosis (Kalff et al., 2005; Slaats-Willemse et al., 2007), which adds strength to the case for considering dimensional models of ADHD. Such an approach suggests we can identify cognitive problems associated with disorder in children below the average diagnostic age, which is important for the development of early interventions.

3.4.6 Conclusion

The current findings indicate that young children with emerging ADHD symptoms, specifically those with symptoms of inattention, exhibit problems in cognitive processes. However, comorbid separation anxiety may improve specific cognitive processes – visuospatial memory and response inhibition – in children with high levels of inattention problems. The cognitive benefits of anxiety in ADHD may be less detectible on tasks requiring high levels of attentional processing, on which a high proportion of children performed in the below-average range, regardless of level of separation anxiety. These results suggest that targeting visuomotor and attentional control for early intervention is likely to be useful in reducing the cognitive and behavioural problems associated with developing ADHD. This approach would also benefit children with additional anxiety problems, who may show fewer problems in other cognitive processes.

Chapter 4. Cool and hot executive function problems in young children: Linking self-regulation processes to emerging clinical symptoms[4]

4.1 Introduction

According to the Research Domain Criteria (RDoC) framework, three domains of functioning are relevant to the study of SR; these are the 'cognitive', 'positive valence' and 'negative valence' systems, which involve controlling attention and inhibition, processing and valuing rewards, and responding to aversive situations such as punishment or loss (Cuthbert & Insel, 2013; www.nimh.nih.gov/research-priorities/rdoc/index.shtml). Chapters 2 and 3 of this thesis demonstrated that young primary school-aged children who raise concern in classroom teachers exhibit heterogeneous difficulties on a range of processes within the 'cognitive' systems. However, processes within the 'positive valence' and 'negative valence' systems have not yet been explored.

Difficulties in 'cool' cognitive processes were found to be predominantly associated with ADHD symptomatology, in line with previous research (Kofler et al., 2019; Schoechlin & Engel, 2005), except for cognitive flexibility (associated with ODD; Chapter 2). Poor regulation of cognitive control under 'cool' (non-motivational) conditions is associated with structural and functional differences in the frontal-striatal brain regions of individuals with ADHD (Rubia, 2018). At the same time, processes within the positive/negative valence systems, assessed by tasks which involve regulating responses under 'hot' conditions (which include rewards and/or losses) are mediated by orbitofrontal-limbic neural regions (Zelazo et al., 2010), and are often compromised in children with ODD/CD. For example, reduced sensitivity to threats of punishment is associated with difficulties in learning to refrain from

[4] The study described in this chapter is under review in the journal of *European Child & Adolescent Psychiatry*

inappropriate behaviours (Matthys et al., 2012). In depression, blunted positive affect and anhedonia are associated with altered reward sensitivity (Foti et al., 2014), resulting in risk-aversion (Smoski et al., 2008), whereas individuals with anxiety struggle to learn from reward-response contingencies due to heightened sensitivity to loss and punishment (Hein et al., 2021). Therefore, to align with our aims to position SR within the RDoC framework and study processes within each domain (cognitive, positive/negative valence), Chapter 4 additionally examined 'hot' EFs, to operationalise the areas of difficulty which may be associated with problems in regulating emotions, and behaviour as well as cognition in children with emerging clinical symptoms (Deutz et al., 2018; Ip et al., 2019).

While cool and hot EF processes are typically associated with separate disorders, there is evidence to suggest these difficulties can also co-occur across diagnoses. For example, individuals with ADHD have been found to show problems with hot EF compared to typically developing controls (Noreika et al., 2013), suggesting that altered reward sensitivity (positive valence) may be a problem to consider in ADHD (Sonuga-Barke et al., 2010). Similarly, cool EF problems have been found in ODD/CD (Hobson et al., 2011). However, these findings are not consistently replicated (e.g., Vilgis et al., 2015; Woltering et al., 2016). Furthermore, most research that examined cool and hot EFs from a psychopathological perspective used group-level analyses of single processes, comparing those with a clinical diagnosis to typically developing controls, which neither captures the high levels of symptom variability nor the varying profiles of strengths and difficulties which exist in those with the same diagnostic label. This heterogeneity and potential for overlapping EF problems between clinical categories has led to increased recognition of the limitations of studying single processes and using a case-control design (Astle & Fletcher-Watson, 2020). Instead, research examining SR may benefit from adopting a transdiagnostic and broad assessment approach to capture the wide range of EF difficulties and clinical symptoms which are exhibited in those with varying levels of cognitive, emotional, and behavioural problems.

A further issue which adds to the complexity of studying SR in children is that ADHD, disruptive behaviour, and emotional disorders frequently co-occur. For example, approximately half of children with ADHD meet the criteria for comorbid ODD/CD (American Psychiatric Association, 2013; Oerbeck et al., 2017), and almost a third for anxiety (Schatz & Rostain, 2006). These comorbidities may alter neuropsychological processes but are not always accounted for in studies of cool and hot EF (e.g., Castagna et al., 2019; Toplak et al., 2005). Therefore, it is currently unclear to what extent disorders, such as ADHD and ODD, have unique or share underlying cognitive difficulties, such as poor inhibition control, and whether comorbidity is associated with co-occurring disorder-specific problems or more severe dysregulation. For example, in children with ADHD and ODD poor cognitive control (unique to ADHD), combined with poor regulation of negative emotions (unique to ODD), may exacerbate impulsive aggression (Bubenzer-Busch et al., 2016). Conversely, comorbid anxiety in ADHD might counter-act hypoactivation of cognitive control regions and improve cool EF performance (e.g., Ruf et al., 2017). Because the comorbidity rates are so high, using strict exclusion criteria to isolate “pure” cases can greatly reduce the representativeness of a study sample. Comorbidity may also influence cool and hot EF at a sub-threshold level (e.g., Carter Leno et al., 2018); a dimensional approach that takes co-occurring low-level symptomatology into consideration is therefore needed to examine how self-regulatory processes are associated with individual disorder dimensions in children. Furthermore, many children have NDD symptoms without reaching the threshold for a diagnosis and still perform at below age-expected levels on measures of SR processes, such as EF (e.g., Holmes et al., 2014). A dimensional approach to assessment ensures that subthreshold children who may exhibit SR difficulties and clinical symptoms, and who could benefit from intervention, are not overlooked. In addition, there is a need for studies that use community samples of children identified by teachers as struggling at school (e.g., Astle et al., 2019), rather than those that rely on a clinical diagnosis for inclusion.

The current study utilised a sample of children identified by teachers as having cognitive, emotional or behavioural problems at school to (1) examine to what extent young children exhibit difficulties in cognitive control and decision-making, (2) identify constructs extracted from a range of cognitive control and decision-making task-based measures, and (3) examine how these constructs are dimensionally linked to severity of ADHD, ODD, anxiety and depression while controlling for co-occurring symptoms. There is limited research which has used a factor analytic approach to collectively examine cognitive, positive, and negative valence RDoC processes in primary school-aged children identified by teachers, thus no strong hypotheses were made (Ip et al., 2019). However, we expected to be able to extract constructs that would tap into cognitive, positive, and negative valence system functioning and be specifically associated with different clinical symptom dimensions. Specifically, we predicted associations between poorer cognitive control and ADHD severity, higher risk-seeking and ODD, and greater loss sensitivity, and depression.

4.2 Method

4.2.1 Participants

The participants in the study (n = 212; boys = 146, girls = 66; mean age = 6.57, SD = 1.01) were selected from a larger sample of children referred to Cardiff University’s Neurodevelopment Assessment Unit (NDAU; https://www.cardiff.ac.uk/neurodevelopment-assessment-unit) by classroom teachers or Special Educational Needs coordinators. Children were included in the current study if they demonstrated moderate to high hyperactivity, conduct and/or emotional problems in the school setting, as confirmed by the Strengths and Difficulties Questionnaire (SDQ) categorisation bands (scoring in the top 20% of the population; Goodman et al., 2000). Children referred from the same schools who did not have elevated teacher-reported problems (scoring in the 'close to average' range) were used as a comparison group (n = 30, boys = 16, girls = 14, mean age = 6.84, SD = .97), but were not included in factor structure/dimensional analyses.

4.2.2 Background Information

Parents provided child and family background information by completing questionnaires, which included details such as ethnic background. Children in the study sample were 87% White British (13% other race/ethnicity; including 3% Asian/Asian British, 9% multiple ethnic groups and 1% not specified).

4.2.3 Measures

4.2.3.1 Strengths and Difficulties Questionnaire (SDQ)

The teacher SDQ (Goodman et al., 2000), completed when making a referral to the NDAU, was used as inclusion criterion to identify children with moderate to high cognitive, emotional, and behavioural problems, according to the hyperactivity, emotional, and conduct problems scales (Winsper & Wolke, 2014).

4.2.3.2 Child Behaviour Checklist (CBCL) – Parent Version

The CBCL (Achenbach et al., 2003) was completed by children's parents/carers (usually mother). The CBCL is a widely used and well-validated measure of clinical symptoms (Nakamura et al., 2009). For all dimensional analyses (correlations, regression), we used the attention problems, ODD, anxiety, and depression T scores. Some children's parents were unable to complete the CBCL because of time constraints (n = 21), thus the sample of children included in all dimensional regression analyses was smaller than the original sample (n = 191).

4.2.3.3 Cognitive Control

Cognitive control was measured using assessments taken from the Amsterdam Neuropsychological Tasks (ANT) battery (De Sonneville, 1999). The selected tasks have successfully been used to determine the neurocognitive difficulty profiles for various clinical disorders, including children at-risk of ADHD (Groot et al., 2004; Kalff et al., 2003, 2005) and have demonstrated satisfactory test-retest reliability and validity (De Sonneville, 2014). Z scores were used to indicate performance in line with previous studies (e.g., Samango-Sprouse et al., 2017). These Z-scores are converted from raw test scores using a nonlinear regression function derived from data of 2340 typical controls (De Sonneville, 2014). The ‘Pursuit’, a measure of visuomotor control and attention, and the ‘Response Organisation Objects (ROO)’, a measure of response inhibition, were used (see Finken et al., 2013 for more details).

4.2.3.4 Positive/Negative Valence systems: reward-seeking, sensitivity to loss, decision-making

The hot EF tasks used in the current study are adapted versions of well-established assessments of decision-making under risk; the Balloon Analogue Risk task (BART; Lejuez et al., 2002) and IOWA gambling task (Bechara et al., 2005). Previous research has validated these hot EF tasks in two ways. First, the performance of older children, adolescents and adults corresponds with real-life risky behaviour, such as substance use, gambling and criminal behaviour (Lejuez et al., 2003; Verdejo-Garcia et al., 2006). Second, the tasks elicit autonomic responses following rewards and losses, indicating activation of positive and negative valence processes (e.g., increases in heart rate and skin conductance; Crone & van der Molen, 2007).

