Trait Inattention and Goal Representations

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Copyright Statement

Abstract

Inattention is a symptom of many clinical disorders. Research has shown that the symptom of inattention is best thought of as being on a continuum. Consistently, sub-clinical inattention has been shown to be related to impairments in working memory, particularly those functions related to goal maintenance. In six studies, the link between trait inattention and working memory limitations was investigated with the aim of differentiating inattention from hyperactivity and impulsivity, which are commonly comorbid with inattention in ADHD. Across two studies, it was found that trait inattention predicted the daily life reports of mind wandering. However, this relationship was also observed in hyperactive and impulsive traits. Unique relationships were however observed between trait inattention and goal neglect (as measured by a letter-monitoring task). Furthermore, it was found that inattentive traits uniquely predicted decreased performance on task switching and Stroop tasks where the use of goal maintenance (proactive control) would be beneficial to task performance; and goal neglect mediated these relationships. I discuss how these findings relate to the inattention, goal neglect and proactive control literatures. The key finding was the consistent replication of the unique link between inattention and goal neglect frequency (Chapter 3, Chapter 5), and the role that goal neglect plays in producing impairments in proactive control use.

Thesis Structure

This thesis conforms to an “integrated thesis” format whereby the chapters (Chapters 2 – 6) are included as discrete articles written for publication in peer-reviewed journals. The first and seventh chapters present an introduction/overview and discussion for the thesis, bringing each chapter together to reveal a consistent structure for the thesis. Each experimental chapter also begins with a preface clarifying the connections of the contribution to the overall aims and hypotheses of the thesis. The articles included in this thesis are at various stages of the publication/review process (see page 5). The main text of each chapter is presented as an exact replication of that prepared for submission meaning repetition between chapters is inevitable, particularly in the introductory sections. Figures and tables are numbered within each chapter, a list of these are presented pages 9–13.

Status of Articles from this Thesis

Chapter 2 has been published as:

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Chapter 4 is currently under review with the journal “Psychological Research”

Chapter 5 is submitted to the journal “Acta Psychologica”

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Authors Declaration

I hereby declare that the work presented in this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Chapter 1: Thesis Introduction

Introducing Inattention & ADHD

Inattention refers to the set of behaviours that could be attributable to the symptoms of many clinical disorders. Inattentive individuals tend to have difficulty in organising actions/thoughts and following conversations/instructions. Inattentive individuals also struggle to sustain their attention for extended periods (APA, 2013; Woods, Lovejoy, & Ball, 2002), especially in tasks that are not highly motivating (Huguet, Ruiz, Haro, & Alda, 2017). They are also forgetful and prone to boredom (Castens & Overbey, 2009; Kass, Wallace, & Vodanovich, 2003). Consequently, they hesitate to engage in activities with sustained mental effort (APA, 2013) and procrastinate (Weyandt & DuPaul, 2006). Another characteristic of inattention is careless mistakes due to lack of attention to detail (APA, 2013). Inattentive individuals also report frequent mind wandering like experiences and related problems such as inner restlessness and intrusive cognitions (Weyandt & DuPaul, 2006).

Inattention as a Symptom of Clinical Disorders

Inattention is a symptom of many clinical conditions including ADHD (APA, 2013) dementia (Kolanowski et al., 2012), major depressive disorder (Trivedi & Greer, 2014) and autism (Brieber et al., 2007; Mayes, Calhoun, Mayes, & Molitoris, 2012; Sinzig, Walter, & Doepfner, 2009). Like inattention, depression is linked to mood disorders, forgetfulness, and an inability to focus (Chamberlain & Sahakian, 2006; Ottowitz, Tondo, Dougherty, & Savage, 2002; Porter, Bourke, & Gallagher, 2007). Symptoms of both conditions also point to a lack of motivation (APA, 2013). The severity of inattention has been shown to be related to the severity of childhood depression (Rajendran, O'Neill, & Halperin, 2013). Furthermore, both ADHD and Autism Spectrum Condition exist on a continuum and thus at sub-clinical levels (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Kessler et al., 2005), and those with these disorders frequently experience depressive symptoms at clinical (Kessler et al., 2006; Lever & Geurts, 2016) and sub-clinical levels (Kanai et al., 2011; McKinney, Canu, & Schneider, 2013; Rosbrook & Whittingham, 2010; Takeda, Tsuji, & Kurita, 2017). Ruminative thoughts are also common in both ADHD (Oddo, Knouse, Surman, & Safren, 2018) and Autism Spectrum Condition (Crane, Goddard, & Pring, 2013). Inattention is also linked to schizophrenia (Egeland et al., 2003; Silverstein, Mavrolefteros, & Turnbull, 2003), with both sharing a common impairment in working memory reflected in altered dorsolateral prefrontal cortex activity (Barch et al., 2001; Barch, Csernansky, Conturo, & Snyder, 2002; Barr et al., 2010; Barr et al., 2011; Perlstein, Carter, Noll, & Cohen, 2001).

Inattention as a symptom of ADHD

Inattention is a core symptom of Attention Deficit Hyperactivity Disorder (ADHD) together with hyperactivity and impulsivity. ADHD is a widely diagnosed childhood onset neurodevelopmental disorder (APA, 2013). ADHD manifests in three presentations: Predominantly Inattentive (ADHD-I), Predominantly Hyperactive/Impulsive (ADHD-HI) and combined (ADHD-C: APA, 2013). Studies suggest that ADHD persists into adulthood (Barkley, Fischer, Edelbrock, & Smallish, 1990; Mannuzza et al., 2011) with primarily inattentive symptoms (Biederman, Mick, & Faraone, 2000; Biederman, Petty, Clarke, Lomedico, & Faraone, 2011; Faraone et al., 2000). ADHD is one of the most common childhood disorder (e.g., Barkley, DuPaul, & McMurray, 1990) with prevalence rates of 5–10 % in childhood (Polanczyk & Rohde, 2007) and 4.4 % in adulthood (Kessler et al., 2005). However, a broader criterion estimates around 17% in childhood (Barbaresi et al., 2002). Further prevalence studies revealed higher number of boys than girls with ADHD (Arnett, Pennington, Willcutt, DeFries, & Olson, 2015; Cantwell, 1996), mostly diagnosed with the common form (Lahey et al., 1994). For example, despite lacking the evidence for a potential sex difference (Derks et al., 2008), within U.K, the prevalence rates for 5-16-year olds were 2.6% for boys and 0.4% for girls (Green, McGinnity, Meltzer, Ford, & Goodman, 2005). This is thought to be due to the research mainly focusing on the combined form of ADHD and the higher rates of hyperactivity and impulsivity related symptoms in boys compared to girls (Weiler, Bellinger, Marmor, Rancier, & Waber, 1999). Latent class analysis on 1,549 female adolescent twin pairs revealed that the prevalence rates of ADHD-I, ADHD-HI and ADHD-C was 4.0%, 2.2%, and 3.7%, respectively (Hudziak et al., 1998). In addition to the unbalanced focus on ADHD-C, inattentive symptoms are also thought to be more difficult to identify (Bradshaw, 2001; Collingwood, 2010; Froehlich et al., 2007). Together these factors indicate a possible under diagnosis of ADHD for those with predominantly inattention such as women and/or adults (e.g., Carlson & Mann, 2002; R. Milich, Balentine, & Lynam, 2001; Weiss, Worling, & Wasdell, 2003).

ADHD Symptoms as Continuous Traits

Clinical diagnosis of ADHD involves a categorical decision after determining either the absence or presence of diagnosis based on the number of symptoms present. Studies using a categorical view of ADHD generally recruit ADHD-C participants and compose a control group of “unaffected” individuals, without considering potential sub-threshold levels of ADHD symptoms (Fair, Bathula, Nikolas, & Nigg, 2012). However, researchers have been criticizing the clinical diagnosis approach suggesting that a categorical view hinders the accuracy of the assessment and uses arbitrary thresholds (Jensen, 2000; MacCallum, Zhang, Preacher, & Rucker, 2002). Frazier, Youngstrom and Naugle (2007) also argued that such a view leads to neglecting sub-threshold levels which could have a significant impact on individuals' lives (Overbey, Snell Jr, & Callis, 2011; Whalen, Jamner, Henker, Gehricke, & King, 2003), and where intervention would otherwise be beneficial (Asherson & Trzaskowski, 2015). The alternative dimensional approach increases variability within the scores and improves statistical power. The idea is that ADHD symptoms exist in the normal population, and, those with a clinical diagnosis compose the extreme end. The continuous view of ADHD symptoms has been supported by genetic and taxometric studies reporting similar genetic variation between clinical and trait level ADHD (Asherson & Trzaskowski, 2015; Frazier et al., 2007; Gjone, Stevenson, & Sundet, 1996; Greven, Asherson, Rijsdijk, & Plomin, 2011; Greven, Rijsdijk, & Plomin, 2011; Levy, Hay, McStephen, Wood, & Waldman, 1997; Merwood et al., 2013; Plomin & Deary, 2015; Sawyer, Graetz, & Baghurst, 2002; Stergiakouli et al., 2015; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and showing a better statistical fit for dimensional as oppose to categorical (taxonic) model (Frazier et al., 2007; Haslam et al., 2006; Lubke, Hudziak, Derks, van Bijsterveldt, & Boomsma, 2009). Researchers also showed the impact of ADHD traits at sub-clinical levels (Asherson & Trzaskowski, 2015; Diamantopoulou, Henricsson, & Rydell, 2005; Haslam et al., 2006; Kim, Lee, & Lee, 2015). As a result, researchers and clinicians have suggested a shift to correlational designs evaluating the ADHD related traits on a continuum (Frazier et al., 2007) with separate dimensions of inattention, hyperactivity and impulsivity. Following this view, researchers have suggested that multi-dimensional disorders like ADHD are generally a result of various genetic, neuropsychological and environmental conditions with small effects, composing a bell-shaped distribution of traits (Coghill & Sonuga‐Barke, 2012; Willcutt et al., 2005). Thus, clinical level ADHD is best considered as the extreme end of a continuous dimension (Frazier et al., 2007) and symptoms and their effects at sub-clinical levels can be substantial and their study will be informative for understanding clinical-level expressions of the symptoms.

Inattention as a Separate Dimension

Most of the literature on ADHD has evaluated it as a unitary disorder, recruiting mainly participants with ADHD-C. Some have questioned whether these separate symptoms should be considered under the same disorder (Barkley, 2001; Diamond, 2005; Hinshaw, 2001; Lahey, 2001; R. Milich et al., 2001). For example, Hudziak (1998) conducted a study using structured assessment of DSM-IV on 1629 pairs of adolescent female twins from the general population. They found evidence for two distinct continuous domains of inattention and hyperactive/impulsive traits with prevalence estimates of 4.0% for predominantly inattentive, 2.2% predominantly hyperactive/impulsive, and 3.7% combined. Scores from the highly inattentive group also predicted academic and family problems while highly hyperactive/impulsive group scores predicted difficulties in social relationships. Hudziak et al. (1998) also concluded that the inattentive and hyperactive/impulsive symptoms belong to separate continuous dimensions. Consistently, using a bi-factor model of confirmatory factor analysis, Toplak et al. (2009) measured the ADHD symptoms on adolescents with ADHD diagnosis. They found evidence for separate factors of inattention and hyperactivity/impulsivity as well as a general factor covarying with these two factors, suggesting an overlap between the inattention and hyperactive/impulsive dimensions. Further studies with bi-factor analysis also revealed similar dimensionality distinction in adults (Smith Jr & Johnson, 1998), adolescents (Dumenci, McConaughy, & Achenbach, 2004; Nichols et al., 2017) and children with ADHD (Martel, Von Eye, & Nigg, 2010). Genetic studies also point to partially distinct aetiologies between inattention and hyperactive/impulsive dimensions (Greven, Rijsdijk, et al., 2011; Hudziak et al., 1998; Levy et al., 1997; McLoughlin, Ronald, Kuntsi, Asherson, & Plomin, 2007; Wood, Rijsdijk, Asherson, & Kuntsi, 2009).

Diamond (2005) stressed the differences in inattention and hyperactivity/impulsivity profiles. She suggested that taken from the name, hyperactivity is a key feature of ADHD-HI whereas ADHD-I represents a profile with more slowed responses. She further suggests that individuals with ADHD-I are overly self-conscious while those with ADHD-HI tend to lack self-consciousness. ADHD has been associated with a characteristic personality trait profile (Nigg, Butler, Huang-Pollock, & Henderson, 2002) with differences in each symptom dimension (Cantwell, 1996; Martel, Roberts, Gremillion, Von Eye, & Nigg, 2011): inattention was related to agreeableness, low extraversion and conscientiousness (Martel et al., 2011) while hyperactive/impulsive dimensions were more related to low agreeableness and high extraversion, negative emotions or neuroticism (Frick et al., 2003; Martel & Nigg, 2006; Martel et al., 2011; Parker, Majeski, & Collin, 2004). Furthermore, Martel and Nigg (2006) found that inattentive traits were related to resilience and effortful proactive control while hyperactive impulsive traits were linked to the use of reactive control.

Hyperactive/Impulsive symptoms were also associated with disruptive behaviours and social problems such as rule-breaking, not taking turns, failing to consider the others and aggressive behaviours (Martel et al., 2011) while inattentive symptoms were related to more internalised problems such as being passive, shy, or withdrawn (Goodyear & Hynd, 1992; Hinshaw, 2002; Wheeler Maedgen & Carlson, 2000), hence being more socially isolated or withdrawn than children with ADHD-HI or ADHD-C (Barkley, 1991; Barkley, Fischer, et al., 1990; Faraone, Biederman, Weber, & Russell, 1998; Nigg, 2000). Consistent to the link between disruptive behaviours, comorbidity with Oppositional Defiant Disorder and Conduct Disorder are more common among ADHD-HI and ADHD-C while internalised disorders like depression and anxiety co-occurs with ADHD-I (Frick et al., 2003; Lahey & Willcutt, 2010; Martel et al., 2011; Parker et al., 2004).

In a study with 497 college students, ADHD traits were linked to problems in dealing with stress (Overbey et al., 2011) while only inattentive traits were related to the lower levels of romantic satisfaction. Inattentive traits were also primarily related to the decreased use of adaptive coping strategies such as the use of personal growth, active coping, devotion of time on romantic relationships and expression of romantic feelings. Finally, both inattentive and hyperactive/impulsive traits were related to behaviours that reinforce negative self-concept such as “telling themselves how stupid they are, that they feel like failures, and that they feel depressed, tense, and anxious.” (Overbey et al., 2011, page 75). Furthermore, among a community sample of adolescents, Tercyak, Lerman and Audrain (2002) found that the use of cigarettes increased with the reported levels of inattentive traits. Inattentive symptoms were related to the use of nicotine to increase arousal and stimulation (Lerman et al., 2001). Inattentive traits were also related to the increased use of cannabis while hyperactive/impulsive traits were more related to the initiation of cannabis use (Bidwell, Henry, Willcutt, Kinnear, & Ito, 2014). Cognitive studies investigating the inattentive traits at sub-clinical levels also revealed limited working memory capacity (Elisa, Balaguer-Ballester, & Parris, 2016; Lui & Tannock, 2007) and frequent failures associated with goal neglect (Elisa et al., 2016).

Neuropsychological Theories Pointing to Heterogeneity of the Core Symptoms

The heterogeneity of inattention and hyperactive/impulsive symptoms has also been evidenced in neuropsychological studies (Chhabildas, Pennington, & Willcutt, 2001; Nigg, Butler, et al., 2002; Schmitz et al., 2002) reporting performance differences in measures of working memory, response inhibition control, set shifting, cognitive speed (Hinshaw, 2002; Lockwood, Marcotte, & Stern, 2001; Martel et al., 2011) and planning (Klorman et al., 1999). Kuntsi (2014) also conducted multivariate genetic model fitting analyses using ADHD scores of twin children from community samples on cognitive tasks. They found that reaction time variability was more correlated to inattention related genes (.64) than the hyperactive/impulsive phenotype (.31).

In his executive inhibition hypothesis, Barkley (1997) suggested response inhibition as the key impairment in ADHD-HI. Consistent with Barkley, poor response inhibition was reported for ADHD participants compare to controls (Crosbie & Schachar, 2001; Nigg & Casey, 2005; Rubia et al., 2001; Willcutt et al., 2010; Willcutt et al., 2005). To this view (Barkley, 1994, 1997, 1999), the response inhibition impairment results in secondary impairments on other executive abilities such as working memory, self-regulation of affect-motivation-arousal, internalization of speech and reconstitution. All these cognitive abilities allowing individuals to perform goal directed actions (Barkley, 1997). Some researchers found that inhibition impairments are accompanied by impairments in other domains of executive functioning such as planning, vigilance, set shifting, and working memory (Holmes et al., 2010; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Re, De Franchis, & Cornoldi, 2010; Willcutt et al., 2005) while others revealed non-significant results (Kuntsi, Oosterlaan, & Stevenson, 2001; Oades & Christiansen, 2008; Schachar, Logan, Wachsmuth, & Chajczyk, 1988; Smith, Taylor, Brammer, Toone, & Rubia, 2006; Van der Meere & Sergeant, 1987, 1988a, 1988b). Nigg et al. (2002) also revealed that response inhibition impairment was primarily related to boys with ADHD-C compare to the boys with ADHD-I while no difference was found for girls. Sample characteristics of the inhibition studies may have yielded inconsistent results (Solanto, Schulz, Fan, Tang, & Newcorn, 2009). Typically, studies recruited combined subtypes of ADHD-C and ADHD-I despite the evidence for the heterogeneity (Booth et al., 2005; Bush et al., 1999; Durston et al., 2003; Lahey, 2001; Katya Rubia et al., 1999; Schulz et al., 2004; Schulz et al., 2005; Vaidya et al., 1998). Further research found that inattention was linked to executive impairments while hyperactivity/impulsivity was linked to risky decision making (Toplak et al., 2009). Barkley (1990) also suggested that his model represents ADHD-HI and ADHD-C better than ADHD-I.

Further attempts to explain the symptoms of ADHD focussed on regulations between moderators of arousal, activation and effort (Sergeant, Oosterlaan, & van der Meere, 1999; Zentall & Smith, 1993; Zentall & Zentall, 1983). Sergeant (2000) elaborated the executive function impairments argument within his Cognitive Energetic Model of ADHD. According to this view (Sergeant & Van der Meere, 1990; Sergeant et al., 1999), ADHD individuals are impaired in three energetic pools (arousal, activation, and effort) that regulate the stages of information processing needed for inhibition (Berger & Posner, 2000; Halperin & Schulz, 2006; Nigg & Casey, 2005; Sagvolden, Johansen, Aase, & Russell, 2005; Sonuga-Barke, 2003). Consistently, Castellanos, Sonuga-Barke, Milham and Tannock (2006) manipulated stimulus presentation rate which they hypothesised that it will reveal impairments associated with motivation and arousal. They showed that children with ADHD had particular problems on executive function tasks with a slow presentation rate while being unimpaired in tasks with fast presentation rate (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Van der Meere, Wekking, & Sergeant, 1991). This finding supported the cognitive energetic model because it suggests a role for these energetic pools in producing impaired performance rather than an impairment in the executive processes themselves. It is again important to note that most of these studies has samples of ADHD-C rather than looking at inattention individually. This may be important as some researchers argued that this was because the executive impairment is related to inattention while hyperactivity and impulsivity is more related to the motivation related impairment (Castellanos et al., 2006; Kuntsi et al., 2001; Shang, Sheng, Yang, Chou, & Gau, 2018; Sonuga-Barke, 2005) which is closely linked to the functioning of energetic pools, especially the effort component (Sergeant, 2005).