Balloon Emotional Learning Task; BELT (Humphreys et al., 2013)

The BELT is a computerised risky decision-making task in which participants pump up balloons and earn points (for a detailed description of the task and measures extracted, see Humphreys et al., 2016). We focused on reward-seeking under certain-short conditions, where feedback is most likely to be encountered (Humphreys et al., 2013). Risk-taking was measured as the number of pumps made (pumps made/total number of possible pumps), while successful decision-making was measured using the proportion of points earnt. We assessed loss sensitivity using post-explosion pump reduction (mean number of pumps - mean number of pumps following an explosion). Positive values indicate fewer pumps on the subsequent balloon (greater loss sensitivity).

Hungry donkey

The hungry donkey task is a child-version of the IOWA gambling task (see Crone & van der Molen, 2007). The first 10 trials are excluded because risk/loss contingencies have not yet been experienced and learnt (Groppe & Elsner, 2014). Risk-taking was measured using the total number of disadvantageous choices made under risky conditions, successful decision-making was the net score over the full task, and sensitivity to loss was the number of switches to a disadvantageous choice after a loss (Aïte et al., 2012; Rosi, 2022).

4.2.3.5 Verbal Ability

To control for variation in verbal ability, we used age-standardised verbal reasoning scores from the Lucid Ability Computerised Assessment System (Version 5.15; GL Assessment, 2014).

4.2.4 Procedure

Following a referral from school, children, and their primary caregivers (usually mother) visited the NDAU for an assessment. Children completed measures of cognitive control and decision-making while their caregivers completed a clinical interview and questionnaires on family background and child symptomatology in a separate room.

We gained informed consent from the caregiver and verbal assent for each child before the assessment and all procedures were approved by the Cardiff University ethics committee (EC.16.10.11.4592GR).

4.2.5 Data analysis

4.2.5.1 Preliminary analysis

We examined associations between SR processes and symptom severity scores with potential confounding variables (age, sex, verbal ability) and checked assumptions (normality, multicollinearity; Tabachnick & Fidell, 2007).

4.2.5.2 Cognitive control and decision-making difficulties in children with moderate to high teacher-reported problems

We compared our sample of children with moderate to high teacher-reported problems (n = 212) to children with scores in the typical range (n = 30) using independent samples t-tests. We also estimated the prevalence of below average cognitive control by comparing participant performance to age-equivalent norms (De Sonneville, 2014). For the decision-making tasks, there are limited studies which have examined performance on the BELT and hungry donkey in children of this age group (e.g., Garon et al., 2006; Kerr & Zelazo, 2004). Therefore, to examine poor performance we looked at the proportion of children who failed to show improvement as each of the decision-making tasks progressed (Bechara et al., 2005; Humphreys et al., 2013).

4.2.5.3 Extracting constructs from a range of cognitive control and decision-making measures

In line with previous studies (e.g., Ip et al., 2019) a Principal Components Analysis (PCA) with Varimax rotation was used to create constructs from the different tasks. All moderate to high risk children were included in this analysis (n = 212). All variables were converted to Z scores and cognitive control measures (scores extracted from the ANT tasks) were reverse scored so that higher scores reflected better performance. In total, eight variables (visuomotor control, inhibition, 2 x risk-taking (BELT, hungry donkey), 2 x loss sensitivity (BELT, hungry donkey), % points on the BELT, net score on the hungry donkey) were entered into the factor analysis. Between-task bivariate Pearson correlations, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were used to determine the appropriateness of a PCA. We extracted regression factor scores from the PCA to create composite scores for each formed construct.

4.2.5.4 Associations between extracted constructs and dimensional measures of clinical symptoms

Bivariate Pearson correlations were used to examine associations between the composite scores extracted from the PCA and the CBCL symptom scores in children whose parents completed this questionnaire (n = 191). Where we observed significant associations, linear regression analyses were conducted to examine these relationships further. We entered potential confounding variables (age, sex, verbal ability) in Step 1, co-occurring symptoms (ADHD, ODD, anxiety, depression) in Step 2, and extracted composite scores in Step 3 to examine whether the formed constructs predicted significant variance in specific symptom dimensions.

4.3 Results

4.3.1 Sample Characteristics

Over half of the sample had scores within the clinically significant range on the CBCL for at-least one disorder (n = 112, 53%). ADHD symptoms were most prevalent (n = 87, 46%), while approximately a third of children scored in the clinically significant range for ODD (n = 63, 33%), anxiety (n = 60, 31%) and depression (n = 60, 30%).

4.3.2 Preliminary Analyses

We examined whether children who had missing CBCL data (n = 21) differed from children with a full set of data (n = 191) on potentially confounding variables (age, sex, verbal ability) and teacher-reported problems, and found no significant differences.

All data followed a normal distribution except for visuomotor control, so we examined Spearman's correlations to confirm associations where this variable was concerned. Examination of correlations and residual plots in SPSS showed that the assumptions for multiple regression were met.

Age was associated with scoring more points on the BELT ($r = .17$, $p = .01$). Corrected t-tests showed that girls showed worse inhibition than boys ($t(84.21)$[1] = -2.79, $p = .01$, d = -.51). Verbal ability was associated with better inhibition ($r = -.15$, $p = .04$).

4.3.3 Cognitive control and decision-making difficulties in children with moderate to high teacher-reported problems

We compared children with moderate to high teacher-reported problems ($n = 212$) to a comparison group with no problems (n = 30) on measures of cognitive control and decision-making (see Table 4.1). The groups did not differ in age or verbal ability, but the moderate to high risk group had more boys (69% compared to 53%). Independent samples t-tests showed that children with moderate to high problems showed poorer performance on assessments of visuomotor control and decision-making than children with no problems, reflected in worse accuracy on the ANT-Pursuit; $t(60.20)$[5] = -2.69, $p = .01$, $d = -.34$), and fewer points earnt on the BELT task ($t(240) = 2.89$, $p <. 01$, $d = .56$).

[5] Because Levene's test for equality of variances was significant ($p <. 05$), t-test result reflects analyses where equal variances were not assumed

Table 4.1.

Performance of sample on EF measures

	Controls (*n* = 30)	Moderate to High-Risk Children (*n* = 212)
Visuomotor control and attention		
Mean (SD)	.80 (1.99)	1.98 (3.59)
Prevalence of children scoring in below average range: n (%)	10 (33)	104 (49)
Inhibition		
Mean (SD)	.45 (1.31)	.53 (1.32)
Prevalence of children scoring in below average range: n (%)	9 (30)	55 (26)
Decision-making: BELT		
Proportion of points earnt		
Mean (SD)	.47 (.19)	.37 (.18)
Learning failure: n (%)	4 (13)	51 (24)
Decision-making: hungry donkey		
Net score		
Mean (SD)	12.00 (12.50)	12.10 (21.16)
Learning failure: n (%)	8 (27)	58 (27)

Note. BELT = Balloon Emotional Learning Task.

As shown in Table 4.1, in the group of children with moderate to high problems, 49% showed poor visuomotor control and attention, and 26% showed below average inhibition compared to norm data for typically developing children (De Sonneville, 2014). Approximately a quarter of the sample of children showed no learning of choice-outcome contingencies on the BELT and hungry donkey decision-making tasks (24% and 27%, respectively), as measured using improvement between the first and last task blocks (Bechara et al., 2005; Humphreys et al., 2013).

4.3.4 Extracting constructs from a range of cognitive control and decision-making measures

Our correlational analysis (see Table 4.2) showed that there were significant correlations across tasks, indicating the presence of shared underlying processes. The KMO and Bartlett test validated that structure detection was appropriate for our data [KMO = .545, all individual values were above 0.5; $\chi^2(28) = 196.44$, $p < .001$]. The Principal Components Analysis suggested a four-factor solution based on visual inspection of the scree plot; the four components had eigenvalues greater than 1, the factors were interpretable and every variable presented a high loading on one component only (Thurstone, 1947). The component loadings for our 8 measures are shown in Table 4.3. Together, the 4 components formed accounted for approximately 68% of the variance (see Table 13). The interpretation of the components was guided by constructs within the positive valence, cognitive systems, and negative valence domains of the RDoC framework (Cuthbert & Insel, 2013; Ip et al., 2019), and previous studies which have shown that some constructs are at the intersection of multiple domains (e.g., impulsivity; Glenn et al., 2017). The first component, explaining 21% of the variance, was associated with processes within the “positive valence” system and reflected low reward-seeking as assessed via performance on the hungry donkey task (fewer risky choices, more points). The highest loadings on the second component, explaining 18% of the variance, reflected cognitive control processes within the “cognitive systems” domain, with high loadings from measures of inhibition and visuomotor control. The third factor (16% variance explained) was associated with both positive and negative valence; elevated reward seeking and greater loss sensitivity on the BELT, thus tapping into ‘emotional impulsivity’. The final factor (14% variance explained) was specifically associated with “negative valence”; sensitivity to loss (i.e., more choice switches after a loss on hungry donkey task), as well as success rate on the BELT (more points gained). We extracted regression factor scores from the PCA to create individual composite scores for each formed RDoC construct.

Table 4.2.

Associations between age, verbal ability, symptom score variables and all task variables in at-risk children.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Age													
2. Verbal Ability	-.13												
3. ADHD	.08	-.04											
4. Anxiety	.04	-.07	.26**										
5. Depression	-.02	-.03	.35**	.61**									
6. ODD	-.03	-.05	.53**	.38**	.54**								
7. Visuomotor control	-.10	-.02	.12	-.21**	-.11	-.08							
8. Inhibition	-.07	-.15*	.19**	-.05	.01	.04	.42**						
9. Risk-taking (BELT)	.06	-.12	.06	.08	.10	.19**	.01	.03					
10. Loss sensitivity (BELT)	.00	-.11	-.07	-.06	-.07	-.14*	.03	.14*	.18**				
11. % Points (BELT)	.17*	-.04	-.12	-.06	-.09	-.06	-.16*	-.05	-.13	-.05			
12. Risk-Taking (HD)	-.09	-.09	.02	-.11	-.09	.10	.18**	.17*	.25**	.11	-.19**		
13. Loss sensitivity (HD)	-.07	-.10	-.17*	-.05	-.16*	-.15*	-.13	.03	.01	.07	.04	.16*	
14. Net Score (HD)	-.07	.10	.00	.11	.22**	.04	-.15*	-.13	-.17*	.01	.04	-.59**	.00

Note. ADHD = Attention Deficit Hyperactivity Disorder. ODD = ODD. BELT = Balloon Emotional Learning Task. HD = Hungry Donkey. * *p* < .05, ** p < .01.

Table 4.3.

Principal component analysis to identify RDoC constructs in our sample using cognitive control and decision-making tasks.

Measures	Component			
	Low reward-seeking (+ valence)	High cognitive control (cognitive systems)	High emotional impulsivity (+ and - valence)	High loss sensitivity (- valence)
Visuomotor/attention	.138	**.794**	.052	.268
Inhibition	.075	**.841**	-.113	-.107
Risk-taking (BELT)	-.335	.175	**.625**	-.228
Loss sensitivity (BELT)	.132	-.189	**.788**	.183
% Points (BELT)	.145	.065	-.365	**.578**
Risk-taking (HD)	**-.851**	-.136	.191	.054
Loss sensitivity (HD)	-.155	.058	.217	**.774**
Net Score (HD)	**.871**	.092	.089	.008
Explained variance (%)	21.022	17.984	15.632	13.807
Eigenvalue	2.004	1.301	1.115	1.056

Note. BELT = Balloon Emotional Learning Task. HD = Hungry Donkey. **Bold** indicates factor loadings > .40.

4.3.5 Associations between extracted constructs and dimensional measures of clinical symptoms

Our correlational analysis examined associations between extracted constructs and CBCL dimensional symptom scores (n = 191). As shown in Table 4.4, the severity of ADHD symptoms was significantly associated with poorer cognitive control, severity of anxiety was significantly associated with better cognitive control, and severity of depression was significantly associated with lower reward-seeking. ADHD, ODD, and depression symptoms were all significantly negatively associated with "negative valence".

Regression analyses were used to examine specific associations between different SR processes and symptom dimensions whilst controlling for age, sex, and verbal ability as well as co-occurring clinical symptoms (Table 4.5). This demonstrated that ADHD symptoms were specifically associated with poor cognitive control, ODD with greater reward-seeking, and depression severity with low reward-seeking. Anxiety was associated with better cognitive control.

Table 4.4.

Correlational associations between disorder symptom dimensions and formed RDoC constructs

	1.	2.	3.	4.
1. ADHD				
2. Anxiety	.26**			
3. Depression	.35**	.61**		
4. ODD	.53**	.38**	.54**	
5. Low reward-seeking (+ valence)	-.01	.09	.15*	-.07
6. High cognitive control (cognitive systems)	-.16*	.17*	.08	.07
7. High emotional impulsivity (+ / - valence)	-.01	.04	.06	.02
8. High loss sensitivity (- valence)	-.20**	-.07	-.18*	-.17*

Note. * $p < .05$, ** $p < .01$. ADHD = Attention Deficit Hyperactivity Disorder. ODD = ODD.

Table 4.5.

Summary of final step multiple regression analyses examining formed RDoC constructs as predictors of disorder symptom severity, controlling for co-occurring symptoms age, sex, and verbal ability

Formed RDoC constructs	Statistic	Symptom dimensions			
		ADHD	Anxiety	Depression	ODD
Step 3:	ΔR^2	.05**	.02	.02	.02
Low reward-seeking (+ valence)	ß 95% CI	.016 [-1.13, 1.45]	.02 [-1.13, 1.63]	.13* [.20, 2.54]	-.13* [-2.23, -.18]
High cognitive control (cognitive systems)	ß 95% CI	-.20** [-3.28, -.73]	.13* [.06, 2.83]	-.01 [-1.27. 1.15]	.10 [-.26, 1.83]
High emotional impulsivity (+ / - valence)	ß 95% CI	-.02 [-1.50, 1.03]	.01 [-1.27, 1.43]	.02 [-.92, 1.41]	.01 [-.92, 1.12]
High loss sensitivity (- valence)	ß 95% CI	-.12 [-2.54, .03]	.04 [-.90, 1.88]	-.08 [-2.08, .30]	-.01 [-1.10, .99]

Note. ADHD = Attention Deficit Hyperactivity Disorder. ODD = ODD. * $p < .05$, ** $p < .01$

4.4 Discussion

Young children exhibiting moderate to high cognitive, emotional, and behavioural problems at school had difficulties on computerised assessments of visuomotor control and decision-making. An analysis of the underlying structure of the variables extracted from these tasks revealed a four-factor solution separating the domains of cognitive control, reward seeking behaviour (positive valance), loss sensitivity (negative valence) and emotional impulsivity (positive and negative valence). We found that problems with cognitive control were associated with severity of ADHD symptoms, and that reward seeking behaviour (positive valence) was associated with both depression (lower reward-seeking) and ODD (greater reward-seeking). Although greater loss sensitivity (negative valence) was significantly negatively correlated with ADHD, depression and ODD symptoms, these associations were not maintained when age, sex, verbal ability, and co-occurring symptoms were controlled for. These results indicate that positioning self-regulation within the RDoC framework and adopting a dimensional approach to clinical assessment may be useful in identifying specific processes that could be targeted for intervention in young children with a range of clinical symptoms.

Consistent with previous research highlighting the multidimensional nature of SR (e.g., Heatherton, 2011; Nigg, 2017), we identified four distinct constructs which corresponded to different self-regulatory processes. Our measures of cognitive control (visuomotor control and attention, response inhibition) mapped onto a single factor and were separate from the variables extracted from hot EF tasks. In line with the proposed RDoC framework, our results suggest cool EF tasks elicit top-down cognitive control (Cohen et al., 2016; Cohen & Lieberman, 2010) and are differentiated from positive/negative valence processes which involve a more complex network of brain regions (Buhle et al., 2014).

Our results demonstrate that it is difficult to disentangle specific positive and negative valence constructs within some decision-making tasks. In contrast to the 'hungry donkey' task, where reward-seeking (positive valence) is separated from loss sensitivity (negative valence), the positive and negative valence measures extracted from the BELT decision-making task were combined into a single factor. We therefore created a combined positive/negative valence construct reflecting impulsive behaviour driven by heightened emotions irrespective of valence (i.e., emotional impulsivity; Elliott et al., 2023). Previous research shows that the tendency toward regrettable behaviour in states of high emotion predicts a vast range of severe internalising and externalising problems (Berg et al., 2015), and thus may be an important construct for further investigation (Glenn et al., 2017).

We found that ADHD symptoms were associated with poor cognitive control, whereas anxiety was associated with better cognitive control, which aligns with previous research demonstrating that co-occurring anxiety may reduce some cognitive problems in children with clinical symptoms (e.g., Garon et al., 2006). Our finding that only ADHD was associated with poorer cognitive control fits with theories of self-control difficulties under 'cool' (non-emotional) contexts in ADHD, whereas problems executing self-control in 'hot' emotional contexts is associated with disruptive behaviour and emotional disorders (Arnsten & Rubia, 2012; van Goozen et al., 2022).

We found that low and high reward seeking predicted variance in depression and ODD symptoms, respectively. Previous research indicates that ODD and depression are associated with blunted responsiveness to reward but result in different behaviours: while depression is associated with risk-aversion (Smoski et al., 2008), ODD is associated with high reward-seeking (Bjork & Pardini, 2015). Because ODD and depression were not independently associated with emotional impulsivity, which reflects sensitivity to both reward and loss, the results suggest that ODD and depression are specifically associated with dysfunctional positive-valence processes, as opposed more a general mechanism of impulsivity which spans multiple RDoC domains. Where associations between general impulsivity and ODD or depression have been found (e.g., Junghänel et al., 2022), this may be because co-occurring symptoms (e.g., depression in ODD) were not accounted for.

We found that emotional impulsivity was not independently associated with any disorder symptom scores. Using the same BELT task, Humphreys and Lee (2011) found that children with comorbid ADHD and ODD demonstrated both more reward-seeking and greater loss sensitivity than single disorder groups and controls. We may have found no associations between ADHD or ODD and emotional impulsivity because we examined independent associations rather than the combined effects of these disorders. Children with both ADHD and ODD may react more strongly to negative events because of poor cognitive and affective regulation (Hobson et al., 2011; Nigg, 2017; Schoorl et al., 2016). We found that children with moderate to high problems performed more poorly on the BELT task than children without problems; emotional impulsivity may thus be indicative of a broader or more general dysregulation syndrome than a disorder-specific problem.

The construct corresponding to negative valence processes was significantly inversely correlated with ADHD, ODD and depression symptoms. However, after controlling for co-occurring symptoms no associations between symptom scores and negative valence remained significant, suggesting that loss sensitivity was not independently associated with specific symptoms. Loss sensitivity could be associated with irritability (Brotman et al., 2017), a phenotype implicated in ADHD, ODD and depression (Caspi & Moffitt, 2018). Controlling for comorbidity will dampen associations because of shared variance and reductions in statistical power. Irritability and loss sensitivity in young children could be another transdiagnostic process associated with different clinical symptom dimensions (Dougherty et al., 2015; Wakschlag et al., 2015).

4.4.1 Strengths and Limitations

The current study is one of the first to examine positive and negative valence processes using lab-based cognitive tasks in a relatively large sample of young, pre-diagnosed children. Children were recruited from the community via educational professionals; our sample is therefore more representative of those exhibiting self-regulation problems at school than a volunteer sample recruited via parents.

For the examination of cool EF, we were able to compare our sample to typically developing children using norm scores, but there were no norm referenced scores for the decision-making tasks (BELT, hungry donkey). We therefore used children who had been referred by their teachers but whose teacher SDQ scores were in the 'close to average' range. This may explain why an elevated proportion of children had below average performance on some cognitive tasks (e.g., inhibition, decision-making). However, this comparison group is less likely to differ on some confounding factors (e.g., socioeconomic status, education) which can exaggerate differences between at-risk samples and controls.

The current study also had several limitations. First, caution should be taken when considering the results of our factor analysis, because the number of variables used was small relative to the number of factors extracted. The results of our factor analysis also highlight that separation of positive and negative valence processes is difficult to achieve, because in most decision-making tasks reward and loss sensitivity processes interact and do not operate independently. Second, because this paper focused on associations between multiple dimensions of self-regulation and clinical symptoms, the results should be considered exploratory owing to the fairly large number of analyses carried out. Third, a correlational design was used, thus we cannot infer the direction of causality between self-regulation processes and clinical symptoms.

Finally, in line with other research our sample had a higher proportion of boys than girls with moderate to high dysregulation symptoms (Gaub & Carlson, 1997; Ogundele, 2018). However, we found no sex differences on our measures of cognitive control and decision-making (except for response inhibition, where girls performed more poorly) indicating that being a girl is not entirely protective against difficulties in specific self-regulation processes. Emotion regulation difficulties in girls are less noticed by educational professionals (Molins & Clopton, 2002), thus further research in larger samples of girls exploring the cognitive processes associated with symptoms of anxiety and depression is needed to ensure that girls with emerging emotional problems are not overlooked.

4.4.2 Implications and future directions

Because the current study used a correlational design and we therefore cannot infer causality, there is a need for longitudinal research to verify the causal links between SR processes and clinical symptoms. Surface-level manifestations of clinical symptoms can change over time (e.g., ODD can evolve into depression; Burke et al., 2010; Doerfler et al., 2020), whereas SR problems may be more stable and consistently mediate links between early genetic and environmental factors and later adverse outcomes (van Goozen et al., 2022). Instead of relying on disorder classification systems assessing SR in clinical or educational settings may be useful, not only to understand underlying psychological difficulties but also to optimise the delivery of personalised interventions (e.g., Garland et al., 2017; Hagerty, 2023).