In addition to impairments in executive functions (Nigg, 2006; Willcutt et al., 2005) and motivation/arousal (Van der Meere et al., 1991), ADHD participants often showed a preference for smaller and immediate rewards over larger but later rewards (Dalen, Sonuga-Barke, Hall, & Remington, 2004; Hoerger & Mace, 2006; Schweitzer & Sulzer‐Azaroff, 1995; Solanto et al., 2001; Sonuga-Barke, 2002; Sonuga‐Barke, Taylor, Sembi, & Smith, 1992), referred as delay aversion (Sonuga-

Barke, 2005). Consistent to the delay aversion hypothesis, children with ADHD were hypersensitive to delay and struggled with waiting for the outcomes (Antrop, Roeyers, Van Oost, & Buysse, 2000; Sonuga‐Barke, 1994; Sonuga‐Barke, Houwer, Ruiter, Ajzenstzen, & Holland, 2004), often attempting to escape the delay (Sonuga‐Barke et al., 2004) and consequently, have problems with working for longer periods (Kuntsi et al., 2001; Neef, Bicard, & Endo, 2001; Schweitzer & Sulzer‐Azaroff, 1995; Sonuga‐Barke, Williams, Hall, & Saxton, 1996; Tripp & Alsop, 2001). The difference in delay aversion between ADHD and controls was independent of inhibitory impairment. This is supported by the finding that children with ADHD were able to wait despite the inhibition demand, however, they chose not to, even in the absence of inhibition demand (Solanto et al., 2001; Sonuga‐Barke, Houlberg, & Hall, 1994; Sonuga‐Barke, 1994). Delay aversion in ADHD has been evaluated in a broader concept as a motivational style (Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008; Sonuga‐Barke et al., 1992), and, ADHD is caused by deficits in the associations between the present action and future reward (Sonuga-Barke, 2005). Taking the motivation related delay aversion hypothesis further, the Dual Pathways model of ADHD (Sonuga-Barke, 2002) suggests that both motivation/reinforcement and executive deficits uniquely predict ADHD (Nigg & Casey, 2005; Solanto et al., 2001; Sonuga-Barke, Bitsakou, & Thompson, 2010; Sonuga-Barke, 2002, 2003). The Dual Pathways model of ADHD is consistent with the previous findings reporting impaired performances in motivation related tasks (Glow & Glow, 1979; Haenlein & Caul, 1987; Sagvolden, Aase, Zeiner, & Berger, 1998; Sagvolden et al., 2005; Sonuga‐Barke, 1994). ADHD participants also had inappropriate responses to unexpected imposition of delay (Bitsakou, Antrop, Wiersema, & Sonuga-Barke, 2006), extinction of reward (Sagvolden et al., 1998), discounted future rewards (Anouk Scheres et al., 2006) and were more affected by slow event rates (Wiersema, Van Der Meere, Roeyers, Van, & Baeyens, 2006). Notably, studies measuring ADHD symptoms in adults from clinical and community samples revealed that specifically hyperactive/impulsive symptoms were related to delay aversion (Scheres, Lee, & Sumiya, 2008). Sonuga-Barke (2005) and others (Kuntsi et al., 2001; Martel & Nigg, 2006) noted a differentiation between inattentive and hyperactive/impulsive dimensions within the dual pathways framework. They suggested that executive dysfunction was more of an inattentive characteristic while motivational deficits are related to the hyperactive and/or impulsive dimension (but see Lambek et al., 2018).

Diamond's View of Inattention

Diamond (2005) suggested that working memory impairment is the key impairment in inattention but not in hyperactivity/impulsivity (Elisa et al., 2016; Hinshaw, 2002; Martel & Nigg, 2006; Nigg, 2001). She argued that this working memory limitation is reflected in a slowed processing speed (slowed reaction times). Individuals with ADHD-I exhibit slower processing speed than those with ADHD-C (Calhoun & Mayes, 2005; Chhabildas et al., 2001; Malkovsky, Merrifield, Goldberg, & Danckert, 2012; Nigg, 2001; Nigg, Butler, et al., 2002; Solanto et al., 2007; Wodka et al., 2008), which is assumed to be related to the demand on working memory processes (Goth-Owens, Martinez-Torteya, Martel, & Nigg, 2010). The impairment in working memory is also reflected in daily-life in situation that place a high demand on working memory such as presentation of verbal material and responding to complex instructions (Diamond, 2005).

Although research has focused on the inhibitory deficit in ADHD due to the Prefrontal Cortex (PFC) abnormalities (Diamond, 2005; McCarthy, Skokauskas, & Frodl, 2014), working memory is also linked to PFC (Baddeley, 1997; D'Esposito, Postle, & Rypma, 2000; Owen, 1997; Pennington & Ozonoff, 1996; Petrides, 1996; Smith Jr & Johnson, 1998). ADHD-I participants also present similar impairments to frontal lobe patients under working memory demand such as when asked to manipulate numbers kept in working memory (Barkley, DuPaul, et al., 1990; Benedetto-Nasho & Tannock, 1999; Hynd et al., 1991; Welsh & Pennington, 1988; Zentall & Smith, 1993), or solving two step problems (Barbizet, 1970; Barkley, 1997; Luria, 1973). Indeed, inattentive symptoms have been linked to abnormalities in Dorsolateral Prefrontal Cortex (DLPFC: Arnsten, 2006; Seidman, Valera, & Makris, 2005; Siniatchkin, 2017; Van't Ent et al., 2009) which is known to be responsible for working memory (Barbey, Koenigs, & Grafman, 2013; Burgess et al., 2010). Similar to clinical samples (Shaw et al., 2011), the maturational delay of PFC regions such as DLPFC was also linked to inattentive symptoms in a community sample of 357 children and adolescents (Ducharme et al., 2012).

As a result, researchers have accepted ADHD as an umbrella construct with separate dimensions (Castellanos & Tannock, 2002; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Sonuga-Barke, 2005). For example, Zelazo and Muller (2002) proposed a distinction between the core executive (or "cool") functions related to DLPFC (Castellanos et al., 2006) and more motivation/affect related (or "hot") functions mediated by orbital and medial prefrontal cortex (Haber, 2003; Zelazo & Müller, 2002). Indeed, research has supported the idea that inattention is more related to the cool executive functions whereas hyperactivity/impulsivity is a "hot" executive function deficit (Castellanos et al., 2006; Shang et al., 2018 but see Skogli, Egeland, Andersen, Hovik, & Øie, 2014). Biederman et al. (2004) also found that ADHD children with executive function impairment were more inattentive compare to those without the impairment.

Indeed, a sample of children with ADHD-C and ADHD-I showed impaired performance on backward digit span (Mariani & Barkley, 1997; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Milich & Loney, 1979; Shue & Douglas, 1992). Pasini Paloscia, Alessandrelli, Porfirio and Curatolo (2007) also found that ADHD-I had lower scores than controls in digit span backward task. Although the ADHD group overall had worse performance on a visual and phonological N-Back Task, there was no significant symptom specific difference. Martinussen (2006) further revealed that inattentive but not hyperactive/impulsive symptoms predicted performances in verbal and visual-spatial working memory tasks. In another study with total sample of 145 adolescents with ADHD, working memory scores mediated the link between inattention symptoms and reading ability (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). Klingberg (2005) further reported reduced reports of inattentive symptoms following working memory training but similar improvement was also seen for hyperactive/impulsive symptoms. Schweitzer (2006), however, did not find a difference between the ADHD-C and ADHD-I (albeit with very small samples sizes for each group).

It is important to note that most of these studies were on children with ADHD while research on adolescents and adults is much more limited. Gansler (1998) found that only adults with ADHD-I demonstrated working memory impairment compare to the ADHD-HI group, revealing more perseverative responding in a rule switching task. However, Murphy, Barkley and Bush (2001) found no difference between groups. Murphy et al. argued that this inconsistency could be due to the differences in working memory measures and clinical diagnosis between the two studies. For example, Messina, Tiedemann, De Andrade and Primi (2006) found that, despite the nonsignificant subtype difference, ADHD-I showed the most impairment in working memory compared to ADHD-HI and ADHD-C when compared to controls.

The link between working memory impairment and inattentive symptoms is also present at sub-clinical levels. In children, Colbert (2017) and Lui and Tannock (2007) found that poor performance in digit span tasks was associated with inattentive but not hyperactive/impulsive dimensions (see also Alloway, Elliott, & Place, 2010; Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; Martinussen & Tannock, 2006; Thorell, 2007). Sub-clinical inattention was associated with Digit Span Backward performance on adults in a study reported by Kim (2004). Jonkman, Markus, Franklin and van Dalfsen (2017) further compared Operation Span performance of sub-clinical high and low inattentive groups, revealing no significant difference. However, using a larger sample of 95 participants and continuous design, Elisa et al. (2016) used simple (Digit Span Backward) and complex (Operation Span) measures of verbal working memory and reported that inattentive traits predicted working memory performance on both tasks. Although verbal working memory scores were predicted by inattention, it was not possible to conclude if inattention was a unique predictor as Bayes values were insensitive. In addition to the Digit Span Backward and Operation Span tasks, Elisa et al. conducted a further measure of working memory using Letter Monitoring Task (Duncan et al., 2008). They found that inattention was the unique predictor of the Letter Monitoring Task scores. In the Letter Monitoring Task participants are presented with a pair of letters or digits and asked to report the letters on a target side (left or right). Participants are initially instructed with a message of “WATCH LEFT” or “WATCH RIGHT” indicating the target side. After a few trials, a cue (“+” or “-“) is presented as a secondary instruction (“+” indicated to watch right while “-” means watch left) for which side to attend. Participants are expected to update the target side following the cue information. However, participants often ignore the cue instruction, even though they can correctly report the instructions before and after the task. The idea is that, the goal for the cue was neglected due to limited working memory capacity affecting how each component of the task instructions is weighted - the resultant goal representation is sufficient to report the task instructions if prompted, but not to act accordingly during the task itself. This task and its implications are discussed in more detail later (see section on Working Memory, Goal Representations and Goal Neglect below).

In addition to evidence linking inattention to limited working memory capacity in clinical and sub-clinical samples, there is substantial evidence of inattentive behaviour among low working memory groups (Gathercole et al., 2008; Holmes et al., 2014; Kane, Conway, Hambrick, & Engle, 2007; McVay & Kane, 2009). In their meta-analysis, Spencer-Smith and Klingberg (2015) also concluded that working memory training improved inattentive behaviours on children and adults.

In summary, both theory and evidence support a link between inattentive symptoms and impaired working memory at clinical (Messina et al., 2006) and sub-clinical levels (Elisa et al., 2016). However, the number of studies using adult samples is limited, making it difficult to conclude if the impairments in working memory is uniquely linked to inattention, and indeed what components of working memory are impaired.

Working Memory, Goal Representations and Goal Neglect

Together with inhibition and task switching, working memory is one of the three core components of executive functions (Friedman & Miyake, 2017). Although each component is proposed to be unique, there is evidence for a link between them (Roberts Jr & Pennington, 1996; Roberts, Hager, & Heron, 1994). Working memory refers to a limited capacity to hold and manipulate information (Baddeley, 1996; Miyake & Shah, 1999) and eventually, allows us to perform complex daily life activities such as solving math problems, reading and reasoning (Baddeley, 2003; Daneman & Carpenter, 1980; Daneman & Merikle, 1996; de Fockert, Rees, Frith, & Lavie, 2001; Gathercole & Pickering, 2000; Swanson, 1999). Baddeley and Hitch (1974) suggested separate components for verbal (phonological loop) and visual/spatial (visuospatial sketchpad) information. They also suggested Episodic Buffer responsible for the integration of the information from two other components. They further suggested a central executive component responsible for monitoring and manipulation of actively maintained information during complex cognitive tasks (Martinussen & Tannock, 2006).

Baddeley and Hitch's (Baddeley, 1993; Baddeley & Hitch, 1974) working memory model stressed the relationships between information maintenance and controlled processes (attention control) to accomplish goal directed behaviour. That is, working memory is required to do more than simply holding information in memory; it is also involved in cognitive control shielding/maintaining information against interference from irrelevant processes. Common consensus is that maintaining information requires resisting interference from a secondary task (Baddeley & Hitch, 1974) or distraction (Conway & Engle, 1994; Kane & Engle, 2000, 2002). For example, the Operation Span Task (Turner & Engle, 1989) requires participants to maintain a short series of words whilst also solving simple math problems in between. Unlike short term memory tasks, Operation Span Task is correlated with fluid intelligence, suggesting that working memory is linked to complex cognitive processes (Engle, 2001, 2002; Engle, Kane, & Tuholski, 1999; Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002).

Furthermore, the requirement for the maintenance rather than simple storage is a reference to the need for goal maintenance. Accomplishing complex cognitive tasks relies on executive control to bias responses towards task goals that are actively maintained (Roberts Jr & Pennington, 1996). When goals are not maintained, executive control can be captured by the external information, thereby producing errors (Unsworth & Engle, 2007). Thus, working memory capacity refers to more than a capacity for maintaining external information since it also plays a role in keeping goal representations active for successful task performance (Miller, 2000). Kane and Engle (2003) conducted Stroop task to test the goal maintenance role of working memory. In the Stroop task, participants are presented with a colour word written in different ink colours. Participants are asked to name the ink colour rather than read the word. Due to the natural tendency to read, when the colour word and the ink colour are incongruent (e.g., the word RED written in blue ink), participants need to successfully inhibit word reading processes. The tendency for word reading is less problematic in a congruent trial where the word and the ink refer to the same colour (e.g., the word red written in red); here the use of the goal representation for colour naming is less relevant. Kane and Engle (2003) used a version of the Stroop task with frequent congruent trials but rare incongruent trials. Given that most of the trials do not require the active goal representation participants are likely to make an error or suffer more interference from the irrelevant word on incongruent trials. In fact, what is needed under conditions of frequent congruent trials is strong active maintenance of the goal of colour naming. Kane and Engle found that low working memory capacity participants were less accurate than the high working memory capacity participants on the rare incongruent trials with goal representations demand.

Consistent with the goal maintenance role of working memory, research showed that the measures of working memory such as Operation Span Task correlated with proactive control, which is the ability to bias future behaviours in advance based on the maintained task goals (Braver, Gray, & Burgess, 2007; Kane et al., 2007; Redick, 2014). Braver et al. (2007) proposed that when performing complex cognitive tasks, individuals may response using two distinct control mechanisms, proactive and reactive control. Proactive control refers to the situations where individuals use internally maintained information such as goal representations to guide their behaviours in preparation for an upcoming event while reactive control is the use of immediate information available in the external information at the time at the time a decision is required. Thus, the use of proactive control depends on internally maintained goal representations (Iselin & DeCoster, 2009).

The concept of working memory has also been used to explain goal neglect (De Jong, 2000; De Jong, Berendsen, & Cools, 1999; Duncan, 1990, 1993, 1995; Jong, 2001). De Jong et al. (1999) argued that when attention is weakly focused on the task, participants fail to sufficiently utilise their inhibitory capabilities due to the problems in translating task goals into relevant task sets. As a result, participants may fail to perform well, despite, in principle, being capable of performing well if they had optimal goal drive. Using a fast-paced and slow-paced version of the Stroop Task, De Jong et al. reported that Stroop interference was much reduced in the fast-paced condition. They argued that this was because the fast-pace condition encouraged participants to stay on task and make better use of the goal representation (inhibition of the word meaning). In contrast, the slow-pace of the task encouraged slowed responses, leading weak inhibitory control of the word reading. De Jong et al. referred to this failure to fully engage inhibitory control in the slow-paced condition as goal neglect after Duncan et al. (1996).

Duncan et al (1996) defined goal neglect as the failure to follow some task instructions despite being able to report the instructions before and after the task (Duncan et al. 1996). Duncan et al. (2008) suggested that all relevant facts and instructions must be turned into goals that compose the *task model*. The model must be organised into small chunks of information and later retrieved when necessary. Task components compete to be represented as the information in the task model is increased. Consequently, weakly represented components are lost from the task model, resulting in neglect of those components of the goal. Duncan et al. (2008) argued that the task model differs from traditional working memory measures such as complex span tasks. For example, whilst the Operation Span Task requires maintenance of letters sequences presented (while also solving simple math problems in between), the letters needed to be maintained only for relatively short periods since they are continuously disregarded as they become unnecessary (e.g., periodic probes to report the last four-five letters). Participants also know that once they are reported, words will not be required for the rest of the task so that they can be disregarded periodically. On the basis of these assumptions, Duncan et al. (2012) argued that the task model refers to the capacity for goals/instructions, resembling the episodic buffer component of Baddeley and Hitch's (2000) working memory model. Duncan et al. argued that, like the task model, the capacity of the episodic buffer refers to more than the ability to process immediate information. Consistent with Duncan et al.'s (2012) argument, goal neglect is linked to fluid intelligence which is itself linked to executive functions (Bhandari & Duncan, 2014; Duncan, Burgess, & Emslie, 1995; Kane & Engle, 2003; Marshalek, Lohman, & Snow, 1983; Oberauer, Süß, Wilhelm, & Wittman, 2003). Other researchers also suggested the link between working memory and goal neglect is due to the role of working memory in maintenance of the task goals to bias future behaviour (Kane & Engle, 2003; Miller, 2000).

Patients with frontal cortex damage often demonstrate goal neglect-like behaviours. Individuals with frontal lobe lesions failed to perform certain instructions (e.g., raising the hand) when a cue appears (e.g., lights switching on), despite being able to report the instructions successfully (Luria, 1966). Milner (1963) also reported the resistance to switch from rules that are no longer correct, whilst being able to verbally report that these rules are no longer correct. That is, similar to working memory (Duncan & Owen, 2000; Koechlin, Ody, & Kouneiher, 2003; Miller & Cohen, 2001; Owen, Evans, & Petrides, 1996; Petrides, 1996, 2000, 2005; Petrides, Tomaiuolo, Yeterian, & Pandya, 2012), goal neglect seems to be related to the frontal lobe functioning.

In summary, Duncan et al. argued that in the absence of transparent external cues, complex behaviours (instructions of a complex task) must be organised into abstract goals to bias response selection. They argued that due to the attentional problems in goal weighting (mediated by PFC: Kane & Engle, 2003), participants fail to execute the actions that are insufficiently represented. That is, goal neglect is an example of failure to act based on the task goals in the absence of environmental cues (e.g., Duncan et al., 1995; Duncan et al., 1996), indicating a failure in active goal maintenance (Kane & Engle, 2003) (176). Similarly, Roberts and Pennington

(1996) suggested that in order to bias future responses based on the goals, they must be easily accessible. If the goals are not actively maintained, the cognitive processes could be captured by current distractions, resulting in goal neglect. Thus, goal neglect is a failure in working memory processes responsible for goal representations (Kane & Engle, 2003; Miller, 2000).

Inattention and Goal Representations

Although initially demonstrated in frontal lobe patients and older adults with low fluid intelligence (Duncan et al., 2008), goal neglect (failure in goal representations) has also been reported in more typical populations (Altamirano, Miyake, & Whitmer, 2010; Duncan et al., 1996; Duncan et al., 2008; Piek et al., 2004; Towse, Lewis, & Knowles, 2007), and, was linked to ADHD during antisaccade task (Karatekin, 2006; Kofman, Gidley Larson, & Mostofsky, 2008; Pennington & Ozonoff, 1996; Shue & Douglas, 1992; van Lambalgen, van Kruistum, & Parigger, 2008). Importantly, Elisa et al. (2016) found that inattentive symptoms predicted the frequency of goal neglect whilst controlling for fluid intelligence whereas for hyperactivity and impulsivity, no relationship was observed with goal neglect. This unique relationship, along with a similarly unique relationship reported for the Operation Span and Backward Digit Span tasks, is predicted by the hypothesis that inattention results from a working memory impairment. Notably, however, inattention was not found to be related to a spatial working memory task, whereas impulsivity was, suggesting that the relationship between working memory and the symptoms is more complex than an all or none relationship.