We found that negative valence processes and emotional impulsivity were not independently associated with clinical symptoms, highlighting that some RDoC processes may reflect general rather than disorder-specific problems. Other studies exploring the factor structure of cognitive, emotional, and behavioural regulation difficulties in children have found that both specific and general factors contribute to clinical symptoms (Deutz et al., 2018). Further research using both specific and broad measures of dysregulation symptoms (e.g., CBCL-Dysregulation Profile; Geeraerts et al., 2015) is needed to establish the processes which are disorder specific, and those which are implicated more generally across psychopathology. If it is found that sensitivity to loss or emotional impulsivity are general risk factors, they may be useful targets for general prevention interventions (Deplus et al., 2016).

4.5 Conclusions

Self-regulation (SR) processes mediate the link between early familial influences and adverse developmental outcomes (e.g., van Goozen et al., 2022). We found that young school-referred children with varying cognitive, emotional, and behavioural problems exhibit difficulties with cognitive control and decision-making. ADHD and disruptive behaviour symptoms were independently associated with poor cognitive and motivational control, respectively, whereas emotional disorder symptoms were associated with relative strengths on tasks assessing cognitive control (anxiety) and risk-adverse decision-making (depression). We also found that the separation of positive and negative valence processes is complex and hard to achieve, with some evidence of transdiagnostic dysregulation across disorders. Further research using the RDoC framework and dimensional approaches will ultimately offer us better opportunities for intervention, not only targeting specific disorder symptoms, but also more general functional difficulties that span multiple diagnoses.

Chapter 5. General Discussion

5.1 Overview and aims

Childhood mental health problems are a growing global concern. When not addressed, they have a lasting and long-term impact on both the child themselves and those around them (Kessler et al., 2005a; Meltzer et al., 2003). Therefore, it is crucial to improve our understanding of how symptoms of mental health issues emerge, to detect problems and intervene when children are still developing (Liang et al., 2021; Skeem et al., 2014). Various cognitive, emotional and behavioural problems which manifest in childhood are associated with poor SR (e.g., Crocker et al., 2013; Griffith et al., 2019; Zelazo, 2020). Therefore, SR may be a useful transdiagnostic process to (1) identify at-risk children and (2) target them through early intervention (Eisenberg et al., 2017).

SR is comprised of a range of skills that are recruited for cognitive, behaviour and emotional regulation. Previous research indicates that children with various disorders, particularly ADHD but also ASD, ODD, anxiety and depression, exhibit problems in cool and hot EFs (Barkley, 1997; Foti & Hajcak, 2009; Matthys et al., 2012; Snyder et al., 2015; Zelazo, 2020). Therefore, this thesis examined these processes in young children at risk of mental health difficulties, which may have transdiagnostic relevance for early detection and intervention efforts.

Research has traditionally used a diagnostic categorical framework and studied single processes to understand associations between EFs, NDDs and mental health problems in children (e.g., Lansbergen et al., 2007; van Mourik et al., 2005). However, this approach has limited our understanding of the precise EF difficulties that are linked with developing disorders for several reasons. A categorical approach does not account for the high variability of symptoms that children within a diagnostic category demonstrate, or the substantial overlap and comorbidity seen across disorders. Furthermore, how EF difficulties are linked to clinical symptoms exhibited in pre-diagnosed children with subthreshold symptoms has been overlooked, despite evidence that children with subthreshold symptoms can still exhibit persistent difficulties in these skills (Holmes et al., 2014).

The central aims of this thesis were to use a transdiagnostic and dimensional approach to (1) examine to what extent at-risk children exhibit problems in the cognitive processes that are important for SR (e.g., basic cognitive processes, cool and hot EFs), (2) investigate how these processes relate to specific disorder dimensions of ADHD, ASD, anxiety, ODD and depression, and (3) find out whether SR processes can be broken down into disorder-specific domains.

5.2 Summary of findings

Chapter 2 used a broad, transdiagnostic approach to examine to what extent children referred by teachers for a wide range of difficulties (incl. problems with hyperactivity, conduct, prosocial, peer and emotional) exhibit cool EF problems, and how these EF processes were associated with specific symptom severity measures of NDDs and mental health problems. Previous studies have shown that children with clinical symptoms who do not reach the threshold for a diagnostic label exhibit below-average performance on assessments of EF (e.g., Pauli-Pott & Becker, 2011). Some have argued that ADHD and ASD have domain-specific problems with EF, such as inhibition in ADHD and cognitive flexibility in ASD (Barkley, 1997; Yeung et al., 2016). However, this specificity is challenged by broad assessment approaches, which have identified heterogeneous EF problems in children with NDDs (Demetriou et al., 2018; Kofler et al., 2019), as well as evidence of cross-disorder difficulties (e.g., cognitive flexibility problems in ADHD; Coghill et al., 2014b). Alternatively, mixed findings for domain-specificity may be explained by poor control of co-occurring disorder symptoms, which may influence performance on EF tasks, even at a subthreshold level (Carter Leno et al., 2018).

It was found that children with various problems at school exhibit EF problems and that these difficulties are specifically associated with ADHD symptoms (cognitive inhibition, episodic memory) and ODD (cognitive flexibility). In contrast, ASD and anxiety were associated with relative cognitive inhibition and flexibility strengths, respectively. These findings extend the literature by showing that EF problems can be identified in children with emerging symptoms of NDDs and psychopathology. Secondly, the findings indicate that some EF difficulties may be disorder-specific, whereby EF problems are predominantly associated with greater severity of ADHD and ODD symptoms rather than ASD and anxiety. Finally, these results raise the possibility that there may be counteracting effects where disorders co-occur, such as reduced EF problems in children with ADHD and anxiety together.

Chapter 3 took a more focused approach to examine cognitive processes in children with symptoms of ADHD, with and without anxiety. Difficulties in both low-level cognitive processes and cool EF have consistently been associated with ADHD (e.g., Alderson et al., 2008; Barkley, 1997; Coghill et al., 2014b; Willcutt et al., 2005), but there is substantial heterogeneity between studies in terms of the prevalence rates and specificity of these difficulties (Kofler et al., 2019). Some have argued that anxiety may counteract the hypoactivation in the PFC, traditionally thought to underpin EF-related problems in ADHD (Arnsten, 2009; Rubia, 2018). However, limited research has looked at the potentially moderating role of anxiety in dimensional associations between cognitive processes and specific ADHD symptoms in children without a formal diagnosis.

We found that 72% of children referred for ADHD problems exhibited difficulties in cognitive processes: 47% had below-average visuomotor control, 37% below-average response inhibition, and 35% had below-average episodic memory. By separating inattentiveness and hyperactive-impulsive symptoms, we found that task performance and within-subject variability (in visuomotor accuracy and inhibition response times) were negatively associated with inattention symptoms but not hyperactivity-impulsivity. Parents reported symptoms of separation anxiety in over half of the sample (20% meeting full diagnostic criteria), which moderated associations between inattention and episodic memory, and between inattention and inhibition; only children without separation anxiety showed significant correlations between ADHD symptoms and poor performance. However, separation anxiety did not moderate associations between inattention and visuomotor control or sustaining attention. The findings of Chapter 3 suggest that children at risk of ADHD exhibit heterogeneous problems on cognitive tasks and that basic, low-level cognitive processes and specific EF are associated with symptoms of inattention. The results suggest that symptoms of co-occurring disorders, particularly anxiety, should be taken into account when considering emerging neuropsychological difficulties associated with specific disorders, such as ADHD.

Chapters 2 and 3 focused on processes within the “cognitive systems” domain. However, SR also involves processes within the “positive valence” and “negative valence” systems (Strauman, 2017). Therefore, the goal of Chapter 4 was to expand our investigation of SR processes by examining the top-down cognitive processes that operate in motivationally and emotionally significant conditions (‘hot’ EFs; Zelazo & Carlson, 2012). Previous studies have shown that whilst poor regulation of cognitive control under ‘cool’ (non-motivational) conditions is associated with structural and functional differences in the brain regions of individuals with ADHD (Dolan & Lennox, 2013), the processes involved in regulating responses under ‘hot’ conditions are often compromised in children with ODD and CD (Matthys et al., 2012). At the same time, in depression, blunted positive affect and anhedonia are associated with altered reward sensitivity (Foti et al., 2014), resulting in risk aversion (Smoski et al., 2008), and anxious individuals show heightened sensitivity to loss and punishment (Hein et al., 2021). However, the evidence for complete domain-specificity in diagnostic categories is mixed. For example, some studies have found that individuals with ADHD exhibit problems with hot EF compared to typically developing controls (Noreika et al., 2013) and that that are independent associations between ODD/CD symptoms and difficulties on cool EF tasks (Hobson et al., 2011). However, these findings are not consistently replicated (e.g., Vilgis et al., 2015; Woltering et al., 2016). The potential for overlapping SR problems between clinical categories led us to examine independent associations between SR processes in children identified by teachers as having moderate to high 'dysregulation' problems (i.e., cognitive; ADHD, emotional; anxiety/depression and behaviour; ODD) (Winsper & Wolke, 2014).

Compared to children with no teacher-reported difficulties, those with moderate to high problems showed problems with cool and hot EFs. A factor analysis revealed that task variables extracted from cool and hot EF tasks adhered to RDoC dimensions and predicted variance in specific disorders: difficulties in cognitive control predicted ADHD symptoms, low reward-seeking was associated with depression, and high reward-seeking was associated with ODD. We also extracted factors that corresponded to 'emotional impulsivity' and 'loss sensitivity', which were not independently associated with dimensional symptom measures. This Chapter highlights how assessments of both cool and hot EF positioned within the RDoC framework can inform our understanding of disorder-specific and transdiagnostic difficulties in self-regulation, which are associated with diverse clinical symptoms in children.

5.2.1 *Aim 1: To what extent do at-risk children exhibit problems in the cognitive processes important for self-regulation?*

To examine the extent to which children in our sample exhibited problems in the 'cool' cognitive processes that are related to SR, we compared children with raised scores on the SDQ to typically developing children using established norms from each EF task (Akshoomoff et al., 2014; De Sonneville, 2014) (Chapters 2-4). Between a quarter to half of the children in each Chapter sample performed in the below-average range on each task (25-55%: visuomotor control and attention; 47-55%, inhibition; 29-37%, cognitive flexibility; 28%, and memory; 25-35%). Some children exceeded DSM-5 diagnostic criteria for ADHD (24%), but the rest were below this threshold. These results suggest that cognitive problems can be identified before clinical symptoms cross a diagnostic level of severity because the overall prevalence of cognitive difficulties found (66%) is comparable to those exhibited in previous studies using samples of children with a formal clinical diagnosis (e.g., 35%, Biederman et al., 2004; 65% Coghill et al., 2014b).

By expanding our range of tasks to include hot EF (Chapter 4), we found that some children with raised hyperactivity, conduct and/or emotional problems exhibited poor cognitive control on tasks involving rewards and punishments. Our study was one of the first to investigate hot EF in young, primary school-aged children at risk of NDDs and mental health problems using adapted versions of the IOWA gambling (Bechara et al., 2005) and hungry donkey (Crone & van der Molen, 2007) tasks. While we were not able to compare our results to other studies, we found that our sample of children with raised hyperactivity, emotional and conduct problems performed more poorly on the BELT task than a comparison group of children referred to the NDAU with no teacher-reported problems. We found that a quarter of our sample failed to learn the correct choice-outcome contingencies, and greater risk seeking was associated with ODD symptoms.