The frequent experiences of goal neglect for those reporting inattentive symptoms is consistent with the behavioural presentations of inattention such as difficulty in following instructions (APA, 2013). Elisa et al. (2016) also suggested that the problems with verbal instruction in ADHD-I may be due to the difficulty in representing and integrating each component of the instructions rather than failing to follow each one individually. As a result of goal neglect (Verbruggen, McLaren, & Chambers, 2014), individuals may fail to perform the instructed behaviours despite being able to understand them (Cole, Laurent, & Stocco, 2013). Consistently children with ADHD-I struggle to solve multiple-step problems although they are able to solve each step individually (Barbizet, 1970; Barkley, 1997; Luria, 1973). This is similar to Duncan's notion of knowledge chunking and organising goals into smaller parts to be able to perform complex tasks (Bhandari & Duncan, 2014), although it is this very same process of chunking or organising a task into components that results in some components being neglected. To sum, inattention was uniquely linked to the impairments in working memory for goal representations (as oppose to hyperactivity and impulsivity). The aim of this thesis is to investigate whether the potential consequences of the failures in goal representations are unique to inattention (as opposed to hyperactivity and impulsivity).

Figure 1. is a depiction of the role of working memory in constructing and maintaining goal representations (and task models). Figure depicts the three largely independent core executive functions of task switching, inhibition and working memory as identified by Miyake et al. (2000). As noted above, there is evidence for an impairment in working memory in those with inattention, although it is not clear whether this is unique to inattention or whether hyperactivity and impulsivity also result from impairments in components of working memory. There is evidence for an impairment in inhibition in those with hyperactivity (Barkley, 1997; Nigg,

Blaskey, et al., 2002) but the literature on inhibition impairments in inattention is not conclusive. For task switching, much of the work has been done on the ADHD combined groups. It is unclear which symptom of ADHD is responsible for poor task switching performance when it has been observed (Cepeda, Cepeda, & Kramer, 2000; King, Colla, Brass, Heuser, & von Cramon, 2007; Kramer, Cepeda, & Cepeda, 2001), and, moreover, the research here is contradictory (Oades & Christiansen, 2008; Rauch, Gold, & Schmitt, 2012; Wu, Anderson, & Castiello, 2006).

As noted above, working memory plays a role in the construction of goal representations needed for goal-oriented behaviour and also when following instructions (Kane & Engle, 2003; Miller, 2000). Working memory is also responsible for maintaining the constructed goal representations and shielding them from irrelevant, interfering stimuli and thoughts (Baddeley, 1993; Baddeley & Hitch, 1974; Duncan et al., 2008). Finally, working memory is shown to play a role in the simultaneous maintenance and manipulation of information in complex span tasks which were designed as measures of working memory capacity (Turner & Engle, 1989). Based on the data of Elisa et al. the Figure shows that neglecting components of task goals is an impairment unique to inattention. It also shows that whilst there is an impairment in span tasks in inattention, it is not an impairment seen on all complex span tasks, the spatial working memory measure was predicted by only impulsivity (Elisa et al. suggested the impairment in inattention might be limited to verbal span tasks) and thus is not unique.

A series of question marks highlight gaps in the literature in terms of their relationship to inattention; gaps this thesis intends to address. The main aim of the thesis is to address the blue question marks since the question being asked is what impairments are unique to the symptom of inattention. The blue questions marks represent the potentially unique impairments in inattention (as opposed to hyperactivity and impulsivity).

The final part of the figure represents the consequences of failures in goal representations and the maintenance/manipulation in the span tasks with green arrows showing the existing relationships in the literature (noted in previous sections). The association of frequent mind wandering to composite scores of ADHD was theoretically explained by its associations to the poor goal maintenance (McVay & Kane, 2009) and low scores on span tasks (Kane & McVay, 2012; Levinson, Smallwood, & Davidson, 2012; McVay & Kane, 2012), which are the characteristics primarily linked to inattention rather than hyperactivity/impulsivity or ADHD in general (Diamond, 2005). Thus, the first two chapters of the thesis address the issue of mind wandering in inattention in both experimental (Chapter 2) and survey (Chapter 3) studies. To foreshadow the results, whilst mind wandering is related to inattention, it is consistently shown not to be unique to inattention. Chapter 4 sought to understand whether inattention results from a unique impairment in task switching since this has not been addressed in the literature. Whilst a unique impairment was found, it was observed only when there was a role for working memory in the task switching task. Indeed, in contrasting two forms of control associated with working memory, namely proactive and reactive control, the study found that impaired task switching performance resulted from a tendency to avoid the use of proactive control when other forms of control were available (e.g., reactive control). Moreover, this tendency to neglect proactive control was accounted for by performance on Duncan’s letter monitoring task. Hence, Chapter 5 addresses proactive control use in inattention during Stroop Task to investigate whether the tendency to avoid proactive control use in inattention is limited to task switching conditions. Whilst those with inattention are again shown to be uniquely impaired in the use of proactive control, this impairment is shown to be accounted for by performance on the letter monitoring task described above; that is, it is shown to be accounted for by the tendency to neglect aspects of the task model. Chapter 5 also revealed that inattention was not linked to performance on the Stroop Task, a key measure of inhibition. The findings from these chapters reinforce the notion that rather than impairments in the cognitive processes of inhibition, switching or proactive control; neglect of task components is the key working memory impairment in inattention, and it predicts an avoidance of the use of proactive control in various contexts. Overall then these data strongly indicate that goal neglect is the key and unique impairment in inattention. The last experimental chapter reported that goal neglect, as indicated by performance on the letter monitoring task, can be ameliorated using Transcranial Magnetic Stimulation (TMS) indicating a potential way to treat this key impairment in inattention.

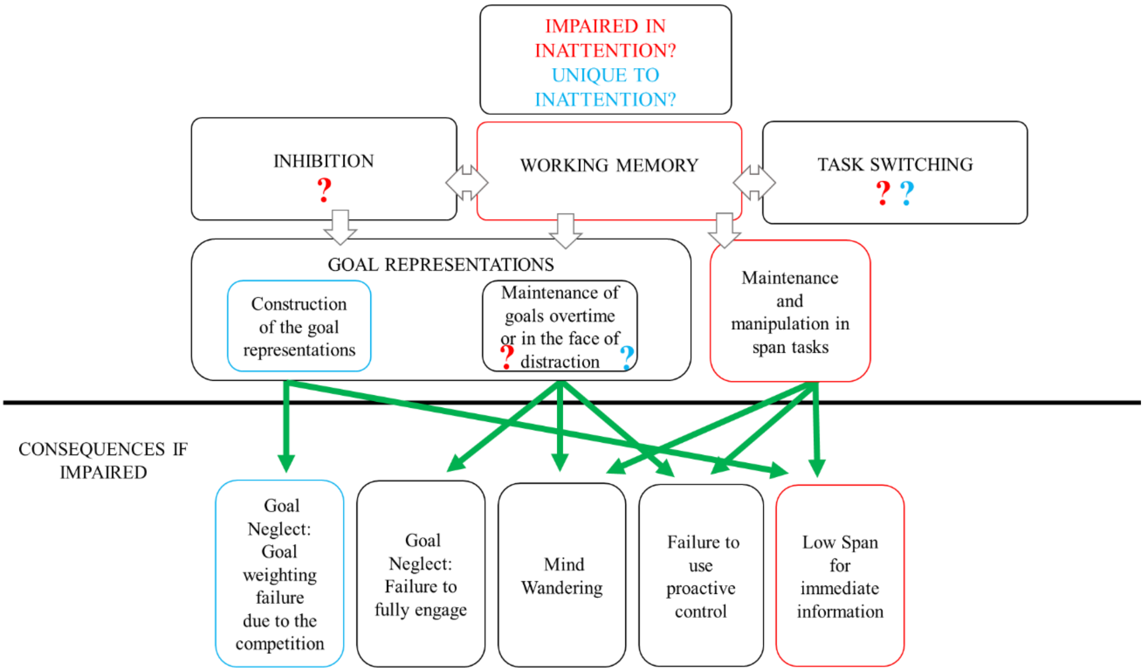

Figure 1. A depiction of the role of working memory in goal-oriented behaviour and in the broader network of executive control processes.

Chapter 2: Probe-caught spontaneous and deliberate mind wandering in relation to self-reported inattentive, hyperactive and impulsive traits in adults

Chapter 2 aims to clarify the link between inattention and mind wandering. As noted in the Chapter 1, the literature consistently reported an impairment in working memory for inattention (e.g., Diamond, 2005; Elisa et al., 2016; Lui & Tannock, 2007). Similarly, mind wandering has been linked to the working memory capacity. Researchers argued that limitations in working memory capacity lead to a disengagement from tasks, resulting in the experience of mind wandering (Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006, 2015). Others also suggested that working memory is needed to adjust the levels of mind wandering (Kane & McVay, 2012; Levinson et al., 2012; McVay & Kane, 2012). The idea is that, individuals tend to inhibit mind wandering when it is a cost to performance (e.g., during a difficult task). Consistently, higher working memory capacity participants report less mind wandering in difficult, compared to easier tasks (Seli, Risko, & Smilek, 2016). Despite the consistent link between working memory and inattention (but not hyperactivity/impulsivity) (Diamond, 2005), up until now the literature has investigated the link between mind wandering and ADHD in general but did not consider inattention as a distinct dimension. Therefore, Chapter 2 aims to investigate the link between mind wandering and inattention during easy and difficult tasks and investigate whether inattention will uniquely predict mind wandering.

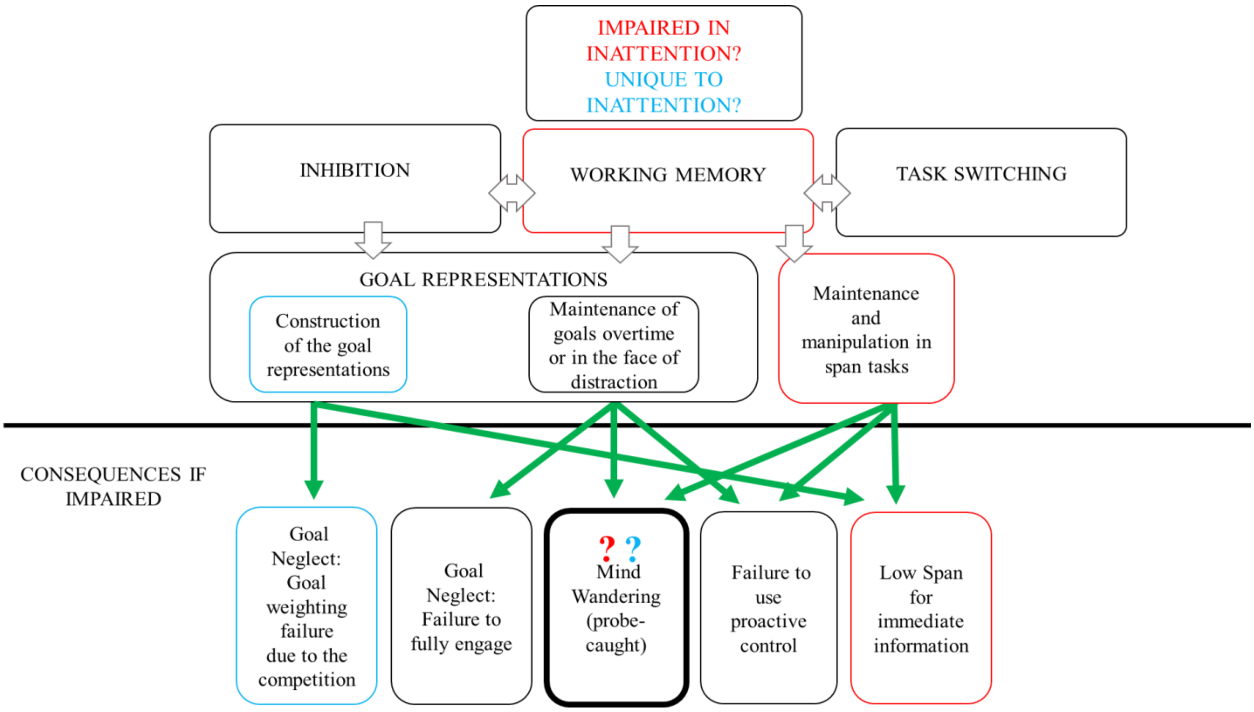

Figure A. A depiction of the role of working memory in goal-oriented behaviour, showing the aim of the Chapter 2 (highlighted in bold)

Abstract

Research has revealed a positive relationship between types of mind wandering and ADHD at clinical and sub-clinical levels. However, this work did not consider the relationship between mind wandering and the core symptoms of ADHD: inattention, hyperactivity and impulsivity. Given that the DMS-V attributes mind wandering to inattention only, and that only inattention is thought to result from impairment to the executive function linked to mind wandering, the present research sought to examine this relationship in 80 undiagnosed adults. Spontaneous and deliberate mind wandering were measured using standard and easy versions of the Sustained Attention to Response Task (SART). Results revealed that spontaneous mind wandering was related to self-reported inattentive traits when the task was cognitively more challenging (standard SART). However, hyperactive and impulsive traits were related to spontaneous mind wandering independent of task difficulty. The results suggest inattentive traits are not uniquely related to mind wandering; indeed, adults with hyperactive/impulsive traits were more likely to experience mind wandering, suggesting that mind wandering might not be useful diagnostic criteria for inattention.

Probe-caught spontaneous and deliberate mind wandering in relation to self-reported inattentive, hyperactive and impulsive traits in adults

Mind wandering has been defined as a shift of attentional resources from an external task toward internal thoughts, thus competing with the cognitive demands of the primary task for limited resources (Smallwood et al., 2007; Smallwood & Schooler, 2006). However, an emerging body of literature suggests conflicting hypotheses as to the nature of mind wandering. Under another view, task-unrelated thoughts (TUTs) are not resource demanding and are automatically and continually generated. Under this view, mind wandering occurs because executive control mechanisms fail to inhibit task unrelated thoughts representing a failure in executive control (McVay & Kane, 2009, 2010, 2012).

The evidence for the executive failure view (McVay & Kane, 2009, 2010, 2012) comes from the finding that those with high working memory capacity exhibit less mind wandering than those with low working memory capacity when the task is cognitively challenging enough (Kane & McVay, 2012; Levinson et al., 2012; McVay & Kane, 2012). Individuals with high working memory capacity are thought to be more able to adjust their levels of mind wandering when a task is challenging so that mind wandering would not hinder task performance. Individuals with low working memory capacity in contrast fail to adequately combat interfering thoughts and as a result, when attentional focus is needed for the primary task, their thoughts stay on-task less. Those with high working memory capacity readily inhibit such thoughts to achieve task performance. For example, during the Sustained Attention to Response Task (SART: Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), a commonly used task to sample mind wandering events, task difficulty has been shown to interact with the level of mind wandering (Seli, Risko, & Smilek, 2016). The SART presents participants with randomly presented digits (from 1 to 9) that participants must closely monitor and press a key on every trial except for when the number 3 appears. A view explaining the demands of the SART, the underload view, suggests that the struggle in performing SART is driven by the monotonous nature of the task (Nachreiner & Hänecke, 1992). Following this view, the SART is not a cognitively effortful which leads to frequent occurrences of attentional lapses (Nachreiner & Hänecke, 1992), making it difficult to stay on task (Robertson et al., 1997).

An alternative view, the cognitive overload view of SART (Head & Helton, 2014), suggests that the task requires constant monitoring of stimuli over a relatively extended period. Frequent attentional lapses resulting from the monotonous nature of the task creates cognitive overload and thus problems inhibiting the responses to the target stimuli. Consistent with the overload view, increased errors were observed with higher task demands during SART (Head & Helton, 2012, 2013, 2014; Head, Russell, Dorahy, Neumann, & Helton, 2012; Helton, Kern, & Walker, 2009; Roebuck, Guo, & Bourke, 2015). Indeed, Seli, Risko and Smilek (2016) employed both the standard SART in which the digits appear randomly and an easier version of the SART in which the digits appear sequentially as a way to manipulate task difficulty. Since the order of the digits was predictable, it is reasonable to argue that the sequential SART would be easier to monitor the target digit.

The literature has also stressed the heterogeneous nature of mind wandering (Seli, Risko, & Smilek, 2016). Although the literature has generally assumed that mind wandering means spontaneously generated thoughts, participants, when probed, report intentional engagement of mind wandering (Seli, Risko, Smilek, &

Schacter, 2016). This *deliberate* mind wandering is an effortful, intentional engagement of unguided thoughts, whereas spontaneous mind wandering refers to experiencing unintentional engagement of unguided thoughts (Carriere, Seli, & Smilek, 2013; Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Seli, Risko, & Smilek, 2016). This distinction has proved useful with individuals reporting more spontaneous mind wandering on the difficult (standard) version of the SART and more deliberate mind wandering on the easy (sequential) version of the SART (Seli, Jonathan, Carriere, & Smilek, 2015), supporting the notion of an act of control over deliberate mind wandering.

Recently, research has revealed a link between ADHD symptoms or traits and frequent experiences of mind wandering (Franklin et al., 2017; Seli, Smallwood, Cheyne, & Smilek, 2015; Shaw & Giambra, 1993). Attention Deficit Hyperactivity Disorder (APA, 2013) is a widely-diagnosed childhood-onset neurodevelopmental disorder with prevalence rates of 5–10 % in childhood (Polanczyk & Rohde, 2007) and 4.4 % in adulthood (Kessler et al., 2005). ADHD manifests itself in three presentations: Predominantly Inattentive (ADHD-I), Predominantly Hyperactive/Impulsive (ADHD-H) and combined (ADHD-C) (APA, 2013). Although clinical diagnosis of ADHD involves determining either the absence or presence of diagnosis based on the number of symptoms present, individuals could be affected by the impairments associated with ADHD at sub-clinical levels (Overbey et al., 2011; Whalen et al., 2003). Indeed, characterising inattention, hyperactivity and impulsivity as continua has been supported by taxometric studies (Haslam et al., 2006; Salum et al., 2014).