These results are consistent with previous research, which has shown that failure to learn from feedback and incentives could be an important component of behaviour regulation problems (Matthys et al., 2012a). Reinforcement learning may thus help to identify a subgroup of children at risk of oppositional behaviour who may benefit from intervention in this domain. Furthermore, these findings have important implications because most parent- and teacher-delivered interventions for children with disruptive behaviour use rewards to reinforce appropriate behaviour and reduce inappropriate behaviour (Veenman et al., 2018). Our study indicates that it is crucial that such interventions accommodate children's potential difficulties in learning processes, for example by use tangible rewards initially (as opposed to social approval) (Luby, 2017; Menting et al., 2013; Webster-Stratton, 2001).

We found that at-risk children exhibit heterotypic problems on assessments of basic cognitive processes, cool and hot EFs. This builds on previous research which has only focused on the EFs traditionally thought to be central to ADHD, such as response inhibition and working memory (Antonini et al., 2015; Hart et al., 2013). We consistently found that at-risk children were more likely to exhibit poor visuomotor control and attention (55%) than these 'core' EFs (15% working memory; 29-37% response inhibition), suggesting that there may be additional cognitive processes that may contribute to poor self-regulation in children with emerging symptoms of the disorder that have not always been considered in previous research.

Previous studies have shown that the processes that are involved in cognitive regulation also enable other types of SR (i.e., behavioural and emotional regulation) to occur (Hunt et al., 2013; Nigg, 2017). For example, working memory plays an important part in cognitive reappraisal, an effective emotion regulation strategy (Hofmann et al., 2012), whereas reinforcement learning is linked to risky behaviour (Matthys et al., 2012). Therefore, our results also suggest that traditional approaches focusing on a single EF, such as response inhibition or working memory, are insufficient to account for the wide range of ways in which SR problems can develop.

5.2.2 Aim 2: How do cognitive processes that are important for SR relate to specific disorder dimensions?

In each Chapter, specific associations between cognitive processes and dimensions of symptom severity (ADHD, ASD, anxiety, ODD and depression) were examined while controlling for co-occurring symptomatology. We found that ADHD symptoms were uniquely associated with poor inhibition, sustained attention, episodic memory and greater within-subject variability (Chapters 2-3). ODD symptoms were specifically associated with worse cognitive flexibility and greater risk-seeking (Chapters 2 and 4). On the other hand, ASD was specifically associated with better cognitive inhibition, anxiety with better cognitive control, cognitive flexibility and working memory (Chapters 2-4), and depression with lower reward-seeking. These associations suggest that some of the top-down cognitive processes involved in SR relate to specific disorder dimensions and are discussed in detail below. Conversely, emotional impulsivity and loss sensitivity were not individually associated with symptom severity measures when comorbidities were controlled (Chapter 4).

5.2.2.1 ADHD

A wealth of research implicates EF problems in ADHD (Kasper et al., 2012; Schreiber et al., 2014; Willcutt et al., 2005), and theories of ADHD are centred around these findings. For example, Barkley (1997) argued that ADHD is explained by a 'core deficit' in inhibition. However, the heterogeneity of EF problems exhibited in ADHD challenges the idea that there is a core single process underlying ADHD, and this has led to the development of more complex theories implicating multiple pathways to the disorder. In addition to a cognitive pathway involving multiple EF, Sonuga-Barke et al. (2010) suggested that children with ADHD may also have difficulties in lower-level cognitive processes, such as timing, and in exerting top-down cognitive control over behaviour under conditions where rewards or punishments are involved (i.e., on hot EF tasks). Behavioural and neuroimaging studies provide converging evidence for cool EF and timing difficulties in ADHD (e.g., Alderson et al., 2008; Rubia, 2018). However, evidence that individuals with ADHD exhibit problems in hot EF are mixed (Antonini et al., 2015; Nejati et al., 2020; Plichta & Scheres, 2014), and high rates of comorbidity between ADHD and ODD/CD (approximately 50%; Oerbeck et al., 2017), which are linked to hot EF (e.g., Hobson et al., 2011; Matthys et al., 2012), may have inflated estimates of poor hot EF when these co-occurring disorders are not accounted for. Therefore, to identify independent associations between ADHD symptoms and cool/hot EF, we used a dimensional approach to account for variation in co-occurring symptoms of ODD.

Throughout the Chapters of this thesis, we consistently found associations between ‘cool’ cognitive problems and ADHD symptoms. The severity of ADHD symptoms was associated with general low-level processes that are involved in encoding and processing information and organising responses (e.g., within-subject variability in response times and visuomotor accuracy, episodic memory; Chapter 3), as well as poor cool EFs (cognitive and response inhibition, sustained attention; Chapters 2 and 3). These results may support multiple pathways to ADHD, implicating both general cognitive processes and specific EFs (Nigg, 2013; Sonuga-Barke et al., 2010). However, the findings in Chapter 4 indicate that there is an underlying factor linked to the performance on the ‘cool’ cognitive tasks, which predicted the largest proportion of variance in ADHD symptoms (Chapter 4). Therefore, ADHD-related difficulties on EF tasks may be more parsimoniously explained by difficulties in basic attention/cognitive processes (Alderson et al., 2008; Sergeant, 2000).

The current study focused on the three core EFs coined by Diamond (2013) and Miyake et al. (2000) (i.e., inhibition, cognitive flexibility, and working memory). Some researchers have additionally found that children with ADHD also exhibit problems with planning (e.g., Willcutt et al., 2005). However, studies using a dimensional approach have found produced mixed results concerning associations between poor planning and symptomatology (e.g., Bauermeister et al., 2011; Sonuga-Barke et al., 2002). Planning is similar to cognitive flexibility because it involves lower-level EFs working together (Diamond, 2013; Rueda et al., 2005), and we found no associations between ADHD symptoms and cognitive flexibility (Chapter 2). Thus, our findings together may suggest that symptoms of inattention in young primary-school-aged children are not directly linked to higher, more complex EFs.

5.2.2.2 ODD

Evidence of cool EF problems in ODD is mixed (Schoemaker et al., 2013), and some have argued that the cool-hot dimension of EF differentiates ADHD (associated with cool EF problems) from ODD/CD (associated with hot EF problems) (Dolan & Lennox, 2013; van Goozen et al., 2022). Our study's findings support the idea that 'hot' EF problems are unique to ODD because we found greater reward-seeking on hot EF tasks was specifically associated with greater ODD symptom severity (Bai & Lee, 2017; Fairchild et al., 2009), as opposed to ADHD. This aligns with neurobiological studies which suggest ODD is uniquely associated with lower activity in brain dopamine systems, which could result in a lack of motivation to exert effort to obtain rewards, poor learning of stimulus-reward associations, or reduced influence of reward-associated stimuli on positive emotions (Matthys et al., 2012b).

However, in contrast to prior studies, we found ODD may be associated with a specific cool EF problem; poor cognitive flexibility (Chapter 2). These results indicate that young children exhibiting signs of ODD have difficulties in both top-down cognitive regulation under 'cool' conditions and when rewards are involved. The findings in this thesis may differ from previous research because ODD is rarely separated from Conduct Disorder (CD) (e.g., Rubia, 2011). Some have found that ODD is more strongly linked to reactive and impulsive aggression (Raine et al., 2022), and may be better conceptualised as a disorder of emotion regulation (Cavanagh et al., 2017), whereas CD involves more proactive and deliberate aggression and antisocial behaviour (England-Mason, 2020). Indeed, cognitive flexibility plays an important role in emotion regulation because it enables one to switch attention from the distressing event (Davis et al., 2010), thus problems in cool EFs may be specific to ODD and the presence of CD symptoms may mask these associations when not accounted for (e.g., Hobson et al., 2011).

5.2.2.3 Anxiety

Chapters 2-4 found that anxiety was associated with strengths in specific EFs, specifically increased cognitive flexibility and cognitive control. Furthermore, Chapter 2 showed that separation anxiety, the most prevalent type of anxiety in our sample, moderated associations between inattention and response inhibition. However, we also found separation anxiety associated with worse sustained attention and working memory. Therefore, although anxiety may improve performance in children with inattention problems on some tasks, this applies only under conditions of low cognitive demand. These differences are consistent with previous research showing that anxiety may positively affect low-level general cognitive processes that are sometimes compromised in children with ADHD (Bellgrove et al., 2004; Loo et al., 2009). On the other hand, anxiety has a negative effect on the 'central executive component' in working memory, worsening performance on tasks that require greater and more enduring attentional and memory processing (Eysenck & Derakshan, 2011; Ruf et al., 2017). Therefore, to understand cognitive problems in young children with emerging ADHD symptoms, the role of co-occurring anxiety should be taken into account.

5.2.2.4 ASD

Most disorders examined in this thesis are characterised by difficulties in SR (i.e., those associated with cognitive [ADHD; inattention], behavioural [ODD; risk-seeking] and emotional [anxiety/depression; prolonged distress, rumination] regulation). In contrast, poor SR is not a core diagnostic feature of ASD (APA, 2013) and the two symptom dimensions of

ASD – social communication difficulties and restricted repetitive behaviours – are not included in transdiagnostic models of dysregulation (e.g., Deutz et al., 2020; Geeraerts et al., 2015). Our results support this distinction because we found no evidence of unique associations between ASD and specific EF problems (see section **2.4.3** for a detailed discussion of this finding).

Instead, ASD was associated with relative strengths in cognitive inhibition. These results may suggest that ASD might mitigate specific EF problems in ADHD; however, previous research indicates this is not the case. ASD+ADHD is associated with poorer EF than these disorders individually (e.g., Cooper et al., 2014). In regard to the moderating effects of anxiety on cognitive function, the proposed mechanism of improvement (i.e., increased arousal) is supported by converging theoretical perspectives and experimental evidence (Arnsten, 2009; Eysenck et al., 2007; Ruf et al., 2017). For ASD, the mechanisms explaining why ASD was associated with better inhibition (e.g., visuospatial strengths; Kuschner et al., 2009) may be insufficient to overcome attentional control problems when ASD and ADHD co-occur.