Whilst previous research has revealed a link between ADHD symptoms or traits and frequent experiences of mind wandering they have not considered the relationship between mind wandering and the core symptoms of inattention, hyperactivity and impulsivity individually. This might be because the DSM-V lists mind wandering as being related to inattention only. The following items appear only in the inattention symptom list: "Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction)" and "Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts" (APA, 2013). This is also consistent with the finding that, whilst inattention, hyperactivity and impulsivity have been associated with poor executive functioning (Nigg, Butler, et al., 2002), only inattention is theoretically and empirically related to impairments in working memory (Barkley, DuPaul, et al., 1990; Benedetto-Nasho & Tannock, 1999; Diamond, 2005; Elisa et al., 2016; Hynd et al., 1991; Zentall & Smith, 1993), the executive function linked to mind wandering. However, contrary to the notion that mind wandering is closely associated with inattention, Shaw and Giambra (1993) reported that experiences of spontaneous mind wandering were more frequent in individuals with higher self-reported hyperactive (e.g., fidgeting) (Seli, Carriere, Levene, & Smilek, 2013) and impulsive (Cheyne, Solman, Carriere, & Smilek, 2009) traits (they did not investigate inattentive traits). Indeed, Seli et al. (2015) have proposed that the distinction between spontaneous and deliberate mind wandering could be crucial in terms of understanding the aspects of ADHD symptomatology. For example, it is possible that hyperactive and impulsive traits are more related to spontaneous mind wandering, whilst inattention is more associated with deliberate mind wandering. This relationship might also be dependent on task difficulty and whether the cognitive underload or overload view of the SART is correct. For example, under the cognitive underload view of the SART (Helton, 2009; Helton &

Warm, 2008; Shaw et al., 2013; Shaw, Satterfield, Ramirez, & Finomore, 2012), the task effectively promotes inattention. Thus, given the nature of the task and evident issues those with inattention have with working memory, cognitive effort (Elisa & Parris, 2015) and sustained attention (Seli, Carriere, et al., 2013; Seli, Cheyne, & Smilek, 2013), it is reasonable to think that high inattentive traits would be associated with frequent deliberate mind wandering, especially in the easy condition. Alternatively, under the cognitive overload view, performing the SART requires constant monitoring over time, using executive resources, and as such inattentive individuals would be expected to report frequent spontaneous mind wandering, especially when the task is more difficult (when the digits are presented randomly) due to their limited working memory capacity (Diamond, 2005; Elisa et al., 2016). Thus, the present study could provide results that are informative to the mind wandering literature. In terms of understanding mind wandering itself and not just the SART, findings showing that ADHD-like traits are associated with spontaneous mind wandering would be inconsistent with the notion that spontaneous mind wandering is resource demanding since ADHD and its traits are associated with poorer executive functions and thus have access to fewer resources (Nigg, Butler, et al., 2002).

The aim of the present work was to investigate the relationship between self-reported traits of inattention, hyperactivity and impulsivity and types of mind wandering in a non-clinical sample of high functioning adults. Participants completed an ADHD questionnaire reporting their behavioural tendencies related to inattentive, hyperactive and impulsive traits. In addition to the ADHD questionnaire, we also measured experiences of spontaneous mind wandering and tendency to engage in deliberate mind wandering during both difficult and easy versions of the Sustained Attention to Response Task.

Method

Participants

Data were collected from an opportunity sample of 80 undiagnosed individuals. Participants were mainly students from Bournemouth University (39 undergraduate and 39 postgraduate and 3 other sources of employment). Participants were recruited through Bournemouth University's research participation system or an advertisement placed around the university listing the inclusion criteria of normal or corrected vision and an age limit (between 18 and 40). Rather than a power analysis, we included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1. Recruited participants were aged between 18 to 37 (*M* = 24.46, *SD* = .50) with self-reported normal or corrected vision. There were 30 male (*M* = 26.10, *SD* = 4.42) and 50 female (*M* = 23.56, *SD* = 4.23) participants. Participants received £10 for their involvement. All experimental protocols were approved by a Bournemouth University ethics committee. We confirm that all participants were provided with a consent form. We also confirm that all methods were performed in accordance with the relevant guidelines and regulations. Data collection and analyses were carried out in accordance with the approved study protocol and the guidelines of The Helsinki Declaration and Code of Human Research Ethics and The British Psychological Society.

Materials

Connors' Adult ADHD Rating Scale: Short Version (CAARS-S:S:

ADHD traits were assessed using CAARS-S:S (Conners, Erhardt, & Sparrow, 1999). Raw scores for inattention, hyperactivity and impulsivity symptoms are transformed into t-scores to make a comparison across participants. T scores range between 28 (lowest) to 90 (highest) calculated based on the age and gender.

Sustained Attention to Response Task (SART):

The Sustained Attention to Response Task was used to induce mind wandering. Two versions of the SART (standard and easy) were used to manipulate task difficulty as variation in task demands are reported to affect the measured frequency of deliberate and spontaneous mind wandering (Seli, Risko, & Smilek, 2016).

a. The Standard Sustained Attention to Response Task (SART; Difficult): On each trial, a single digit (1-9) was centrally presented for 250 ms. Then, an "x" mask was presented for 900 ms (total trial duration = 1150 ms). On each block, a digit was randomly chosen from 1 to 9 without replacement and was presented in black on a white background. Therefore, each digit was presented equally across the experimental trials. Participants were required to make a button press for every digit except 3. The presentation of the digit 3 required withholding the button press response. Participants were instructed to be as fast and as accurate as possible. The digits were presented in Courier New font. The digit sizes varied across all trials to control the familiarity effect. There were five possible font sizes (120, 100, 94, 72, and 48 points). Every nine trials four of the possible font sizes appeared twice and one appeared once (determined randomly).

A thought probe was randomly presented every 45 trials (five blocks of 9 digits), asking “Which of the following responses best characterises your mental state RIGHT NOW?” Participants were expected to choose one of the following possible responses (1) On task (2) Intentionally mind wandering (3) Unintentionally mind wandering. Experimental trials started with nine dummy trials with no thought probe presented to ensure that the thought probe was presented after several trials. Participants performed a total of 900 experimental trials (and nine dummy trials) with 20 thought probes following 18 practice trials with two thought probes.

b. The Sequential Sustained Attention to Response Task (SART; Easy): The procedure of the easy task was identical to the standard version of SART except that the digit presentation was in a sequential order (1 through 9), allowing it to be predictable. The task was adapted from Seli et al. (Seli, Risko, & Smilek, 2016).

Procedure

Initially, informed consent was obtained from all participants. After giving informed consent, participants were asked to sit in front of a computer at a distance of 50 cm. The presentation order of the SART and CAARS was pseudo randomised between participants. The SART conditions (easy and difficult) were also counterbalanced across participants.

Prior to completing the SART, participants received detailed instructions on the thought probes. Participants were informed that being on task means that either they were not thinking anything, or they were thinking about things related to the task (e.g., thoughts about their performance on the task, thoughts about the digits, or thoughts about their response), whereas mind wandering means that they were thinking about something completely unrelated to the task (e.g., thoughts about what to eat for dinner, thoughts about an upcoming test or friends). It was also made clear that participants were required to focus on the task in order to achieve the task performance. They were then informed that if they experience any mind wandering, they should indicate whether the mind wandering occurred intentionally (deliberately) or unintentionally (spontaneously). It was explained that mind wandering may occur unintentionally but may continue intentionally or unintentionally. Providing that participants are motivated to perform the task, mind wandering could/should initiate only in a spontaneous, unintentional manner.

Results

Sample

Scores from the CAARS revealed that 25% of participants scored above average on the ADHD index (M = 53.15, SD = 9.75). For individual symptoms, the percentage of participants scoring above the average was 53% for inattentive (M = 54.41, SD = 9.22), 6% for hyperactive (M = 50.06, SD = 8.68) and 60% for impulsive symptoms (M = 49.12, SD = 9.30). Five participants for inattentive, three participants for hyperactive and three participants for impulsive traits scored above the t-score of 70 which is the cutoff point indicating clinically significant problems (see Figure 1 for more detail). One participant also reported a previous ADHD diagnosis whereas two participants preferred not to state. Please see Table 1 in the supplementary material for detailed participant characteristics. Please note that the data from one participant was missing due to an incomplete data set (the experimental program was shut down half way through the easy SART due to a technical error on the computer and the data were not recorded as the task had not been completed). One participant's scores for deliberate and spontaneous mind wandering was removed due to unreliable task performance (the participant reported probe questions but did not respond to digits 1-9 except for 3 for more than half the trials). Total data loss was 1.25%.

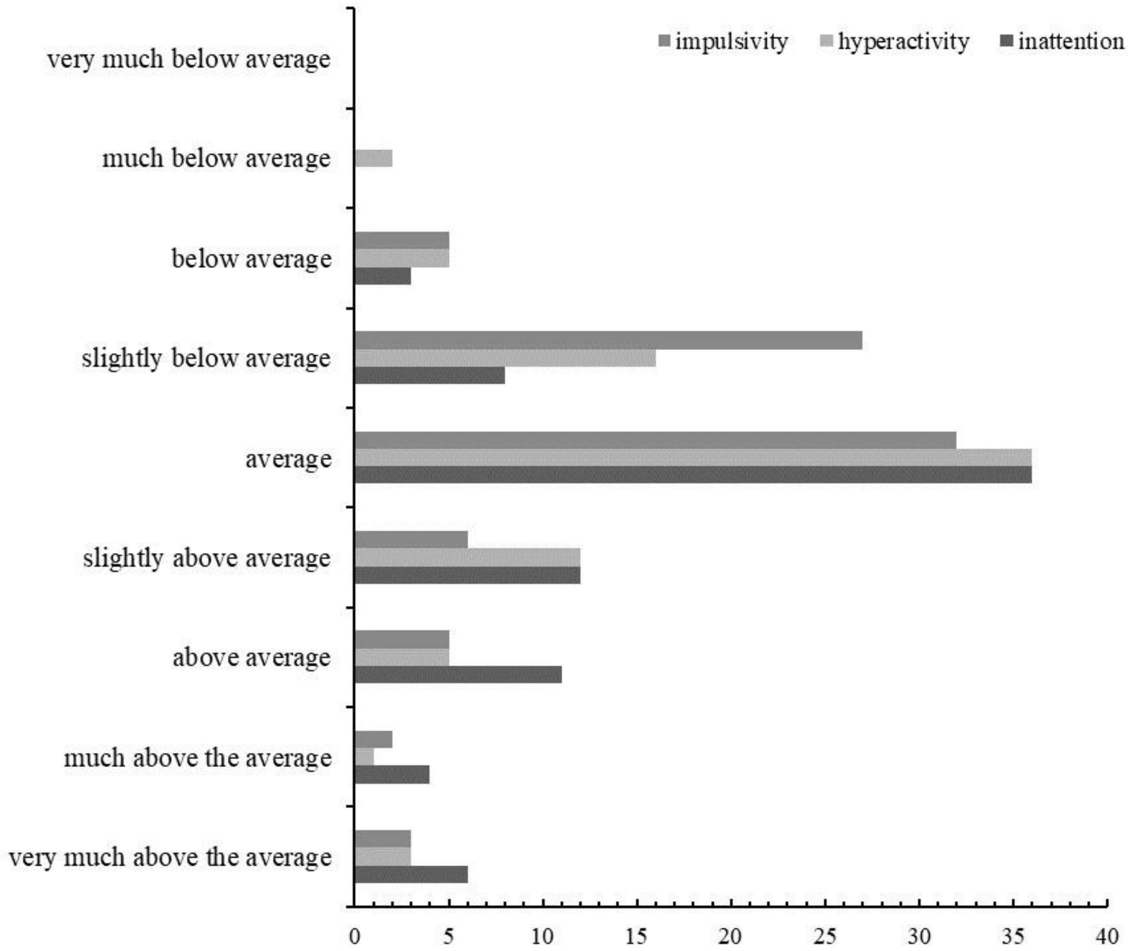

Figure 1. Number of participants falling into each category based on CAARS guidelines

Task Difficulty and Mind Wandering

We conducted a 2 (condition: easy, difficult) x 3 (Mind Wandering Type: spontaneous, deliberate and on-task) repeated-measures ANOVA to evaluate the effect of task difficulty on mind wandering. A Mind Wandering Type main effect was found, F (2, 77) = 17.52 p < .001, η^2 = .19. Bonferroni corrected pairwise comparisons revealed that participants reported more spontaneous than deliberate mind wandering (M_{diff} = 2.29, *SE* = .64, *p* = .002, *d* = .66), and, more on-task reports than spontaneous mind wandering (M_{diff} = 2.06, *SE* = .80, *p* = .037, *d* = .53). There were also more on-task reports than deliberate mind wandering reports (M_{diff} = 4.35, *SE* = .76, *p* < .001, *d* = 1.16).

Additionally, a Condition x Mind Wandering Type interaction was found, *F* (2, 77) = 7.23, *p* = .001, η^2 = .09. Bonferroni corrected paired samples t-tests were conducted to evaluate the Condition X Mind Wandering Type interaction (Figure 2). Participants reported more deliberate mind wandering in the easy condition (*M* = 5.27, *SE* = .51 vs. *M* = 3.64, *SE* = .38, *t* (77) = 3.33, *p* = .001, *d* = .41). However, levels of spontaneous mind wandering between the easy and difficult conditions did not differ, *t* (77) = .16, *p* = .87. There were also more on-task reports in the difficult than in the easy condition (*M* = 9.48, *SE* = .47 vs. *M* = 7.96, *SE* = .59, *t* (78) = -3.19, *p* = .002, *d* = .32).

Furthermore, in the difficult condition, participants reported more spontaneous than deliberate mind wandering (*M* = 6.70, *SE* = .47 vs. *M* = 3.61, *SE* = .38, *t* (78) = 4.35, *p* < .001, *d* = .82) whereas in the easy condition there was no significant difference between spontaneous and deliberate mind wandering, *t* (77) = -1.78, *p* = .078. On task reports were higher than both spontaneous (*M* = 9.70, *SE* = .47 vs. *M* = 6.70, *SE* = .47, *t* (78) = -3.49, *p* = .001, *d* = .72) and deliberate (*M* = 3.61, *SE* = .38, *t* (78) = 8.48, *p* < .001, *d* = 1.61) mind wandering in the difficult condition whereas on-task reports did not significantly differ from spontaneous *(t* (77) = -1.38, *p* = .17), and, deliberate (*t* (77) = 2.77, *p* = .007; non-significant following Bonferroni correction) mind wandering in the easy condition. In order to investigate the overall amount of mind wandering (the sum of spontaneous and deliberate) in the easy and difficult conditions, we also ran a pairwise comparison. There was more mind wandering reports in the easy than the difficult condition (M = 11.97, SE = .59 vs. M = 4.08, SE = .46, t (77) = -3.22, p = .002, d = 1.70). That is, the task difficulty manipulation modified type of mind wandering by reducing deliberate mind wandering in the difficult condition. In summary, overall mind wandering was higher in the easy compared to the difficult condition, and, participants reported more on-task reports in the difficult condition. We also observed more deliberate mind wandering in the easy condition. Please note that the accuracy and reaction time data for the SART were not analysed due to a programming error during data collection.

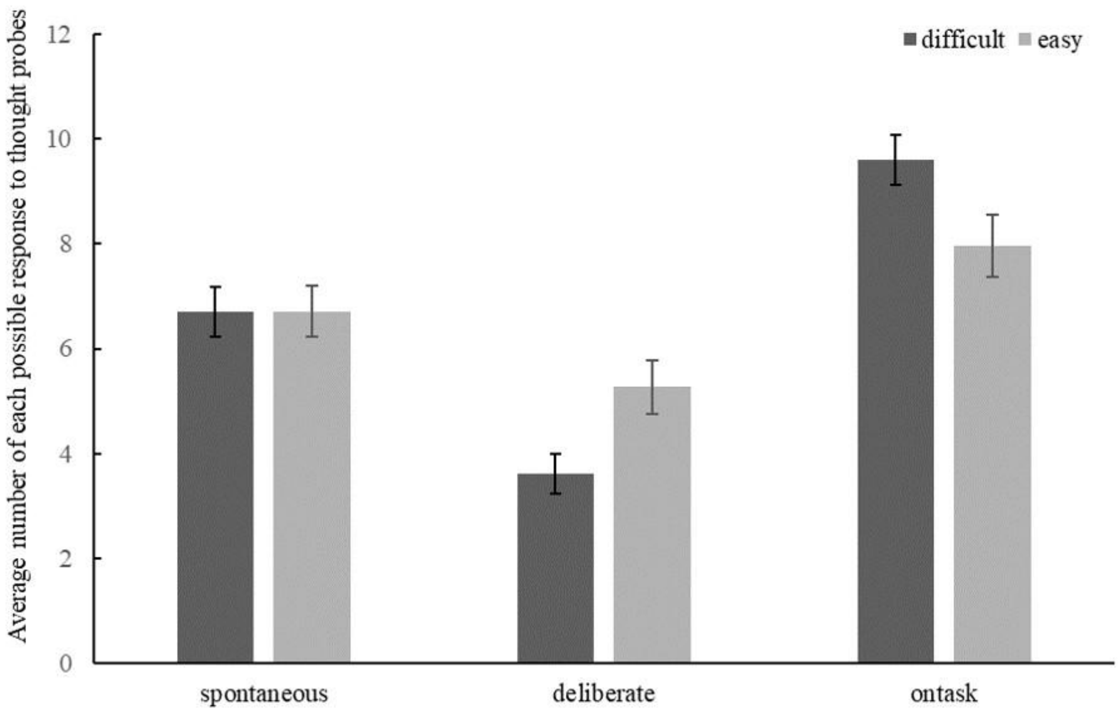

Figure 2. Average number of participants' reports of spontaneous and deliberate mind wandering and on task events by condition. Error bars indicating the standard error.

ADHD Symptoms and Mind Wandering

We first examined the bivariate correlations between the independent and dependent variables (Table 1). We then conducted multiple regression analyses with the enter method for each step to determine how CAARS scores for each individual trait (inattention, hyperactivity and impulsivity) were related to the different types of mind wandering in the easy and difficult task conditions. Variables were included in the same order for all models. The variable order was as follows: inattention, hyperactivity and impulsivity. We first entered inattention scores into the model since it seems to be the most likely candidate to predict types of mind wandering, as noted above. We then entered the scores for hyperactivity (Seli, Carriere, et al., 2013) and impulsivity (Cheyne et al., 2009) related traits. We also aimed to see whether the scores for inattentive traits alone would predict types of mind wandering and if so, would the predictive value of inattention be shared when controlling for other traits (hyperactivity and impulsivity). We used Bayes Factors (B) following the procedures of Dienes (2014) with the proposed cut-offs (Jeffreys, 1998) to assess the strength of evidence in support of hypotheses when the p value was not significant. In all cases where a Bayes Factor is given we modelled the predictions of the theory of some evidence for a relationship with a half-normal whose mean and standard deviation values were taken from a significant predictor of relevant regression analysis.

Table 1

Correlations between variables.

	N	Mean	SD	1	2	3	4	5	6	7	8	9
1. Inattention	80	54.41	9.22	-								
2.Hyperactivity	80	50.06	8.68	.51**	-							
3. Impulsivity	80	49.13	9.30	.45**	.56**	-						
4. Spontaneous MW (difficult condition)	79	6.70	4.16	.38**	.34**	.05	-					
5. Spontaneous MW (easy condition)	78	6.71	4.31	.19	.27*	-.06	.49**	-				
6. Deliberate MW (difficult condition)	79	3.61	3.38	-.02	.05	.16	-.40**	-.19	-			
7. Deliberate MW (easy condition)	78	5.27	4.52	.03	.16	.25*	.03	-.30**	.43**	-		
8. On-task (difficult condition)	80	9.60	4.25	-.37**	-.35**	-.19	-.62**	-.34**	-.41**	-.39**	-	
9. On-task (easy condition)	79	7.96	5.24	-.19	-.35**	-.17	-.43**	-.57**	-.21	-.62**	.62**	-

*p < .05, **p < .01

Spontaneous mind wandering. We conducted hierarchical regression analysis to test if the self-reported traits of ADHD measured by CAARS predicted types of mind wandering in both difficult and easy task conditions. For the difficult condition (Table 2), at stage one, scores for inattentive traits significantly predicted spontaneous mind wandering, $F(1, 78) = 13.14$, $p = .001$. At stage two, inattentive scores remained a significant predictor and the model explained 15% of the variation, $F(2, 78) = 7.93$, $p = .001$. At stage three, with the addition of impulsivity scores the model explained more of the variation (23%), $F(3, 78) = 7.30$, $p < .001$. Interestingly the relationship between spontaneous mind wandering and impulsivity traits was negative where the greater the reports of impulsivity, the fewer instances of spontaneous mind wandering reported.

Table 2

Summary of the regression model for inattention, hyperactivity and impulsivity scores of CAARS on spontaneous mind wandering in the difficult condition.

	Variable	*b*	SE*b*	β	*t*	R^2	R^2 change	Semi-partial correlation
Step 1						.15	.15**	
	inattention	.17	.05	.38	3.63**			
Step 2						.17	.03	
	inattention	.13	.06	.28	3.33*			.26
	hyperactivity	.09	.06	.19	1.57			
Step 3						.23	.05*	
	inattention	.16	.055	.34	2.33**			.31
	hyperactivity	.16	.06	.33	2.46*			.27
	impulsivity	-.13	.06	-.29	-2.28*			-.25

*p < .05, **p < .01

For the easy condition (Table 3), at stage one the model was not significant and inattention scores of CAARS alone did not predict spontaneous mind wandering. With the addition of the scores for hyperactive traits of CAARS, the model became significant and explained 8% of the variation, $F(2, 77) = 3.13$, $p = .049$. When scores for impulsivity related traits were added, hyperactivity scores became significant while inattention scores were still non-significant ($p = .276$, $B_{H(0, .07)} = 0.06$; the population prior was calculated from the variable hyperactivity in the same model). As with spontaneous mind wandering in the difficult condition, CAARS scores for impulsivity traits had a negative relationship with spontaneous mind wandering. The model explained more of the variation, $F(3, 77) = 4.53$, $p = .006$. Interestingly, this shows that whilst spontaneous mind wandering was predicted by the reports of inattentive traits in the difficult condition, it was not in the easy condition whereas both the scores for impulsivity and hyperactive traits predicted spontaneous mind wandering in both the difficult and easy conditions.

Table 3

Summary of the regression model for inattention, hyperactivity and impulsivity scores of CAARS on spontaneous mind wandering in the easy condition.

	Variable	*b*	SE*b*	β	*t*	R^2	R^2 change	Semi-partial correlation
Step 1						.04	.04	
	inattention	.09	.05	.19	1.68			
Step 2						.08	.04	
	inattention	.03	.06	.07	.52			.06
	hyperactivity	.12	.07	.24	1.82			.21
Step 3						.16	.08*	
	inattention	.07	.06	.14	1.10			.13
	hyperactivity	.20	.07	.40	2.85**			.31
	impulsivity	-.16	.06	-.35	-2.62*			-.29

*p < .05, **p < .01

Deliberate mind wandering. None of the models were significant at any stage: 1) Difficult condition: [Model 1: $F(1, 77) = .03$, $p = .861$; Model 2: $F(2, 78) = .21$, $p = .810$; Model 3: $F(3, 78) = .92$, $p = .434$] and; 2) easy condition [Model 1: $F(1, 77) = .06$, $p = .906$; Model 2: $F(2, 77) = 1.12$, $p = .331$; Model 3: $F(3, 77) = 1.99$, $p = .123$].

Reports of on-task. We conducted hierarchical regression analysis to test if the self-reported traits of ADHD measured by CAARS predicted the number of times participants reported being on-task for both the difficult and easy task conditions. The population prior for the Bayes factor calculation was taken from the variable inattention in the relevant model. For the difficult condition (Table 4), at stage one, scores for inattentive traits significantly predicted the number of on-task reports, $F(1, 79) = 12.37$, $p = .001$. At stage two, the model was significant ($F(2, 79) = 8.04$, $p = .001$) where inattentive traits remained significant when hyperactive traits were a non-significant but insensitive predictor ($p = .072$, $B_{H(0, .06)} = 0.60$). At stage three, with the addition of impulsive traits, the model explained 18% of the variation, $F(3, 79) = 5.44$, $p = .002$. Inattentive traits were the only significant predictor, hyperactive traits resulted in an insensitive result ($p = .06$ $B_{H(0, .06)} = 0.73$) and there was strong evidence for no relationship for the impulsive traits ($p = .539$, $B_{H(0, .06)} = 0.14$).

Table 4

Summary of the regression model for inattentive, hyperactive and impulsive traits of CAARS on the number of on-task reports where mind wandering is absent in the difficult condition.

	Variable	*b*	SE*b*	β	*t*	R^2	R^2 change	Semi-partial correlation
Step 1						.14	.14**	
	inattention	-.17	.05	-.37	-3.52**			-.37
Step 2						.17	.04	
	inattention	-.12	.06	-.26	-2.16*			-.24
	hyperactivity	-.11	.06	-.22	-1.83			-.20
Step 3						.18	.004	
	inattention	-.13	.06	-.28	-2.24*			-.25
	hyperactivity	-.13	.07	-.26	-1.91			-.21
	impulsivity	.04	.06	.08	.62			.07

*p < .05, **p < .01

For the easy condition (Table 5), at stage one, for the model where only inattentive traits were entered, the number of on-task reports was not significant, $F(1, 78) = 2.81$, $p = .10$. At stage two [$F(2, 78) = 5.23$, $p = .007$)], hyperactive traits were a significant predictor but there was strong evidence that inattentive traits were non-significantly related to on-task reports ($p = .903$, $B_{H(0, .07)} = 0.09$). At stage three, the model explained 12% of the variation [$F(3, 78) = 3.47$, $p = .02$] with the addition of impulsive traits. Hyperactive traits were again the only significant predictor whereas there was strong evidence for no relationship with on task reports and inattentive ($p = .855$, $B_{H(0, .07)} = 0.09$) and impulsive ($p = .781$, $B_{H(0, .07)} = 0.10$) traits.

Table 5

Summary of the regression model for self-reported inattentive, hyperactive and impulsive traits of CAARS on the number of on-task reports where mind wandering is absent in the easy condition.

	Variable	*b*	SE*b*	β	*t*	R^2	R^2 change	Semi-partial correlation
Step 1						.04	.04	
	inattention	-.11	.06	-.19	-1.68			
Step 2						.12	.09**	
	inattention	-.01	.07	-.02	-.12			-.01
	hyperactivity	-.21	.08	-.34	-2.72**			-.30
Step 3						.12	.001	
	inattention	-.01	.07	-.02	-.18			-.02
	hyperactivity	-.22	.09	-.36	-2.57*			-.28
	impulsivity	.02	.08	.04	.28			.03

*p < .05, **p < .01

Discussion

The aim of the present experiment was to investigate the relationship between spontaneous and deliberate mind wandering and self-reported traits of inattention, hyperactivity and impulsivity. A sample of undiagnosed adults (mainly university students) was used to explore this relationship given the evidence showing that both ADHD and the individual core symptoms are best described as being on a continuum (Overbey et al., 2011; Whalen et al., 2003). Mind wandering was measured using the probe-caught method during performance of the Sustained Attention to Response Task (SART). Moreover, we measured mind wandering during both standard (difficult) and less challenging (sequential) versions of the SART. The results revealed that inattentive traits were related to spontaneous mind wandering but only under difficult conditions; when the task was easy there was strong evidence for no relationship between inattention and spontaneous mind wandering. Hyperactive traits were related to spontaneous mind wandering in both the easy and the difficult conditions but in both cases only when impulsive traits were added to the model. Impulsive traits also predicted spontaneous mind wandering in both the easy and the difficult conditions. Finally, none of the ADHD related traits were related to deliberate mind wandering in the difficult or easy conditions, which is consistent with the findings of Seli et al. (2015). Importantly, the finding that spontaneous mind wandering was predicted by inattentive traits in the difficult condition only but was predicted by hyperactivity/impulsivity in both conditions is inconsistent with mind wandering being represented only in the inattention symptom list of the DSM-V (APA, 2013).

The strong evidence for no relationship between self-reported inattentive traits and mind wandering under easy task conditions is a surprising result given that hyperactive/impulsive traits uniquely predicted spontaneous mind wandering in the same condition, and given that the DSM-V refers to mind wandering related symptoms only under ADHD-I (APA, 2013). This finding suggests that spontaneous mind wandering in the easy task condition might be more related to failures in the executive function of inhibition. In contrast, the finding that for individuals reporting high levels of inattentive traits, spontaneous mind wandering is present when the task is difficult, suggests that spontaneous task unrelated thoughts may be triggered by the need for extra processing and effort on a task. Given the stronger relationship between self-reported inattentive traits and working memory than between hyperactive/impulsive traits and working memory even in non-clinical samples (Elisa et al., 2016), it is possible that spontaneous mind wandering in the difficult condition may be related to working memory limitations. That is, when resources are consumed by an ongoing task, working memory may be less able to prevent intrusive unrelated thoughts. Thus, our results point to potentially different underlying mechanisms for the same type of mind wandering in different conditions. Further studies with clinical samples would be beneficial to establish if this finding holds at clinical levels of ADHD.

Impulsive traits had a negative relationship with spontaneous mind wandering in both the easy and difficult conditions, indicating that the higher the impulsivity scores, the less mind wandering participants experienced. This was an unexpected result. Before going on to present possible explanations for this, we need to address a potential methodological explanation. The probe caught method itself could have influenced the results: Individuals reporting high impulsivity traits may have been more likely to choose the first possible probe option on the screen (on task was the option presented first). However, in our data, although impulsive traits were negatively related to mind wandering, there was strong evidence for no relationship between reported impulsivity traits and reports of being on-task in both the easy and difficult task conditions, rendering invalid this explanation of the data. Nevertheless, in future experiments it might be preferable to measure mind wandering by presenting the possible probe response options (e.g., deliberate, spontaneous, on task) in random order.

Aside from the practical methodological design explanation, it is possible that the negative relationship between impulsivity and spontaneous mind wandering might have something to do with the SART itself. It has been argued that the SART is a measure of the ability to inhibit impulsive responses (Head & Helton, 2013). Since research has revealed a decrease in mind wandering during challenging tasks (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009) it is possible that if those with impulsive traits find the task more difficult (precisely because the task is a measure of impulse control), they would be expected to report fewer incidences of mind wandering and thus a negative relationship between impulsivity and mind wandering would be observed.

An alternative explanation for this negative relationship is that individuals reporting high impulsive traits may be less able to catch spontaneous mind wandering reliably. Consistently, self-reported impulsive traits have been shown to be positively correlated with error awareness (O'connell et al., 2009), and, impulsive errors (measured by the ability to inhibit impulsive responding during SART) increase when participants are not aware of mind wandering (Smallwood et al., 2007). A methodological issue in mind wandering research is that the studies rely on participants' self-reports, however, mind wandering may continue for some time before it reaches awareness (Schooler & Schreiber, 2004; Schooler, 2002; Smallwood & Schooler, 2006). Therefore, a possible impairment with meta-awareness of spontaneous mind wandering in those reporting high levels of impulsivity traits may result in under recognized thus unreported mind wandering events. Further research is needed to investigate the role of meta-awareness, impulsivity and spontaneous mind wandering.

On the control of spontaneous and deliberate mind wandering

The literature suggests that mind wandering competes with limited cognitive resources (Smallwood et al., 2007; Smallwood & Schooler, 2006). Therefore, it would be expected that individuals would experience more mind wandering when the task requires fewer cognitive resources (easy task) as there would be more available cognitive resources for mind wandering (attentional resources account) (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2006; Thomson, Besner, & Smilek, 2013). Consistent with the attentional resources account, our findings suggest that the overall rate of mind wandering was higher in the easy compared to the difficult condition. However, this was driven by a decrease in deliberate mind wandering in the difficult condition (and an increase in on-task reports), whereas spontaneous mind wandering did not differ between conditions. Such a pattern could be interpreted as showing that only deliberate mind wandering competes with the demands of primary task for cognitive resources. This indicates that participants are more likely to control their deliberate mind wandering when they are aware of task difficulty, but also that it might not be possible to exert control over spontaneous mind wandering. Our results are consistent with Seli, Risko, Smilek, & Schacter (2016) who suggested that deliberate and spontaneous mind wandering reflect different attentional control networks. However, Seli et al. reported that individuals had more spontaneous mind wandering in the difficult compared to the easy SART condition, a finding not replicated in the present study. A possible account for the different findings is that Seli et al. compared mind wandering levels in easy and difficult conditions using a between-subjects design whereas a repeated-measures design was used for the present study to minimize the effect of individual differences in the levels of mind wandering experienced. Indeed, in our study task order analysis showed that participants reported more spontaneous mind wandering in the easy condition when the difficult condition was run first (M_{diff} = 2.5, p = .007) while there was no effect of task order for the difficult condition, suggesting some level of support for Seli et al.'s finding.

In conclusion, we measured the relationship between the frequency and type of mind wandering and self-reported inattentive, hyperactive and impulsive traits of ADHD at sub-clinical levels. We found that all ADHD related traits (inattention, hyperactivity and impulsivity) predicted spontaneous but not deliberate mind wandering, and that spontaneous mind wandering is not uniquely associated with inattentive traits. Moreover, inattentive and hyperactive traits were shown to be differentially linked to spontaneous mind wandering: spontaneous mind wandering was predicted by hyperactive traits in both easy (sequential) and difficult (standard) SART while inattentive traits predicted spontaneous mind wandering only when the task was cognitively challenging (standard SART, difficult condition), which suggests that spontaneous mind wandering might have different underlying causes, depending on task difficulty.

Chapter 3: Daily life mind wandering and its relation to symptoms of inattention, hyperactivity and impulsivity in a community sample of adults

Although Chapter 2 revealed that inattention was not a unique predictor of mind wandering under experimental conditions, it is possible this will differ in more real-life situations. Thus, this chapter addresses the link between inattention and mind wandering using more ecologically valid measure of self-reported daily life mind wandering.

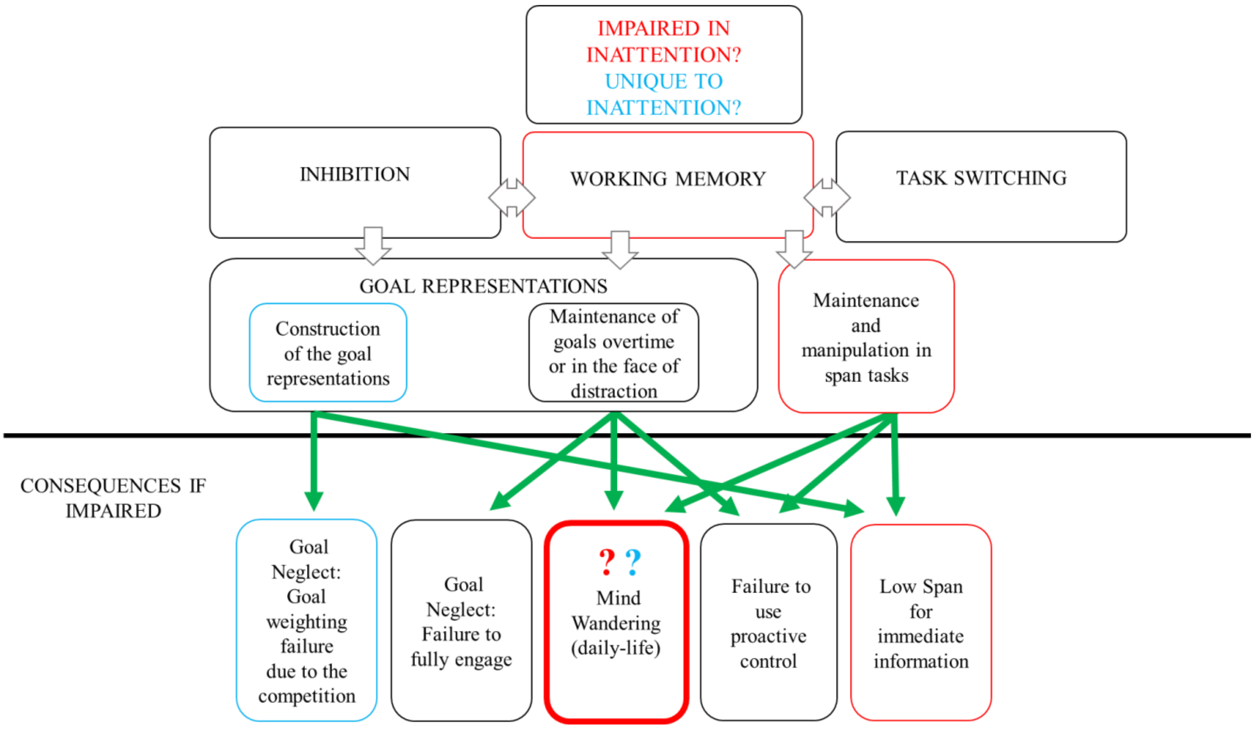

Figure B. A depiction of the role of working memory in goal-oriented behaviour, showing the aim of the Chapter 3 (highlighted in bold)

Abstract

Previous work has shown that the core symptoms of Attention Deficit Hyperactivity Disorder (ADHD), inattention, hyperactivity and impulsivity, predict increased spontaneous mind wandering even at trait (non-clinical) levels in an experimental setting. These findings contrast with the fact that mind wandering is only referenced as a symptom of inattention. In the present work we set out to investigate the mind wandering tendencies of individuals with high levels of inattention, hyperactivity or impulsivity in daily life. We conducted a survey study of 652 adult participants measuring the tendencies of inattention, hyperactivity and impulsivity as well as daily life reports of mind wandering. Consistent with effects in an experimental setting, spontaneous mind wandering was predicted by all three core symptoms of ADHD, with inattention being the best predictor. A novel finding was that inattention and hyperactivity also predicted reports of deliberate mind wandering. Our findings reveal a consistent link between mind wandering and the three core symptoms of ADHD, suggesting that mind wandering should not be associated with just the core symptom of inattention.

Keywords: inattention, hyperactivity/impulsivity, ADHD, mind wandering, spontaneous, deliberate

Daily life mind wandering and its relation to symptoms of inattention, hyperactivity and impulsivity in a community sample of adults

Attention Deficit Hyperactivity Disorder (ADHD) is a childhood onset disorder which persists into adulthood (Barkley, Fischer, et al., 1990; Barkley, Fischer, Smallish, & Fletcher, 2002; Mannuzza et al., 2011) with significant impact in many areas of the adult life such as social, academic, and occupational (Barkley, 1997; Barkley et al., 2002; Biederman, 2005; DuPaul, Weyandt, O'Dell, & Varejao, 2009; Erskine et al., 2013; Faraone, Biederman, & Mick, 2006; 1998; Johnston, Mash, Miller, & Ninowski, 2012; Kessler et al., 2006; Kessler et al., 2010). Together with hyperactivity and impulsivity, inattention is a core symptom of ADHD. Inattentive behaviours include difficulty in organising actions/thoughts and following conversations/instructions. Inattentive individuals also struggle to sustain their attention for extended periods (APA, 2013; Woods et al., 2002), especially in tasks that are not highly motivating (Huguet et al., 2017). Inattentive individuals also report frequent mind wandering (Arabacı & Parris, 2018) and related problems such as inner restlessness and intrusive cognitions (Seli, Smallwood, et al., 2015; Weyandt & DuPaul, 2006). Indeed, the DSM-V (APA, 2013) lists mind wandering as one of the symptoms of inattention, but despite this mind wandering has recently been associated with hyperactivity and impulsivity as well as inattention (Arabacı & Parris, 2018). Given the unique attribution of mind wandering to inattention in the DSM symptom list, here we set out to investigate whether our previous study reporting an association between mind wandering and all three core symptoms of ADHD in an experimental setting is replicated in self-reports of daily life mind wandering.

Mind wandering refers to a shift of attention from external task towards internally motivated unrelated thoughts (Smallwood et al., 2007; Smallwood & Schooler, 2006, 2015). Separate line of research revealed the heterogenous nature of mind wandering (Hu, He, & Xu, 2012). Whilst the definition of mind wandering implies a spontaneous event, research has shown that individuals may intentionally engage in mind wandering (known as deliberate mind wandering; Diamond, 2013). Researchers have argued that deliberate mind wandering is effortful and intentional while spontaneous mind wandering is unintentional and unguided (Goth-Owens et al., 2010; Hu et al., 2012; Malkovsky et al., 2012). Indeed, individuals report more spontaneous mind wandering during difficult and more deliberate mind wandering during easy versions of a sustained attention task (Franklin et al., 2017).