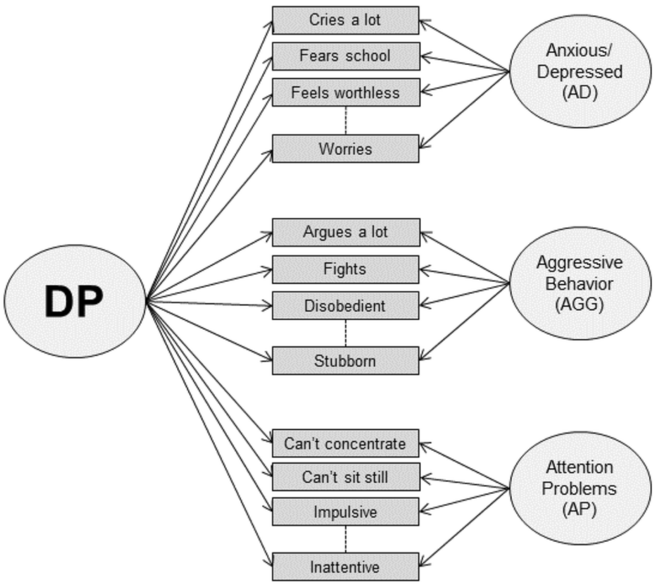
Although we found no evidence for a direct link between problems in cognitive SR processes and ASD traits, the prevalence of ASD symptoms in our sample was high (50%). Previous research has demonstrated that challenges in the modulation of cognition, emotions, and behaviour are a common experience for children with ASD, who are at a greater risk for other disorders characterised by poor SR (Conner et al., 2020; Joshi et al., 2010; Patel et al., 2017). Therefore, holistic assessments that include ASD and psychiatric problems at the same time are important for ensuring that behavioural manifestations of SR problems and underlying cognitive difficulties are not overlooked (Donaldson et al., 2017; Male et al., 2020; Shaw et al., 2022).

5.2.3 Aim 3: Can SR processes be broken down into disorder-specific domains?

Previous research has differentiated the top-down cognitive processes involved in SR into ‘cool’ and ‘hot’ EFs, which coincides with the distinction between cognitive and behavioural/emotional regulation. These SR processes are facilitated by neural regions within the PFC, which are recruited for the top-down control of motor/sensory cortices in cognitive regulation, striatal regions in behaviour regulation, and the amygdala in emotion regulation (Macdonald et al., 2016). At the same time, research investigating the clinical manifestations of SR problems has shown that dysregulation symptoms can be grouped together into those symptoms associated with ‘cognitive dysregulation’ (attention problems, ADHD); ‘emotional dysregulation’ (anxiety/depression); and ‘behaviour dysregulation’ (aggression in ODD/CD), as proposed by the ‘CBCL-DP’ model (Deutz et al., 2020; Geeraerts et al., 2015). Therefore, separations between SR domains may uniquely correspond to the development of clinical disorders, such as cool EF problems in ADHD (‘cognitive dysregulation’) and hot EF problems in ODD/CD (‘behaviour regulation’). However, these dysregulation symptoms frequently co-occur together, which indicates that there may be general underlying processes that contribute to overlapping behavioural manifestations of SR problems, that cut across diagnostic boundaries. Alternatively, there may be both shared and unique processes which are associated with emerging symptomatology, as reflected in a ‘bifactor model’ (Figure 5.1) (Deutz et al., 2018; Winsper & Wolke, 2014). Thus, the final aim of this thesis was to investigate whether the SR processes examined could be broken down into disorder-specific domains or whether these skills reflect overlapping problems across clinical disorders.

Figure 5.1.

Bifactor Dysregulation Profile model (Deutz et al., 2020)



5.2.3.1 Cool cognitive regulation processes and attention regulation problems

Some of our findings suggest SR can be broken down into disorder-specific domains. We found that cool EFs were clustered together (Chapter 4) and predicted variance in inattention symptom severity (Chapter 3), indicating that general, basic cognitive processes and low-level cool EF (e.g., inhibition) are specifically linked to attention regulation problems. Previous studies show that these cognitive processes involve the dlPFC, which is connected to the sensory and motor cortices, facilitating the cognitive regulation of attention and thought (Christakou et al., 2012; Cortese et al., 2012). Children with ADHD show altered activation and delayed maturation of the dlPFC compared to typically developing controls (Seidman et al., 2005; Shaw et al., 2007, 2013). Therefore, our finding that children with emerging symptoms of ADHD, particularly inattention, exhibited poor performance on cognitive tasks may reflect delayed maturation in the regions that mediate these skills.

However, our findings suggest that not all processes in the 'cognitive systems' domain, such as cool EFs, are associated with developing ADHD symptoms because we found that poor cognitive flexibility was associated with ODD symptom severity. Previous research has indicated that cognitive flexibility plays an important role in the emotional regulation problems in ODD (APA, 2013; Cavanagh et al., 2017). Our results may suggest that, when linking SR processes to developing clinical symptoms, it is important to distinguish between lower- and higher-level 'cool' cognitive regulation processes; more complex higher-level processes may be more strongly related to emotional rather than attentional regulation difficulties.

5.2.3.2 Hot cognitive regulation processes and general dysregulation problems

Our findings also indicate the presence of general dysregulation processes that are not accounted for in our classification systems. For example, the DSM separates symptoms of ODD (e.g., stubborn/sullen/irritable) from depression. However, we found that loss sensitivity was associated with both these disorders (Chapter 4), which may indicate a shared underlying process linked to poor SR (Brotman et al., 2017; Caspi & Moffitt, 2018). This overlap is consistent with previous research. For example, studies which have examined the factor structure of the CBCL-DP have found that the irritability symptoms of ODD load onto the general 'dysregulation' factor with depressive symptoms (e.g., looks unhappy, sad) rather than 'aggressive behaviour' (Geeraerts et al., 2015). Similarly, irritability in ODD shares common genetic factors with internalising disorders (anxiety, depression), whereas defiance symptoms are associated with externalising disorders (ADHD and CD) (Burke et al., 2014). This irritability/defiance distinction is relevant to the SR processes examined in this thesis because previous studies have shown irritability is linked to the poor regulation of responses to loss and negative feedback (Deveney et al., 2013), whereas defiance is associated with a dysregulated reward system characterised by impulsive and reward-driven behaviour (Rubia, 2011). Therefore, breaking down symptoms into those associated with defiance and irritability/depression may enhance our understanding how SR processes are linked to behavioural manifestations of ODD in children. Future longitudinal studies could examine whether these SR processes are able to predict different mental health trajectories. For example, children with altered loss sensitivity may be more at risk of developing depression than children who only demonstrate risky behaviour. Furthermore, because some cognitive processes may be associated with transdiagnostic behaviours, such as irritability, revisions of our classification system may be needed to accurately link symptoms to underlying processes (Insel et al., 2010).

5.2.3.3 Cool/Hot EFs and emotion regulation

Although loss sensitivity was examined as an indicator of poor emotion regulation (Chapter 4), the precise strategies that were used to down-regulate emotional responses on the task were not assessed, and we largely focused on 'cool' cognitive regulation. The two main strategies of emotion regulation are cognitive reappraisal and expressive suppression (Gross, 2014). Cognitive reappraisal involves cognitive re-interpreting the meaning of an emotional event and is associated with the activation of cognitive control areas within the brain (Poon et al., 2022). In contrast, expressive suppression is the inhibition of behavioural expression and is linked to increased activation in the amygdala (i.e., the emotion-generating part of the brain) and reduced activation of the regions involved in cognitive control (Zilverstand et al., 2017). Some studies have found associations between EFs and cognitive reappraisal (Schmeichel & Tang, 2015); thus, poor EF may explain poor emotion regulation in some children. Indeed, recent research indicates that individuals with ADHD are less likely to use this strategy and are more likely to compensate using expressive suppression (Liu et al., 2022), which is maladaptive because the emotional response is still fully activated (Cutuli, 2014; Gross, 2014; Kivity & Huppert, 2019). Therefore, strengthening EFs may be helpful in improving emotional regulation in ADHD indirectly.

However, EF difficulties cannot fully account for problems in emotion regulation. This is particularly apparent in children at-risk of ADHD and anxiety. We found co-occurring anxiety reduced inattention-related EF problems (Chapter 3), yet previous studies have shown that children with ADHD+Anxiety are more susceptible to being distracted by fearful stimuli and have greater difficulties in executing top-down cognitive control in anxiety-inducing situations (Liu et al., 2022; Pan et al., 2018). To explain these seemingly conflicting findings, it is important to consider the influential role of bottom-up processes in SR, such as stimulus-driven attention and emotional reactivity (Luria, 1973; Nigg, 2017), which interact with top-down cognitive control processes in a reciprocal manner. These interactions are particularly important in emotional contexts because physiological responses to stress support neural activity in the PFC in an inverted U-shaped fashion; whilst increased stress hormones are needed to activate EFs, high levels overwhelm PFC function, resulting in more reactive and unregulated responses (Robbins & Arnsten, 2009). Therefore, despite strengths in 'cool' cognitive control processes, children with emerging symptoms of anxiety and ADHD may be at greater risk for emotion regulation problems because bottom-up-driven processes, such as stimulus-driven attention and prolonged emotional distress disrupts the recruitment of these skills (Mah et al., 2016).

Anxiety co-occurs with ADHD in a high number of cases; 23-50% (Kessler et al., 2005a; Souza et al., 2005), affects treatment response (Hinshaw et al., 2015), and is associated with more attentional problems, school phobia, mood disorders and lower levels of social competence than either ADHD or anxiety alone (Gnanavel et al., 2019; Spencer et al., 1999). Yet, anxiety has received limited research attention relative to other comorbidities in ADHD (e.g., ODD/CD; Jarrett et al., 2016). The findings of this thesis and previous research indicate that targeting cognitive and EF problems in these children may be inefficient, particularly if top-down cognitive control is easily overridden by bottom-up responses, thus future studies should investigate other mechanisms that can be targeted to improve SR in this subgroup.

In summary, the findings of this thesis suggest that parcelling out the SR processes that are involved in disorders characterised by cognitive, behavioural and emotional regulation is not as simple as using the 'cool' to 'hot' EF distinction. For example, 'cognitive flexibility', a cool EF, was associated with ODD, and we found that regulating responses to loss may involve more general processes associated with multiple disorders. Our findings support efforts to revise dimensional classification systems with a greater endorsement of broad phenotypes that transcend diagnostic boundaries (e.g., irritability, aggression, impulsivity) (e.g., HiTOP; Michelini et al., 2021; RDoC; Insel et al., 2010), which will help to improve the mapping of overt behaviours to the underlying processes that contribute to SR. More specifically, breaking down specific disorders (e.g., ODD, ASD) further into symptom dimensions associated with specific processes (e.g., defiance; Griffith et al., 2019) may be necessary to differentiate between the symptom manifestations associated with behavioural regulation (i.e., risk-taking), and emotional regulation (e.g., cognitive flexibility, loss sensitivity). In order to integrate these findings and use both specific disorder dimensions (e.g., inattention) and more general manifestations of poor SR (e.g., irritability), linking SR difficulties to clinical symptom measures is best achieved using a bifactor model. This model acknowledges both shared and specific processes underlying dysregulation symptoms. Our findings suggest that this kind of transdiagnostic approach is necessary to provide a full picture of emerging difficulties in children and may be useful in future studies.