Shaw and Giambra (1993) reported frequent spontaneous mind wandering in those reporting higher hyperactivity and impulsivity. They did not consider inattention however. Seli et al. (2015) used daily life questionnaires asking about spontaneous and deliberate mind wandering as well as self-reported ADHD symptoms. Across two large sub-clinical samples, Seli et al. found that the reports of spontaneous mind wandering increased with increased ADHD scores. However, they did not consider inattention and hyperactive/impulsive symptoms individually. Franklin et al. (2017) also revealed that sub-clinical ADHD predicted the experiences of mind wandering. However, they did not consider the intentionality (spontaneous/deliberate) nor the heterogeneity of ADHD symptoms (inattention and hyperactivity/impulsivity).

As noted above, mind wandering-like symptoms are listed only under the inattentive presentations of ADHD (APA, 2013). For example, the following symptoms of inattention have direct references to mind wandering: “Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere), even in the absence of any obvious distraction" and "Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts)." Additionally, mind wandering (Kane & McVay, 2012; Levinson et al., 2012; McVay & Kane, 2009, 2010; Randall, Oswald, & Beier, 2014; Rummel & Boywitt, 2014; Unsworth & McMillan, 2013) and inattentive symptoms (clinical: Diamond, 2005; Gansler et al., 1998; Klingberg et al., 2005; Martinussen et al., 2005; Martinussen & Tannock, 2006; Rogers et al., 2011; sub-clinical: Colbert & Bo, 2017; Elisa et al., 2016; Lui & Tannock, 2007) have been linked to limitations in working memory impairments and sub-clinical. Finally, in an experimental context, Arabaci and Parris (2018) investigated probe-caught mind wandering and it relationship to the core symptoms of ADHD. Using difficult and easy versions of the Sustained Attention to Response Task (SART), they found that that inattentive symptoms were linked to spontaneous mind wandering when the task was challenging, but, revealed no relationship for when the task was easy. Hyperactivity and impulsivity, however, predicted spontaneous mind wandering independent of task difficulty suggesting that mind wandering is in fact more common in those with hyperactivity and impulsivity than in those with inattention; a finding that has implications for the diagnosis of inattention. Given the important implications of the findings, the aim of the present study was to investigate whether Arabaci and Parris' finding holds in the more ecologically valid measure of self-reported daily life mind wandering.

Method

Participants

We collected data from an opportunity sample of 652 undiagnosed adults (486 female) aged between 18 and 39 (*M* = 21.30, *SD* = 3.66). Rather than a power analysis, we included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1.

Materials

Deliberate and Spontaneous Mind Wandering Scale:

The four-item Deliberate Mind Wandering Scale (MW-D) and four-item Spontaneous Mind Wandering Scale (MW-S: Carriere et al., 2013) were used to measure deliberate and spontaneous mind wandering. Items of the MW-D scale are "I allow my thoughts to wander on purpose," "I enjoy mind-wandering," "I find mind-wandering is a good way to cope with boredom," and "I allow myself to get absorbed in pleasant fantasy." Items of the MW-S scale are "I find my thoughts wandering spontaneously," "When I mind-wander my thoughts tend to be pulled from topic to topic," "It feels like I don't have control over when my mind wanders," and "I mind-wander even when I'm supposed to be doing something else." Each item was scored using a 7-point Likert scale ranging from "rarely" (1) to "a lot" (7) for Items 1, 2, and 4, and ranging from "not at all true" (1) to "very true" (7) for Item 3. Participants were instructed to select the option that best represents their everyday mind wandering. Higher scores indicated higher frequencies of mind wandering.

Connors' Adult ADHD Rating Scale: Short Version (CAARS-S:S:

ADHD traits assessed using CAARS-S:S (Conners et al., 1999). The scale requires participants to rate the frequency of the 26 items (symptoms) using a four-point rating scale. Responses range from "not at all, never" (0) to "very much, very frequently" (3). Raw scores for inattention, hyperactivity and impulsivity symptoms are transformed into t-scores to make a comparison across participants. T scores range between 28 (lowest) to 90 (highest) with a mean of 50 and standard deviation of 10. Although the guidelines of the CAARS proposes certain cut-off for the categorisation of the symptom severity, we used the continuous scores for inattention, hyperactivity, impulsivity and index, given the usefulness of dimensional view of the symptoms (Overbey et al., 2011; Whalen et al., 2003).

Adult ADHD Self Report Scale (ASRS):

ASRS was also employed as an additional measure of ADHD (Adler et al., 2006; Kessler et al., 2005). ASRS includes total of 18 items consisting the ADHD symptoms of Diagnostic and Statistical Manual of Mental Disorders Fourth edition (DSM-IV) (APA, 2000). There are nine items indicating inattentive symptoms (1,2,3,4,7,8,9,10,11) and nine items indicating hyperactive/impulsive symptoms (5,6,12,13,14,15,16,17,18). ASRS asks participants how often a particular symptom of ADHD has occurred to them over the past six months on a five-point response scale ranging from “never” (0), “rarely” (1), “sometimes” (2), “often” (3), to “very often” (4). The ASRS was scored by participants’ ratings on each of the 18 symptoms to determine the presence or absence of each symptom. That is, each symptom was treated as existing on a dichotomous scale.

Procedure

Participants were asked to complete a series of online questionnaires regarding ADHD traits (ASRS and CAARS) and mind wandering (MW-S, MW-D). After giving informed consent, participants completed a short questionnaire for demographic information such as age and gender. Following demographic information, participants were asked if they have ever been diagnosed with ADHD. Subsequently, participants were presented with the MW-S, MW-D, and CAARS in a random order. Items in MW-S and MW-D were presented randomly, similar to the literature (Seli, Smallwood, et al., 2015).

Results

Sample

Scores from CAARS revealed that the mean and standard deviations of our inattention (M = 57.18, SD = 10.75), hyperactivity (M = 50.46, SD = 8.95), impulsivity (M = 49.99, SD = 9.27) and index (M = 53.53, SD = 10.02) were within 1 standard deviation around the proposed mean of 50 and standard deviation of 10.

The percentage of participants scoring in each category provided by the CAARS guidelines are reported in Figure 1. Following the guidelines, total of raw scores for each symptom were transformed into standardised T-scores so that all sub-scales have mean of 50 and standard deviation of 10. T scores range between 28 (lowest) to 90 (highest) calculated based on the age and gender. Following the proposed CAARS cut-offs, the amount of participants who had clinically significant levels were 8.06 % for overall ADHD diagnosis (index), 15.14% for inattention, 3.49% for hyperactivity and 3.38% for impulsivity. Our mean and standard deviations for impulsivity, hyperactivity and index scores were within half a standard deviation from the proposed mean and standard deviations for CAARS-S:S. The mean for the inattention scores was half a standard deviation above the proposed mean but still within the confidence interval values. Fifteen participants also reported previous ADHD diagnosis while seven participants preferred not to state. Please see Figure 2 for detailed participant characteristics.

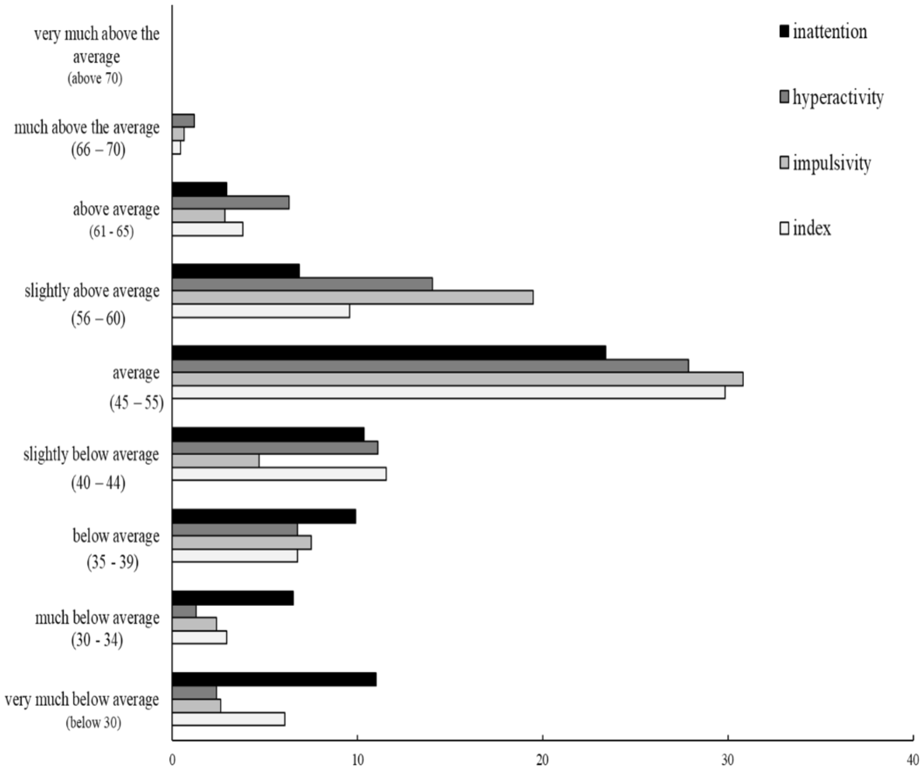

Figure 1. The percentage of participants falling into each category based on the proposed cut-offs by CAARS manual.

For CAARS, inattention and hyperactivity scores were normally distributed while impulsivity scores appeared skewed. However, the skewness value for impulsivity was .78, well within the acceptable limits of ±2 (Andy, 2000; Gravetter & Wallnau, 2010; Trochim & Donnelly, 2001). Similarly, the scores from ASRS also revealed that inattention (*M* = 2.04, *SD* = .03), hyperactivity/impulsivity (*M* = 1.52, *SD* = .03) and total (*M* = 1.78, *SD* = .03) scores of ADHD was distributed normally (Figure 2).

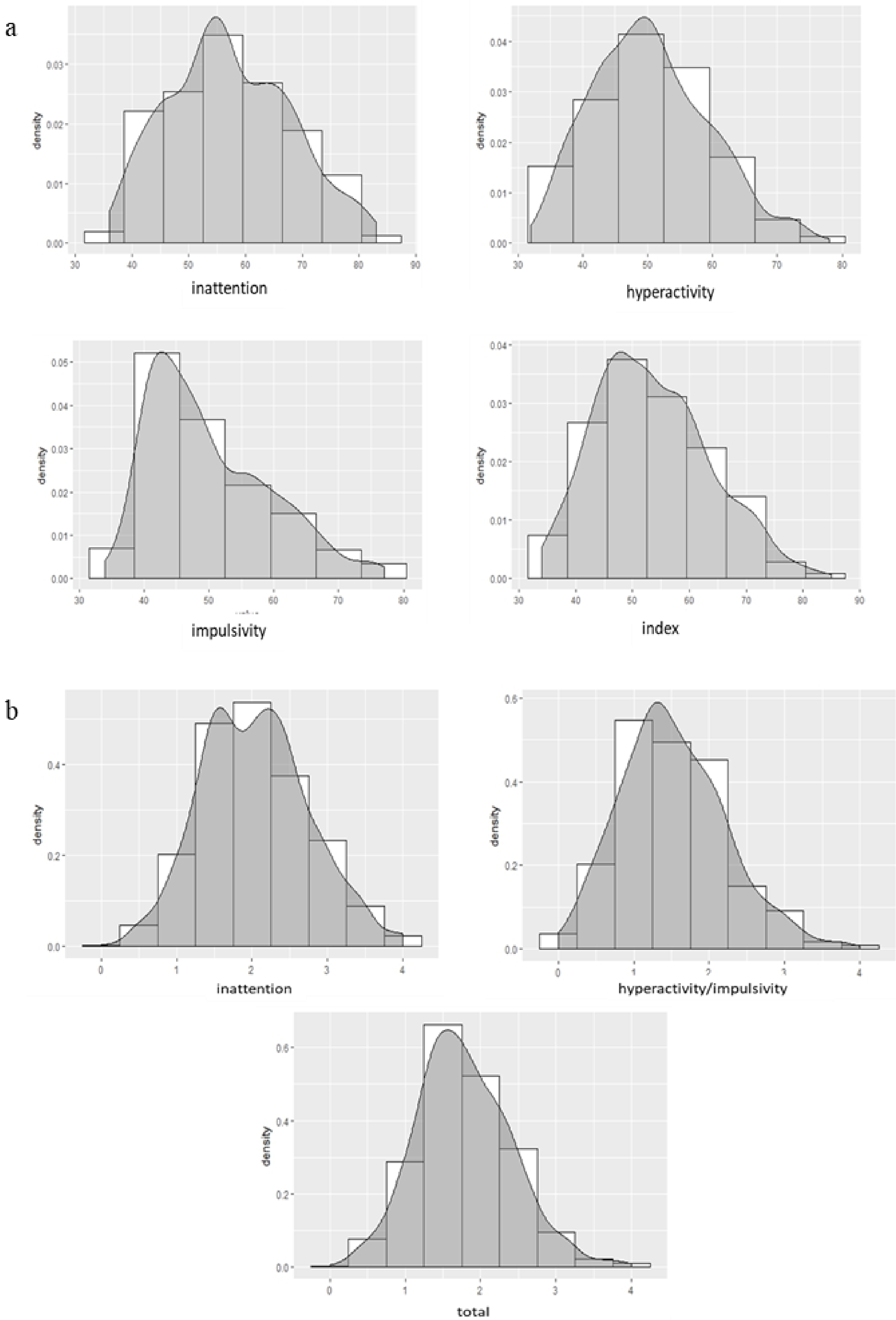

Figure 2. The distributions of the ADHD scores from (a) CAARS and (b) ASRS

We used Bonferroni corrected paired samples t-test to compare individual ADHD symptoms for CAARS and ASRS across participants. For CAARS, our sample had more inattention scores than hyperactivity [$t(647) = 17.11$, $p < .001$, $M_{diff} = 6.63$, $d = 0.67$] and impulsivity [$t(651) = 18.19$, $p < .001$, $M_{diff} = 7.19$, $d = 0.72$], while there was no significant difference between hyperactivity and impulsivity, $t(647) = 1.61$, $p = .108$. Similarly, for ASRS, participants had more inattention scores than hyperactivity/impulsivity, $t(651) = 21.11$, $p < .001$, $M_{diff} = .52$, $d = .74$. Please see Figure 3 for density plots for a comparison.

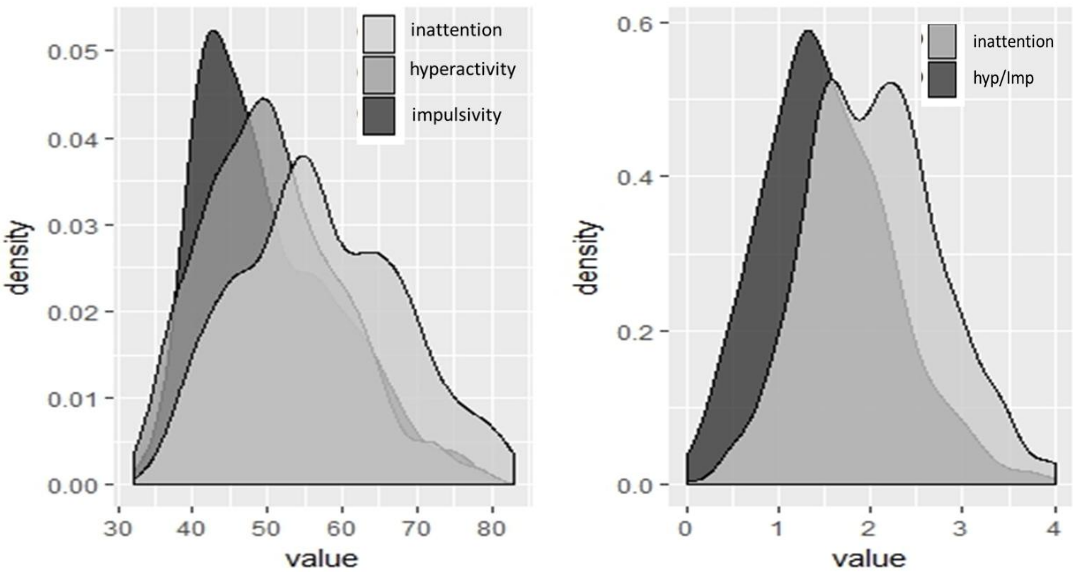

Figure 3. The density plots comparing the individual symptom scores from CAARS (left) and ASRS (right)

Mind Wandering and ADHD Scores

First, we examined the bivariate and partial correlations between the independent and dependent variables (Table 1). Consistent with previous research (Carriere et al., 2013; Seli, Jonathan, et al., 2015; Seli, Smallwood, et al., 2015), Pearson correlation coefficients revealed a significant positive correlation between spontaneous and deliberate mind wandering scores (*r* = .50, *p* < .001). Across CAARS and ASRS scores, reasonable correlations between inattention scores (*r* = .76, *p* < .001), hyperactivity and hyperactivity/impulsivity (*r* = .70, *p* < .001), impulsivity and hyperactivity/impulsivity (*r* = .58, *p* < .001) and composite scores (*r* = .79, *p* < .001) indicate consistency across both scales (Table 1). Spontaneous and deliberate mind wandering were correlated with all the scores across CAARS and ASRS (Table 1).

Table 1

Correlations within variables

	Mean	SD	1	2	3	4	5	6	7	8	9
1. Spontaneous MW	16.23	5.82	-								
2. Deliberate MW	17.23	5.39	.50**	-							
3. CAARS Inattention	57.18	10.75	.58**	.32**	-						
4. CAARS Hyperactivity	50.46	8.95	.50**	.27**	.51**	-					
5. CAARS Impulsivity	49.99	9.27	.47**	.22**	.50**	.54**	-				
6. CAARS Index	53.53	10.02	.66**	.34**	.78**	.71**	.76**	-			
7. ASRS inattention	2.04	.71	.65**	.31**	.76**	.53**	.54**	.75**	-		
8. ASRS hyp/imp	1.52	.70	.56**	.28**	.45**	.70**	.58**	.67**	.60**	-	
9. ASRS total	1.78	.63	.675**	.33**	.68**	.69**	.62**	.79**	.90**	.89**	-

*p < .05, **p < .001

Multiple linear hierarchical regression analyses were used to test the unique predictive value of inattention on participants' mind wandering scores. This method was chosen as we aimed to see the variance accounted for by inattention when hyperactivity and impulsivity were already included in the model. To determine if there was evidence for no relationship between a symptom and a type of mind wandering, we used a Bayes Factor (Dienes, 2008, 2011, 2014), where we contrasted the theory that there was some relationship, with the null hypothesis that there was no relationship. In all cases where a Bayes Factor is given we modelled the predictions of the theory of some evidence for a relationship with a half-normal whose mean and standard deviation values were taken from the variable inattention in the relevant model of regression analysis. $B_{\mathrm{H}(0,\,\mathrm{X})}$ refers to the Bayes Factors testing each hypothesis, where 'H' indicates a half-normal distribution, 0 indicates the mean and 'X' the predicted standard error of the mean of this half-normal.

The regression model where CAARS scores predicting spontaneous mind wandering (Table 2, Model 1) explained 41% of the variation, $F(3, 644) = 147.42$, $p < .001$. Although inattention had the largest predictive value, all symptoms significantly predicted spontaneous mind wandering. The multiple regression where ASRS scores predicting spontaneous mind wandering revealed (Table 2, Model 2) explained 46% of the variation, $F(2, 648) = 279.28$, $p < .001$. Although inattention had the larger predictive value, hyperactivity/impulsivity also significantly predicted spontaneous mind wandering. The semi partial correlations between ADHD scores and spontaneous mind wandering ranged from small to moderate and linear (Figure 4).

Table 2

Summary of multiple regression models self-reported ADHD scores from CAARS (Model 1) and ASRS (Model 2) predicting spontaneous mind wandering

	Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
Model 1						.41	.41	
	CAARS Inattention	.21	.02	.39	10.62**			.39
	CAARS Hyperactivity	.14	.03	.22	5.78**			.22
	CAARS Impulsivity	.09	.02	.15	3.94**			.15
Model 2						.46	.46	
	ASRS Inattention	3.92	.30	.48	13.25**			.46
	ASRS Hyperactivity/Impulsivity	2.29	.30	.28	7.61**			.28

*p < .05, **p < .01

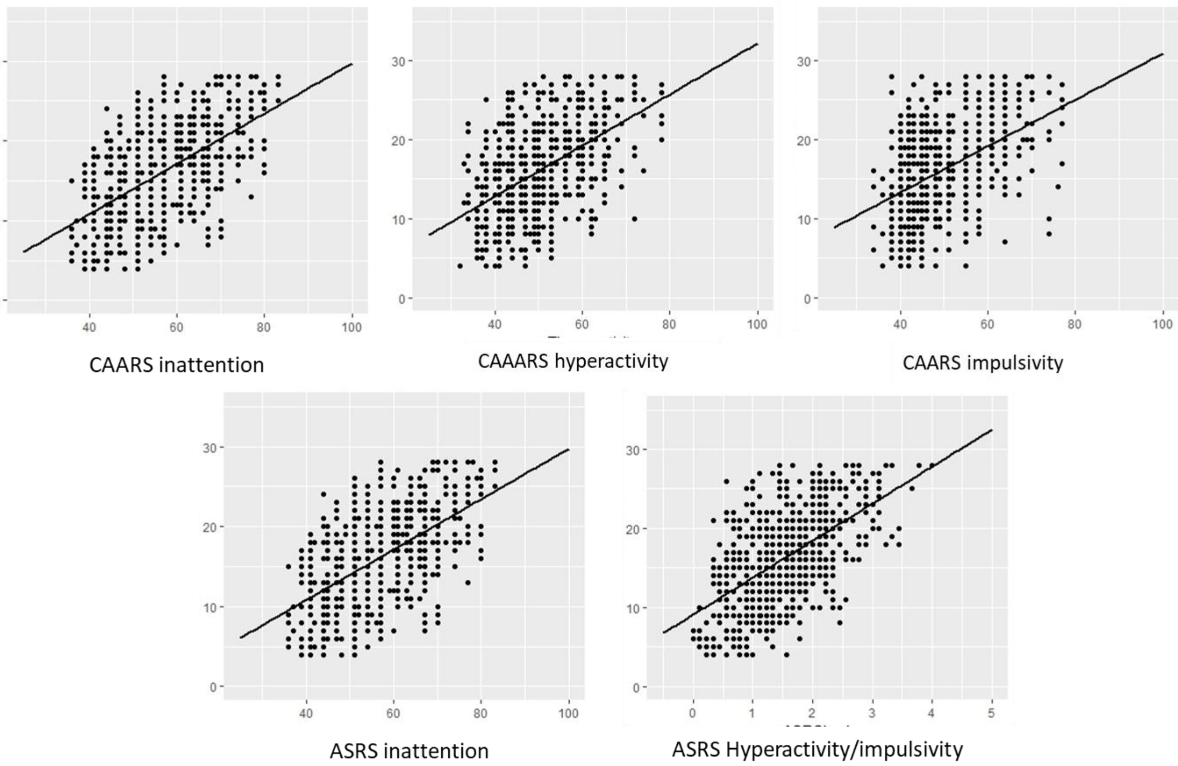

Figure 4. Scatterplots showing the associations of ADHD scores on spontaneous mind wandering

The multiple regression where CAARS scores predicting deliberate mind wandering revealed (Table 3, Model 1) explained 12% of the variation, $F(3, 643) = 28.86$ $p < .001$. Both inattention and hyperactivity were significant predictors while Bayes values suggested that impulsivity was non-significant ($p = .456$, $B_{H(0,\ .02)} = 0.11$). The multiple regression where ASRS scores predicting deliberate mind wandering (Table 3, Model 2) explained 12% of the variation, $F(2, 647) = 43.96$, $p < .001$. Both inattention and hyperactivity/impulsivity significantly predicted deliberate mind wandering scores. The semi partial correlations between ADHD scores and deliberate mind wandering were small (Figure 5).

Table 3

Summary of multiple regression models where self-reported ADHD scores from CAARS (Model 1) and ASRS (Model 2) predicting deliberate mind wandering

	Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
Model 1						.12	.12	
	CAARS Inattention	.11	.02	.22	4.88**			.18
	CAARS Hyperactivity	.09	.03	.15	3.17**			.12
	CAARS Impulsivity	.02	.03	.04	.75			.03
Model 2						.12	.12	
	ASRS Inattention	1.77	.35	.24	5.01**			.19
	ASRS Hyperactivity/Impulsivity	1.14	.36	.15	3.18**			.12

*p < .05, **p < .01

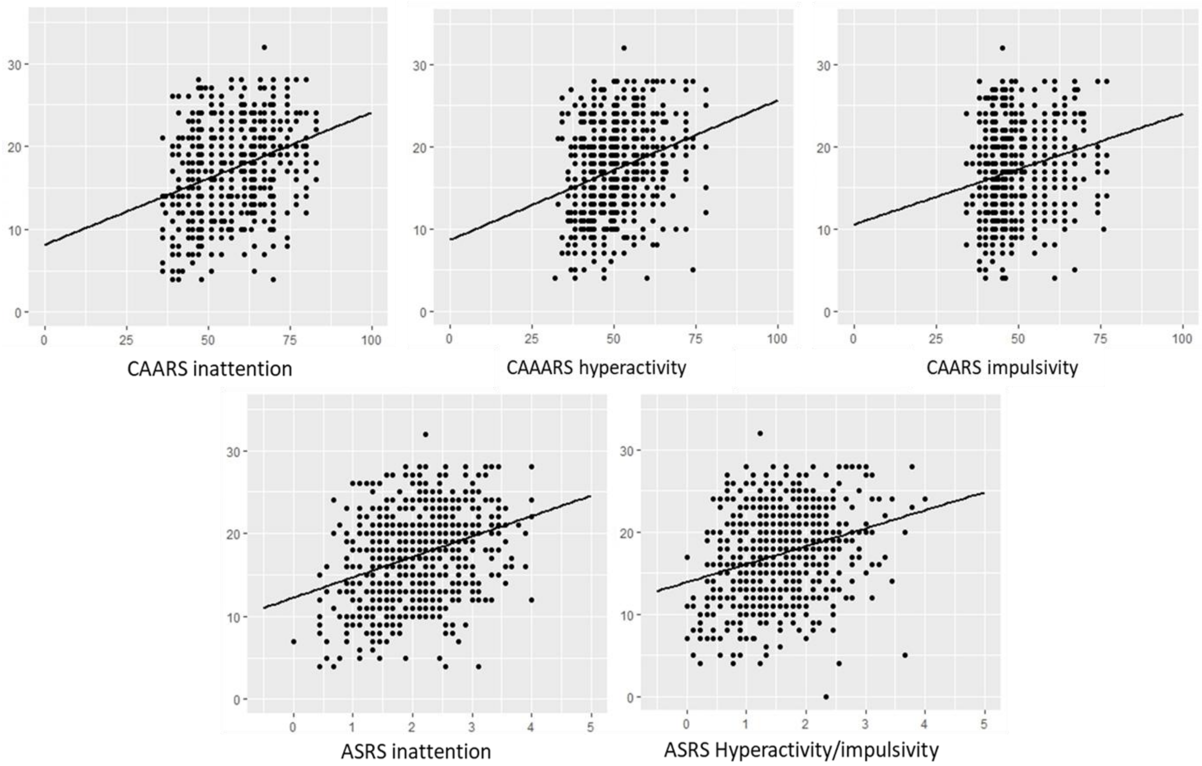

Figure 5. Scatterplots showing the associations of ADHD scores on deliberate mind wandering

Discussion

We aimed to investigate the relationship between inattention, hyperactivity and impulsivity to daily life spontaneous and deliberate mind wandering among a sub-clinical sample of adults. The scores from CAARS and ASRS were highly correlated (Table 1), both also followed a consistent pattern of distributions (Figure 2) and relationships to spontaneous and deliberate mind wandering (Table 1, 2 and 3). Consistent with previous research, ADHD symptoms in general (CAARS index and ASRS total) were related to both spontaneous and deliberate mind wandering (Seli, Smallwood, et al., 2015; Shaw & Giambra, 1993). We investigated this relationship further by investigating individual symptoms of inattention, hyperactivity and impulsivity. Consistent with Arabaci and Parris (2018), scores from both scales revealed that all individual symptoms predicted spontaneous mind wandering. Although inattention had the largest predictive value for both scales, our findings indicate that spontaneous mind wandering is also a characteristic of hyperactivity and impulsivity. However, DSM-V reference to mind wandering only under inattentive presentations.

The findings showing that inattention is the strongest predictor of spontaneous daily-life mind wandering is somewhat consistent with mind wandering being represented only in the inattention symptom list of the DSM-V. It is also consistent with the notion that working memory plays an important role in determining mind wandering since studies have reported poor working memory capacity being characteristic of inattentive individuals (Diamond, 2005; Elisa et al., 2016; Hynd et al., 1991; Zentall & Smith, 1993). However, poor working memory capacity is not a characteristic of hyperactivity (Elisa et al., 2016), which is also associated with spontaneous mind wandering even after the contribution of inattention is controlled in our data. Arabaci and Parris (2018) also revealed the tendencies to spontaneously mind wander during easy and difficult versions (relatively higher working memory demand) of a continuous reaction time task for hyperactivity and impulsivity while inattention was a significant predictor only during the challenging task, indicating that overall mind wandering was more common in those with hyperactivity and impulsivity.

A novel finding in the present study is that inattention scores from both scales predicted the tendency to deliberately mind wander (Table 3). Nevertheless as with spontaneous mind wandering hyperactivity/impulsivity scores were also significantly related to deliberate mind wandering (based on the ASRS scores). When hyperactivity and impulsivity were individually analysed (using the CAARS), hyperactivity was a significant predictor while Bayes values suggested that impulsivity was not related to deliberate mind wandering. Such a pattern indicated that the deliberate mind wandering is most probably related to hyperactivity but not impulsivity. This is not consistent with the clinical diagnosis of ADHD considering both hyperactivity and impulsivity being considered the same presentations (sub-scales) (APA, 2013). There is also extensive literature revealing a bi-factor model of ADHD with inattention and hyperactivity/impulsivity dimensions (Dumenci et al., 2004; Nichols et al., 2017; Smith Jr & Johnson, 1998; Toplak et al., 2009) as opposed to a three-factor model (Glutting, Youngstrom, & Watkins, 2005; Proctor & Prevatt, 2009; Span, Earleywine, & Strybel, 2002). Nevertheless, our findings indicate a possible distinction between hyperactivity and impulsivity in the tendency to engage in deliberate mind wandering.

In contrast to previous studies (Seli, Smallwood, et al., 2015; Shaw & Giambra, 1993) data from our two studies reveal a consistent relationship between inattention, hyperactivity and deliberate mind wandering. However, they were only weakly related to deliberate mind wandering (it accounted for only 12 per cent of the variance). Our findings also evidence the heterogeneous nature of mind wandering (Arabacı & Parris, 2018; Seli, Risko, & Smilek, 2016; Seli, Risko, Smilek, et al., 2016) and support the notion that it is important to measure the intentionality aspect of mind wandering (e.g., spontaneous and deliberate mind wandering).

The experiences of all three core symptoms were normally distributed in our sample. However, participants reported higher rates of inattention in comparison to other symptoms, which might account for the stronger relationship between inattention and spontaneous mind wandering. Nevertheless, this is also consistent with literature suggesting that mainly inattentive symptoms persist into adulthood

(Biederman et al., 2000; Biederman et al., 2011; Faraone et al., 2000). There are also studies reporting that inattentive symptoms are more common across females (Hudziak et al., 1998). Given that our sample consisted mainly of adult women, higher scores on inattentive symptoms is not surprising.

A limitation of the present study is that we relied on participants' reports of mind wandering in daily life. Whilst still informative, daily–life mind wandering can refer to both on-task and off-task mind wandering in both demanding and non-demanding conditions, where it might be beneficial to mind wander even when the mind wandering event is spontaneous (Andrews‐Hanna, Smallwood, & Spreng, 2014). Mind wandering might not be detrimental if the demands for resources is low. Although our findings are similar to studies reporting a link between spontaneous mind wandering and ADHD symptoms with lab-based probe-caught measures (Arabacı & Parris, 2018; Franklin et al., 2017; Shaw & Giambra, 1993), further research looking at the detrimental effects of daily-life mind wandering would be useful.

In summary, we found that spontaneous mind wandering is related to both inattentive and hyperactive/impulsive symptoms of ADHD and that deliberate mind wandering is related to both inattention and hyperactivity. The finding that inattention is related to mind wandering is consistent with the role of working memory impairments in inattention (Elisa et al., 2016) and the relationship between experiences of mind wandering and working memory capacity (McVay & Kane, 2009).

Chapter 4: Inattention and task switching performance: The Role of Predictability, Working Memory Load and Goal Neglect

As noted above (Chapter 2 and Chapter 3), inattention has been linked to spontaneous mind wandering, however, this link was shown not to be unique to inattention with associations also reported between mind wandering and hyperactivity and impulsivity. Although the findings from these chapters hold important information for the inattention literature, in an attempt to investigate the unique characteristics of inattention, we turned our focus towards task switching.

The thesis introduction (Chapter 1) revealed the unique, yet inter-related nature of the core executive functions, suggesting that working memory and task switching are related (Friedman & Miyake, 2017). Task switching and working memory are also theoretically associated due to the need for working memory to hold task relevant information during task switching tasks (Emerson & Miyake, 2003; Liefooghe, Vandierendonck, Muyllaert, Verbruggen, & Vanneste, 2005; Miyake, Emerson, Padilla, & Ahn, 2004). Further research also suggested that working memory capacity for goal representations is needed to prepare for a predicted switch trial (i.e., for the use of proactive control), improving task switching performance (De Jong et al., 1999). Although task switching has been linked to the ADHD in general (Cepeda et al., 2000; King et al., 2007; Kramer et al., 2001), to our knowledge, it has not been associated with any one of the core ADHD symptoms. Given the unique link between inattention and goal neglect (failure in constructing goal representations), Chapter 4 aimed to test whether the link between ADHD and task switching is driven by the inattentive symptoms.

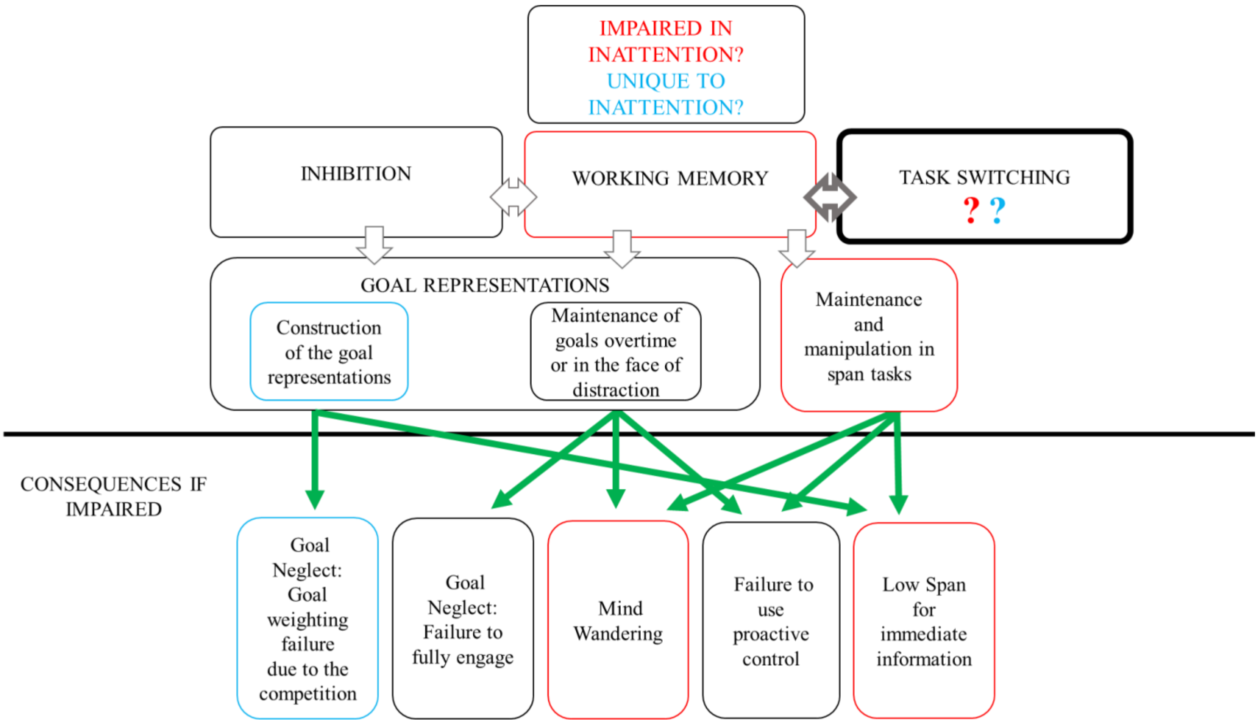

Figure C. A depiction of the role of working memory in goal-oriented behaviour, showing the aim of the Chapter 4 (highlighted in bold)

Abstract

Inattention is a symptom of many clinical disorders including Attention Deficit Hyperactivity Disorder (ADHD), and, is thought to be primarily related to limitations in working memory. In two studies, we investigated the implications of inattention for task switching performance. In study one, we measured task switching performance using predictable and unpredictable conditions in adults who self-rated inattention and other ADHD-related tendencies. Tasks required proactive control and reactive control, respectively, under both high and low working memory loads. Results revealed that inattentive, but not hyperactive/impulsive traits, predicted switch costs when switching was predictable and working memory load was high. None of the ADHD traits were related to unpredictable switch costs. Study two was designed to: 1) de-confound the role of proactive control and the need to keep track of task order in the predictable task switching paradigm; 2) investigate whether goal neglect, an impairment related to working memory, could explain the relationship between inattention and predictable task switching. Results revealed that neither predictability nor the need to keep track of the task order led to the association between switch costs and inattention, but instead it was the tendency for those high in inattention to neglect preparatory proactive control, especially when reactive control options were available.

Inattention and task switching performance: The Role of Predictability, Working Memory Load and Goal Neglect

Inattention is a symptom of many clinical and mental disorders although it is most closely associated with Attention Deficit Hyperactivity Disorder (ADHD). Inattention is characterised as a difficulty in sustaining attention, listening/following conversations/instructions, and organising. Furthermore, it is associated with mind wandering-like experiences (e.g., “mind seems elsewhere” or “distractible by unrelated thoughts”), forgetfulness and hesitation to engage in activities requiring sustained mental effort (APA, 2013).