5.3 Strengths, limitations and future directions

5.3.1 Strengths

A strength of this thesis was that all Chapters used a community sample of teacher-referred primary school-aged children, which was useful for several reasons. Firstly, our sampling method enabled us to show that problems in specific SR processes are present in young, pre-diagnosed children with emerging clinical symptoms. Typically, children who exhibit lower levels of problems, or those who do not have a formal diagnosis to confer eligibility for specific interventions, are turned away from mental health services (Batstra et al., 2014; Edbrooke-Childs & Deighton, 2020; Male et al., 2020; McShane & Rouse, 2015). Our study indicates that these children still exhibit substantial problems in processes important for SR and would benefit from intervention in this domain. Secondly, by collaborating with schools to identify children at risk of NDDs and mental health difficulties, we were able to assess SR in children who also are less likely to access clinical services because of being in vulnerable groups, such as those who have experienced deprivation, trauma, or parental mental health problems (Doran, 2018). Third, by using both teacher- and parent- reports, we can be reasonably confident that children's symptoms were consistent across settings (NICE, 2008). We did not exclude children if they met specific diagnostic criteria and found substantial overlap in the problems that children were referred for (Figure 2.1). By including children with varying problems, our study reflects a realistic presentation of how NDDs and emerging mental health problems manifest in children, and our findings may be generalisable to young, at-risk children in the community.

5.3.2 Limitations

It should be noted that few children (< 6%) were referred for 'pure' emotional symptoms in line with reports that anxiety disorders typically emerge later in development (Aschenbrand et al., 2003; see Chapter 2). When anxiety is exhibited in young children, it is typically expressed as fears about separation, as opposed to generalised or social anxiety disorder (Beesdo et al., 2009), hence our focus on separation anxiety in Chapter 3. In other Chapters, our non-specific assessment of anxiety may reflect milder symptoms, which could benefit EF performance, whereas severe anxiety may be detrimental (Gunther & Pérez-Edgar, 2021). Because children with internalising symptoms can be overlooked by educational professionals (Marsh, 2015), our study may be underpowered to detect the effects of severe anxiety. Future studies focusing recruitment efforts on anxious children may be able to confirm whether or not anxiety has positive associations with low-level EFs or whether the relationship between anxiety and EF is an inverted U-shape one.

There are several confounding factors that this thesis did not take into consideration in data analyses. For example, socioeconomic status is associated with symptoms of NDDs and mental health problems (Merikangas et al., 2009; Russell et al., 2015) and poor SR (Backer-Grøndahl & Naerde, 2017). Therefore, it is unclear how substantially between-child factors (e.g., environmental resources) may have contributed to associations between SR processes and disorder symptoms. Similarly, we have found that the parents of children referred to the NDAU exhibit high rates of poor mental health, such as anxiety and depression (Adegboye et al., 2021). Parents play an important role in scaffolding and modelling effective SR (Berthelsen et al., 2017; Eisenberg et al., 2010b), and parents with greater mental health difficulties may struggle to regulate their own emotions and behaviour (Eiden et al., 2009; Feldman et al., 2009). As a result, children with emerging symptomatology whose parents have mental health issues are more likely to have poorer SR skills (Berthelsen et al., 2017). Therefore, parental mental health and socioeconomic status may have contributed to mediatory processes associated with clinical symptoms, as well as independently predicting symptomatology via genetic, biological and temperamental factors (Robinson et al., 2022). Therefore, the proportion of children in our sample living with parents with mental health problems and in poverty may have added to the severity of cognitive difficulties children displayed.

All Chapters of this thesis used a correlational design. Thus, we cannot comment on the causal relationship between SR processes and clinical symptoms. Therefore, although we argue that SR mediates links between early risk factors and clinical symptoms, it is also possible that emerging symptoms of NDDs and mental health problems result in poorer performance on cool and hot EF tasks. The neural processes within the PFC that are involved in SR continue to develop throughout childhood and adolescence (Diamond, 2013; Skeem et al., 2014). Therefore, follow-up studies of our sample are needed to examine how these processes, over time, predict changes in children's symptomatology.

This thesis used a dimensional and transdiagnostic approach, which aligns more closely with the development of neural, cognitive, and behavioural processes associated with developing NDDs and mental health problems than diagnostic cut-offs (Caspi & Moffitt, 2018; Krueger et al., 2018). We found that breaking down ADHD into inattention and hyperactive-impulsive symptoms yielded different results regarding underlying cognitive processes (Chapter 3). Similarly, previous studies have shown that breaking down disorders into specific symptoms may improve our understanding of SR processes in ODD and ASD (Griffith et al., 2019; Schmitt et al., 2019), but this level of complexity was beyond the scope of the current study. Moreover, breaking down DSM disorders does not fully overcome issues of symptom overlap. For example, symptoms of ADHD and anxiety disorders both include difficulty concentrating, irritability, and restlessness (Krone & Newcorn, 2015). Therefore, future studies may benefit from abandoning DSM classifications altogether. For example, within the HiTOP hierarchical dimensional classification of mental health problems (Kotov et al., 2017), syndromes and disorders do not correspond to broad disorder composites (e.g., ADHD) and instead represent specific independent dimensions (i.e., hyperactivity, anhedonia, irritability impulsivity) (Gomez et al., 2021). Because these alternative classification systems may be more strongly representative of underlying aetiology, behavioural manifestations and psychological processes, they may have greater clinical utility for prognosis and treatment

(Conway et al., 2019), and may help us to understand further sources of heterogeneity in SR problems (Michelini et al., 2021).

As discussed in previous Chapters, all samples had a higher proportion of boys than girls (68%-71%), which is comparable to studies which have examined rates of NDDs and externalising mental health problems in primary school-aged children (Ogundele, 2018). Previous research has shown that teachers are more likely to recognise and be intolerant of overt and externalising behaviours in boys, whereas girls are more likely to mask and internalise symptoms (Dean et al., 2017; Dhuey & Lipscomb, 2010; Gaub & Carlson, 1997; Levy et al., 2005; Marsh, 2015). Each study looked at differences between boys and girls, and collectively we found that girls only performed better on our assessment of cognitive flexibility (Chapter 2). Therefore, our findings suggest girls are still at-risk of SR problems as a result of poor cool/hot EF and increasing teachers' awareness of how SR problems and clinical symptoms manifest in girls is important to ensure their needs are not overlooked.

5.3.3 Implications

Children and young people who are referred to mental health services by teachers are more likely to be rejected than children referred by medical professionals (Smith et al., 2018). This thesis shows that teachers can identify children with clinically significant symptoms of clinical disorders (Chapter 3) as well as EF and SR difficulties (Chapters 2-4), both of which are associated with significant problems later in life (Chorozoglou et al., 2015; Eisenberg et al., 2017; Moffitt et al., 2011). Indeed, previous research shows that parental reports of teacher concerns are more predictive of ADHD than parental concerns alone (Ford et al., 2005), and schools are an important location for early detection and intervention because children spend so much time there (Domitrovich et al., 2017; Grimm et al., 2022). Therefore, one important future direction is to investigate ways of supporting teachers in identifying and supporting young children whom they identify as struggling at school. Furthermore, more integrated work between education and medical services will help to promote earlier access and appropriate intervention for children if teachers are recognised as valuable identifiers of at-risk children.

The current study confirms the substantial heterogeneity of cool/hot EF problems that can be exhibited in at-risk children. Relying on diagnostic categories to interpret underlying problems may lead to errors if co-occurring symptoms are not considered; thus, objective assessments of these skills are still necessary to fully understand the cognitive problems a child may be exhibiting. It is also important to recognise that the surface manifestations of some disorders can change (e.g., ODD to depression, Burke et al., 2010; Ip et al., 2019), whereas underlying processes such as self-regulation may be relatively stable in predicting psychopathology symptoms and other negative outcomes later in life (Becker et al., 2014; Cheng et al., 2018; Dassen et al., 2018). Similarly, recent research indicates that there are multiple pathways to clinical symptoms, yet mediatory processes such as SR may be consistently useful indicators of risk that are easier and less expensive to measure than early risk factors (e.g., genes) (van Goozen et al., 2022; Zdorovtsova et al., 2023).

All Chapters in this thesis used a correlational design; thus, there is a need for longitudinal research to verify the causal links between the SR processes (e.g., cool EF, memory, reward-seeking) and clinical symptoms. Furthermore, SR is a bidirectional system; executing EF is related to bottom-up, less volitional responses to the environment through attention, emotion and stress (Blair, 2002; Blair & Dennis, 2010; Ursache et al., 2011). Although the current study did consider how bottom-up and top-down processes interacted by studying hot EF (Chapter 4), the use of EF in daily life, where other stressors influence one's ability to carry out cognitive control, was not considered.

If indeed it is found that improvements in specific cognitive processes are associated with reductions in symptoms and associated difficulties, the findings of this thesis may have useful implications for the development of interventions. The development of cognitive control is associated with changes in the PFC, such as synaptic pruning and myelination, during middle childhood and adolescence. Thus, early childhood reflects an age of relative neural plasticity (Huizinga et al., 2006; Tamnes et al., 2013), which provides an opportunity for early intervention before PFC dysfunction becomes increasingly entrenched over time (Macdonald et al., 2016). Currently, the evidence that cognitive training can reduce symptoms of disorders is mixed (Cortese et al., 2015), with limited evidence that these programs produce effects that transfer beyond the intervention to clinical symptoms (e.g., Dovis et al., 2015; Jones et al., 2019; Kollins et al., 2020). However, attempts to train SR processes largely use a 'one size fits all' approach and focus on older children. This thesis found difficulties were detectable in younger children and that there was substantial heterogeneity in the kinds of difficulties that children exhibited, indicating that it is important that interventions can be carried out in younger samples and that they should be tailored to specific cognitive problems. Furthermore, the findings of Chapters 2 and 3 highlight the importance of considering the potential moderating role of co-occurring symptoms, such as ASD and anxiety, which may alleviate specific cognitive problems. As a result, children with some comorbid symptom profiles may require a different approach.

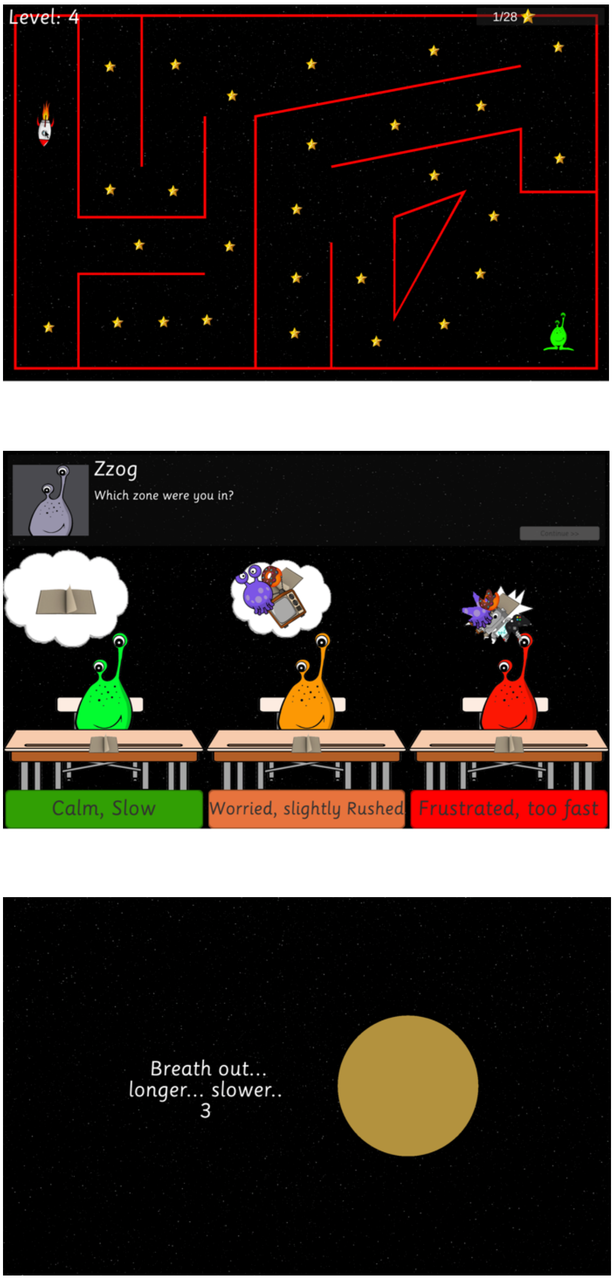
As well as bearing in mind heterogeneity, it may also be beneficial for intervention efforts to be informed by 1) how well training one process transfers to another, 2) the identification of the cognitive problems that are most prevalent, and (3) a consideration of which processes are less influenced by comorbidity (Delalande et al., 2019; Rapport et al., 2013). Hierarchical models of EF development and some results in this thesis suggest that intervention efforts should focus on more basic and general cognitive/attentional processes. In contrast, specific higher-level EF develop later and are more heterogenic. Because basic processes are the building blocks for more complex processes, training these skills early in life may positively affect the development of more complex cognitive processes that develop later (Butzbach et al., 2019). Throughout Chapters 2-4, we consistently found that a large proportion of children demonstrated problems on tasks requiring high levels of motor control and attention (ANT-ROO, ANT-Pursuit), and further found that performance on these tasks mapped onto a single factor which predicted variance in ADHD symptoms (Chapter 4). We also found that deterioration in performance over the full 5 minutes of the visuomotor and attentional control task was associated with inattention severity, and this effect was not moderated by comorbid anxiety (Chapter 3). Collectively the findings in this thesis, therefore, suggest that it may be beneficial for interventions for ADHD to shift their focus from working memory, which has been the main target of cognitive training programs (van der Donk et al., 2015), to visuomotor control and attention, in order to be suitable for a larger proportion of children.

5.3.3.1 Zzog's Adventure; a self-regulation training

The findings of this thesis have been used to inform the development of a self-regulation training program for children: 'Zzog's Adventure' (Figure 5.2). The training focuses on visuomotor control and attention, the most persistent difficulties we found in our sample. The training also involves emotional control (through rewards and punishments) to increase transferability by training these processes in motivationally demanding contexts and align with our finding (Chapter 4) that loss sensitivity and reward-seeking are important SR processes associated with ODD. The training also teaches children mindfulness strategies to regulate 'bottom-up' responses (see section **5.3**). The high prevalence of cool and hot EF problems in children referred to the NDAU and the findings from this thesis suggest that light-touch training is something that can be done easily by teachers in schools and is in line with an informed and targeted early intervention approach.

Figure 5.2

Zzog's Adventure



5.4 Conclusions

The need for earlier detection and intervention for individuals with mental health problems is becoming increasingly recognised (Grimm et al., 2022; McShane & Rouse, 2015), leading to efforts to identify intermediate processes that link early risk factors to adverse outcomes (van

Goozen et al., 2022). Accumulating evidence illustrates that the cognitive processes involved in SR offer an opportunity to identify young children at risk of clinical difficulties, particularly ADHD (Barkley, 2011; Blair & Raver, 2015; Heatherton, 2011; Zelazo, 2020). However, ADHD is a complex disorder associated with high heterogeneity and comorbidity, and we still have a limited understanding of the extent to which SR problems manifest in at-risk children, as well as the precise links between difficulties in SR processes and emerging clinical symptoms. To further our understanding of how SR problems can be utilised to identify at-risk children and develop tailored interventions, research adopting a broad transdiagnostic and dimensional approach is needed. This thesis is one of the first to have done so by examining SR processes in young, primary school-aged children referred by teachers for varying cognitive, emotional and behavioural problems.

The children in our sample exhibited substantial problems with processes important for SR, which were comparable to some studies of children with a clinical diagnosis (e.g., 72% in our study; 65% in Coghill et al., 2014b). These problems, such as memory and cognitive inhibition, were specifically related to ADHD symptomatology, whereas cognitive flexibility was associated with ODD. On the other hand, anxiety was associated with better cognitive flexibility and ASD with better cognitive inhibition. These results suggest that it is important to take a dimensional approach to parcel out specific SR process-symptom associations, and further highlight the potential moderating role of anxiety, which may improve inhibition in children with inattention symptoms. The thesis also investigated the role of hot EF processes; it was found that reward-seeking was associated with ODD (high reward-seeking) and depression (low reward-seeking). On the other hand, negative valence processes, such as loss sensitivity, were not disorder-specific.

Previous research has shown that difficulties in SR are not only predictive of symptoms of specific disorders but also of a range of adverse outcomes (Blair & Raver, 2015;

Bull & Scerif, 2001; Moffitt et al., 2011). Our findings highlight the importance of these processes, which could be used to inform early detection and intervention efforts. Currently, mental health services are set up in a way which does not consider younger children with lower levels of problems and traditionally relies on children to have a diagnosis to be eligible for intervention (Batstra et al., 2014; Edbrooke-Childs & Deighton, 2020; Male et al., 2020; McShane & Rouse, 2015). However, there is growing interest in how we can increase 'risk support' for children with emerging problems as well as provide treatment for children with more severe problems, as reflected in recent ideas for system change (Farr et al., 2021; Wolpert et al., 2019). The findings of this thesis align with these new approaches to prevent and alleviate mental health difficulties as early as possible because it is both inefficient and unnecessary for children to wait to have a diagnosis before receiving support. Our results underline the value of child-centred and needs-based approach to assessment and intervention. These approaches which acknowledge heterogeneity and comorbidity are more realistic than fitting children into categories, as is happening in current diagnostic systems. It follows that interventions targeting children's self-regulation by training specific processes, such as visuomotor control and attention, may be useful. Future studies may want to break down symptom manifestations further to improve our understanding of the development of SR problems in children.

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Appendix A.

RDoC domains and battery of neurodevelopmental measures for the Neurodevelopment Assessment Unit

RDoC Domain	Construct/Variable	Method	Task/Measure
Ability/Language	Receptive language	Computer	British Picture Vocabulary Scale (10 min)
	Expressive language	Verbal	Renfrew Bus story (4 min)
	Cognitive ability	Computer	Lucid ability test (Vocab. and Mental Rotation) (13 min.)
Cogn. Systems	Working Memory	Computer	Backward Digit Recall (AWMA, Pearson; 13 min.)
	Episodic Memory	Computer	NIH Toolbox*: Picture Seq. Memory (6 min.)
	Attention and inhibitory control	Computer	NIH Toolbox*: Flanker (7 min.) + ANT ROO (Resp. Org. - Part 1, 2 & 3; 8 min)
	Motor Coord. & Sustained Attention	Computer	ANT Pursuit^ (5 min.)
	Cognitive flexibility	Computer	NIH Toolbox*: DCCS (8 min.) + ANT ROO Part 3
Neg. and Pos. Valence systems	Empathy (cognitive, affective)	iMotions/ Verbal	Verbal reactions to real-life videos (25 min.)
	Emo. Recognition	Computer	Facial Emotion Recognition test (FER; 8 min.) Face/Body Emotion task
	Response to Threat & Reward	Computer	Balloon Emotion Learning Task (BELT; 7 min.)

	Risk aversion, impulsivity	Computer	Hungry donkey task (2 deck IGT) (7 min.)
	Frustrative non-reward	Observation /Computer	Perfect Blue Circle (PBC; 5 min.)
Arousal/Regulatory systems	Heart-rate	Actiwave	Heart-rate data (Baseline, Flanker, Perfect Blue Circle)
	Sensory Room	Observation	Subjective ratings + Ranking task
Systems for Social Processes	Social Attention	Eye-track§	AOIs to eyes, mouth in face
	Social Orienting	Eye-track§	First fixation / duration of first fixation
	Social Communication	Facial coding	Facial expression imitation
	Theory of Mind	Verbal/ Observation	Smarties identity task (1 min.) + Coco pops task (3 min.) + Sally-Anne location task (2 min.) + Second-order false belief task (4 min.) Tom and Jerry (6 minutes)
	Self-perception/esteem	Verbal	Harter scales (10 min)
	Social Functioning	Observation	
		Observation	
	Social Cognition	Computer	Social synchrony tasks x 2 (8 min + 8 min)
Motor development	Synchrony	Computer	Perception of auditory synchrony (8 min.) Motor synchrony (finger tapping) (3 min.)
	Coordination	Computer	ANT tapping & tracking^ (8 min.)
	Movement activity	Actiwave	Tri-axial accelerometer movement data during tasks (Baseline, Flanker, Perfect Blue Circle)
Physical development			Height and weight measurement
Genetic information		Saliva sample	

✜ RDoC = Research Domain Criteria (RDoC; https://www.nimh.nih.gov/research-priorities/rdoc/index.shtml); a research framework for new ways of studying mental disorders. It integrates many levels of information (from genomics to self-report) to better understand basic dimensions of functioning underlying the full range of human behaviour from normal to abnormal.

* *NIH Toolbox : http://www.nihtoolbox.org/Pages/default.aspx*
The selected tests are part of the Early Childhood Cognition Battery, recommended for ages 3-6. In addition to individual measure scores, administering this battery will yield an Early Childhood Composite Score, but only if we administer the Vocabulary which we are not currently 16.06.17.

^ *ANT: Amsterdam Neuropsychological Test battery (computer-based EF tests for ages 4 and above).*

§ *Eye tracking data are collected during empathy and emotion recognition tasks.*

Appendix B.

Parental interviews and questionnaires

Domain	Purpose of assessment	Method	Task/Measure
Child development and mental health	Family history, perinatal data, child development*	Questionnaire	SAGE questionnaire, ECHO questionnaire
	Broad symptom assessments	Questionnaire	Strengths & Difficulties Questionnaire (Goodman, 1997)
		Questionnaire	Child Behaviour Checklist (Achenbach & Rescorla, 2001)
	ADHD Symptoms	Questionnaire & Interview	SDQ & ADHD Development and Well Being Assessment (DAWBA) scale http://www.dawba.info/a0.html)
	Anxiety	Interview	DAWBA scales assessing generalized anxiety, social anxiety and separation anxiety
	Depression	Interview	Depression DAWBA scale
	ODD/CD	Interview	ODD/CD DAWBA scale
	ASD symptoms	Questionnaire	Autism Spectrum Quotient (AQ; DOI: 10.1007/s10803-007-0504-z)