Whilst ADHD is a widely diagnosed neurodevelopmental disorder with prevalence rates of 5–10 % in childhood and 4.4 % in adulthood (Kessler et al., 2005), research has suggested that inattention, like the other ADHD symptoms, is best thought of as being on a continuum as opposed to being categorically different from sub-clinical levels of the disorder (Barkley & Murphy, 1998). Based on this view, tendencies of inattention, hyperactivity and impulsivity are also experienced by sub-clinical populations, and, those with a clinical diagnosis represent the extreme end of the spectrum. Measuring ADHD related experiences on a continuous scale has been supported by taxometric studies (Haslam et al., 2006; Salum et al., 2014) and studies report a significant impact of ADHD-related traits at sub-clinical levels (Elisa et al., 2016; Overbey et al., 2011; Seli, Smallwood, et al., 2015).

Diamond (2005) argued, and research has supported, that inattention is primarily related to limitations in working memory (Barkley, 1994; Nigg, 2001, 2006). For example, Martinussen and Tannock (2005) revealed that inattentive (but not hyperactive/impulsive) symptoms were related to verbal and visuospatial working memory (WM) impairments in clinical samples (see also Klingberg et al., 2005). Using non-clinical samples, Gathercole et al. (2008) revealed that low WM capacity children had more inattentive traits than a high WM group. Lui and Tannock (2007) also reported that poor performance on WM tasks predicted parent-rated inattentive traits at sub-clinical levels. In adults, Elisa et al. (2016) found that self-reported inattentive traits predicted the performance on verbal WM at sub-clinical levels. Thus, the literature provides evidence for a link between inattentive symptoms and WM performance at clinical and sub-clinical levels.

Although the core executive functions of WM, response inhibition and task switching are thought to be independent processes, research also suggests that they may still be interrelated (Friedman & Miyake, 2017). Therefore, WM limitations in inattentive individuals might produce impaired performance on other executive function tasks, such as task switching (e.g., Emerson & Miyake, 2003; Liefooghe et al., 2005; Miyake et al., 2004). Moreover, since the relationship between inattention and task switching performance has not yet been investigated, it is possible that inattention also leads to impaired task switching performance irrespective of WM involvement.

Task switching paradigms (TSPs) measure the cognitive flexibility required to achieve task goals when the environment is constantly changing. Switching refers to an individual's ability to self-adjust their performance based on the current requirements to achieve task goals. To perform a switch, attentional resources must shift to the relevant task set (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Rogers & Monsell, 1995; Spector & Biederman, 1976). Task-set refers to the parameters required to perform a particular task such as stimulus identification, response selection, and response execution (Logan & Gordon, 2001; Vandierendonck, Liefooghe, & Verbruggen, 2010).

In TSPs, participants are often asked to perform two tasks in quick succession. A participant might be required to repeat the same task (e.g., judging whether a number is higher or lower than 5) a number of times before they are asked to perform another task (e.g., judging whether a presented number is odd or even). These two tasks would be presented such that there are a number of repeat and switch trials in each experiment. Switching from one task to another is associated with longer reaction times (RTs) and higher error rates compared to repeat trials. These performance costs are referred to as *switch cost* (Altmann, 2004; Dreisbach, Haider, & Kluwe, 2002; Koch, 2001; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). Various accounts have been made to explain the source of switch costs including the role of interference from the previous task-set (Allport et al., 1994) and task-set reconfiguration (Rogers & Monsell, 1995).

It has been argued that task switching performance calls upon WM processing for the activation and maintenance of task-sets (Emerson & Miyake, 2003; Liefooghe et al., 2005; Miyake et al., 2004) and for tracking sequential action plans (Bryck & Mayr, 2008). However, research has failed to find an effect of WM on task switching (Kane et al., 2007; Logan, 2004 but see Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008). Nevertheless, the reliance of task switching on WM might depend on the parameters of the task switching requirements. For example, WM would be required to prepare for the upcoming task when the information about the upcoming task is available in advance as in predictable TSPs. The reconfiguration account of task switching suggests that switching requires a mental form of ‘gear changing’ (*task-set reconfiguration*) to trigger the task specific processes, such as retrieving the relevant *task-set*. If advanced knowledge and sufficient time is allowed, individuals are able to prepare for the upcoming task, thereby reducing the switch cost (reconfiguration view; Rogers & Monsell, 1995). This has been referred to as *proactive control* (Braver et al., 2007).

The distinction between proactive and reactive control was first introduced by Braver, Gray and Burgess (2007) who proposed the dual-mechanism theory of cognitive control, suggesting two types of control for the flexible, goal-related behaviour. Proactive control refers to the active maintenance of information (e.g., general task instructions, relevant information from the previous stimuli or salient cues) that is beneficial for responding to upcoming stimuli (Engle & Kane, 2003; Kane et al., 2007), and, the ability to make use of the previous stimuli to predict the upcoming event (Braver et al., 2007). Reactive control involves retrieving contextual information that is relevant for current decision making. Proactive control requires maintaining previous knowledge and using this to respond efficiently when a future event is consistent with expectations. In an attempt to integrate the role of preparation and interference during switching, Vandierendonck et al. (2010) evaluated the switch costs in two processing stages: preparation and stimulus-based processing. They suggested that two forms of control are needed: reactive control to overcome the interference due to task-set inertia and proactive control to shield the task relevant goal and instructions. Research has found that high WM capacity participants are better at making use of prior information or cue information to predict the upcoming event in various tasks. High WM capacity participants are also more able to maintain the goal relevant information in memory (Engle & Kane, 2003; Redick, Calvo, Gay, & Engle, 2011; Unsworth, Schrock, & Engle, 2004) and use this information proactively to bias their responses (Redick & Engle, 2011). In individuals reporting high levels of inattention one would therefore be expected to exhibit poorer use of cue information and poorer maintenance of goal relevant information. In sum, during predictable task switching, a form of proactive control is needed to perform advanced reconfiguration to prepare for the upcoming stimuli and shield the relevant goal, and this is related to WM capacity. When the use of proactive control is not possible (i.e., future events cannot be reliably predicted), individuals rely on reactive control (Redick, 2014). Furthermore, reactive control would be used to overcome task set inertia.

Task switching and ADHD

Whilst there has been no research, to our knowledge, considering task switching performance and inattention, studies using TSPs on participants with ADHD have revealed conflicting results. Using the same task, Cepeda et al. (2000) and Kramer et al. (2001) reported larger switch costs in those with ADHD compared to controls while Oades and Christiansen (2008) failed to find a significant difference in switch costs. Other studies reported significantly larger switch costs for ADHD participants (King et al., 2007) while others did not (Rauch et al., 2012). For example, Wu et al. (2006) investigated the switching performance for those with and without ADHD under WM load. Participants were asked to switch between colour naming and word reading in a predictable manner in two conditions: cue-absent and cue-present. In the cue-present condition, the stimuli were presented with a circle divided into four equal segments, and, the stimuli were presented in one of the possible segments in clockwise order. The task was cued in a way that participants could work out the required task based on the position of the stimulus. In cue-absent conditions, the circle disappeared, forcing participants to keep track of the task order (to increase the

WM load). Wu et al. (2006) failed to find a group difference between cue-absent and cue-present conditions for ADHD participants, suggesting no relationship between task switching and ADHD and that the WM load did not affect those with ADHD any more than control participants.

There may be several reasons for the inconsistent findings. First and most importantly, the inconsistent results could be the unexplored differences in cognitive performance between ADHD-I and ADHD-C/ADHD-HI and the extent to which the TSP relied on WM. If the TSP has a high WM load component you would expect those with ADHD-I or self-reported inattention to exhibit greater problems with task switching.

Another possible explanation for larger switch costs for ADHD participants when they have been observed, and one that we also explore here in self-reporting adults, and is potentially unrelated to WM capacity, is that the costs were observed under interference load (incongruent stimuli). For example, Cepeda et al. (2000) reported much larger switch costs to incongruent than congruent stimuli for ADHD participants, suggesting that the overall increase in switch costs could be due to the slowed responses on incongruent trials only. The interference view of task switching (Allport et al., 1994; Allport & Wylie, 1999; Wylie & Allport, 2000) suggests that the switch costs (larger RTs to switch than repeat trials) are observed because the persistent activation of the previously activated task-set interferes with the current activation of the new task-set, creating proactive interference. When sufficient time is allowed (long response-stimulus intervals), the activation of the previous task-set decays (*task-set inertia*), allowing participants to switch more efficiently due to the minimum amount of interference (Allport et al., 1994).

Mayr and Keele (2000) also suggested that the reactivation of the recently inhibited task-set is more difficult than if the task set is inhibited a longer time ago. This was because the after effect of inhibition would decay over the time, leading to *negative priming* in the former but not the latter. Using a TSP with three tasks (i.e., A, B, C), they found impaired performance in n-2 repetition (e.g., ABA) compared to n-2 switch (e.g., CBA) trials (see also Arbuthnott & Frank, 2000; Arbuthnott, 2005; Arbuthnott & Woodward, 2002; Hübner, Dreisbach, Haider, & Kluwe, 2003; Koch, Philipp, & Gade, 2006; Schuch & Koch, 2003; Sdoia & Ferlazzo, 2008 for consistent findings). The interference account also suggests that part of the switch cost derives from interference triggered by the stimulus itself (*task rule congruency*). TSPs may involve unique stimuli for each task (*univalent stimuli*) or both (or more) tasks could be associated with the same stimulus set (*bivalent stimuli*). Smaller switch costs in univalent (unique stimuli for each task) compared to bivalent (two or more tasks associated with the same stimulus set) stimuli have been reported, suggesting that switching is more efficient when the stimulus indicates only one type of task-set (Allport et al., 1994; Rogers & Monsell, 1995; Spector & Biederman, 1976). In sum, it is possible that task-set inertia and/or task rule congruency would play a role in the link between switch costs and ADHD symptoms.

In summary, the literature on ADHD and task switching is inconsistent. We argue that the inconsistent findings could be due to a failure to consider each presentation of ADHD (inattention and hyperactive/impulsive) and/or the type of TSP employed. Given the relationship between WM and inattention, it is likely that inattention will affect task switching performance when there is a WM load. Considering the need for WM to perform preparatory proactive control during task switching, it is reasonable to think that inattentive traits may be related to infrequent engagement of proactive control to prepare for upcoming stimuli due to associated WM limitations (e.g., Elisa et al., 2016; Martinussen et al., 2005). However, where larger switch costs have been reported in those with ADHD, it has been argued that it is a failure to inhibit interference, and not a WM issue, that causes the impaired performance.

Study 1

In the present study we measured the trait of inattention in undiagnosed adults (along with hyperactivity and impulsivity traits) and its relationship to predictability, interference and WM load during task switching performance. Each participant performed two TSPs: 1) A predictable TSP where participants have to maintain the task order and use this information to prepare in advance for an upcoming repeat or switch trial. In the cue-present condition (low WM load condition), a cue was provided to indicate task order. In the cue-absent condition no additional information was provided and participants had to maintain task order in WM (high WM load condition). The cue-present condition allowed the use of reactive and proactive control, while the cue-absent condition forced participants to rely on proactive control only; 2) An unpredictable TSP where stimuli appeared in an unpredictable manner (forcing the use of reactive control) in long and short RSIs. Long intervals are used to measure the effect of inhibition (task-set inertia) in switch cost.

Given the limitations with WM capacity in inattention at sub-clinical (Elisa et al., 2016) and clinical levels (Diamond, 2005), one would predict an impairment in maintaining task order and proactively preparing for the next task, resulting in larger switch costs in predictable TSPs, especially when there is no environmental support (the cue-absent condition). In contrast, if inattention was related to a task switching impairment more generally, inattentive traits should predict performance on all TSPs. If instead, an observed switch cost disadvantage was due to a problem with inhibition, there should be an association between one of the core ADHD symptoms in the unpredictable switch cost when the RSI is short. This is because a long RSI confers extra time between the trials to reduce the interference from the previous task-set (Allport et al., 1994).

Method

Participants

Participants aged between 18 and 35 with normal or corrected vision from non-clinical samples were recruited through Bournemouth University's research participation system and through advertisements. Participants were mainly undergraduate and postgraduate students. Undergraduate students received course credits for their involvement. We collected data from 116 individuals (*Mean age* = 20.37, *SD* = 2.87). Initially, sample size was defined by previous research measuring ADHD tendencies on a continuum showing reasonable effect sizes (Elisa et al., 2016). We also included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1.

Materials

Connors' Adult ADHD Rating Scale: Short Version (CAARS-S:S):

ADHD tendencies were assessed using CAARS-S:S (Conners et al., 1999). The questionnaire requires participants to rate the frequency of the 26 items (symptoms) using a four-point rating scale. Raw scores for inattention, hyperactivity and impulsivity symptoms are transformed into t-scores to make a comparison across participants. T-scores range between 28 (lowest) to 90 (highest) calculated based on the age and gender.

Predictable Task Switching Paradigm:

The task involved the alternative run paradigm (Rogers and Monsell 1995) and was adapted from Wu et al. (2006). Participants were presented with digits (1, 2, 3, 4, 6, 7, and 8) and asked to decide whether the digit was even/odd (task A) or lower/higher than 5 (task B). The task required participants to press x if the digit was even or lower than five; and press n if the digit was odd or higher than 5. Response mapping was counterbalanced across participants. Digits requiring the same response for both tasks are referred to as being congruent (2, 4, 1, 3). For example, 2 requires the same response (e.g., x) for both tasks since it is even and lower than 5. Stimuli requiring different key responses for each task were referred to as incongruent (6, 8, 7, 9). For example, 6 requires x response for even/odd task while the correct response would be n for lower/higher task. Stimuli were presented in Courier New (bold) 36 points until an appropriate key response or maximum duration of 5000ms. and followed by 150ms inter stimulus interval.

The task consisted of three blocks: single task block, low load block and high load block. Single task blocks were always presented first to allow participants to establish stimulus-response mappings. In single task blocks, only task A or B was presented consistently within the block. The order of the tasks was randomised across participants. In the low load block, stimuli were presented in a 10cm by 10cm square divided into four 5cm by 5cm squares (Figure 1). Stimulus presentation order was always clockwise and as follows: AABB.

The position of the stimulus indicated the task that needed to be performed. The top half of the square indicated the even/odd task while the bottom half indicated lower/higher task. Therefore, task order was always explicitly cued. Participants were also informed about the task order (e.g., even/odd, even/odd, lower/higher, lower/higher) and were told to “switch task every second trial.” The location indicating each task was counterbalanced across participants (e.g., even/Odd task was required if the digit was in the top half of the square, and in the bottom half for the other half of the participants). After a response, instead of a blank screen, the square with no stimuli was presented for 150ms followed by either the reminder screen (for incorrect responses or time-outs) or the next stimulus screen (if the response is correct). There were total of 160 trials with 12 practice trials for the low load block. The tasks consisted of an equal number of digit, task types and congruency types.

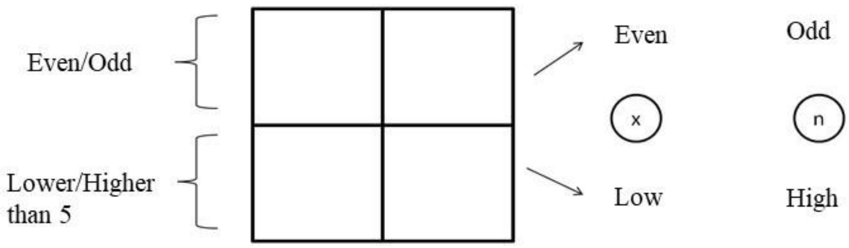

Figure 1. Stimulus cuing frame and instructions for the low load block

Stimulus–response mapping was counterbalanced across participants with the restriction that even and low; and odd and high was always assigned to the same keys. There were an equal number of participants in each stimulus-response mapping condition for the task type position (top/bottom).

The high load block followed the same instructions with the absence of a square frame. Participants were informed about the task sequence (AABB) and expected to keep track of the sequence. In this block, a reminder provided information about (1) the task instructions (2) the task types for the next two trials. The reason for informing participants about the next two trials was to prevent participants from losing track of the task and to prevent an error leading to a series of errors.

Unpredictable Task Switching Paradigm:

The stimuli consisted of eight letters (four vowels: A, E, I, U and four consonants: G, M, L, K) and eight digits (four even: 2, 4, 6, 8 and four odd: 3, 5, 7, 9) presented in uppercase 48-point size in Times New Roman (bold). The same two response keys were used for both task sets. That is, participants were to press the c key if the stimulus was a vowel or if it was even; and to press the m key if the letter was a consonant or if the digit was odd. Target responses for vowel/even and consonant/odd stimuli were counterbalanced between participants. A cue was presented for short (50ms) and long (650ms) durations immediately before the stimulus (until response or maximum 5000ms). A reminder of instructions (2000ms) followed the stimulus screen in the case of incorrect response or time-out.

Single task blocks were always undertaken before the mixed block allowing participants to establish stimulus-response mappings before performing the mixed block. In the single task block participants were always presented with the same type of stimulus (either a letter or a digit). Each task had 64 trials (32 long CSI, 32 short CSI) with 16 practice trials (8 long CSI, 8 short CSI). Only one type of task (A or B) was presented for each block and then the other task was presented.

In the mixed block, digits and letters were presented in a pseudo random order such that it was not possible to predict the next trial. Mixed blocks consisted of six sequences and reverse versions of each sequence. Therefore, task A and B was counterbalanced within participants. Each sequence involved 17 stimuli. After the first trial there were 8 repetition trials, 4 switch trials and 4 negative priming trials (8 switch trials in total). In switch trials, two trials required a switch after two repetitions of the alternative task and two trials occurred after three repetitions of the alternative task. We controlled the number of switch and negative priming trials as they require different levels of inhibition (e.g., Arbuthnott, 2005; Koch et al., 2006; Sdoia & Ferlazzo, 2008). Each sequence was pseudo randomised with the limitations of: (1) the first trial was always followed by a repeat trial (2) negative priming trials were always presented after a repeat trial or another negative priming trial (3) switch trials were always presented after two or three repeat trials. There were total of 16 sequences (17 trials each) each for short and long RSI conditions. The first two sequences (1 long, 1 short) of the mixed block were practice trials. Before each sequence, participants were informed whether the cue duration would be long or short. After each sequence an information screen was shown indicating that the sequence was completed, and participants had to press space key to proceed, thereby having an interval in between each sequence. Total task duration was approximately 20 minutes.

Procedure

The present study included the CAARS-S:S for measuring traits of ADHD, a predictable TSP and an unpredictable TSP. Tasks were administered in a pseudo random order with the condition that unpredictable TSP was always presented before the predictable TSP. Since unpredictable TSP required an extra instruction (lower/higher than 5), in order to prevent the confusion, it was always administered first. All versions of unpredictable TSP (S-R mapping) and predictable TSP (even/odd first, low/high first; and S-R mapping) were counterbalanced across participants.

Results

Sample

Scores from CAARS revealed that 23 participants scored above average on the ADHD index (*M* = 51.24, *SD* = 8.46). For individual symptoms, the number of participants that scored above the average was 35 for inattention (*M* = 55.78, *SD* = 9.34), 26 for hyperactivity (*M* = 49.65, *SD* = 8.21) and 13 for impulsivity (*M* = 48.02, *SD* = 7.86). The number of participants scoring in each category provided by the CAARS-S:S guidelines are reported in Figure 2. Raw scores are transformed into standardised T-scores so that all sub-scales have mean of 50 and standard deviation of 10. T-scores range between 28 (lowest) to 90 (highest) calculated based on the age and gender. Our mean and standard deviations for impulsivity, hyperactivity and index scores were within half a standard deviation from the proposed mean and standard deviations for CAARS-S:S. The mean for the inattention scores was half a standard deviation above the proposed mean but still within the confidence interval values. One participant also reported previous ADHD diagnosis whereas two participants preferred not to state. Please see Figure 2 for detailed participant characteristics.

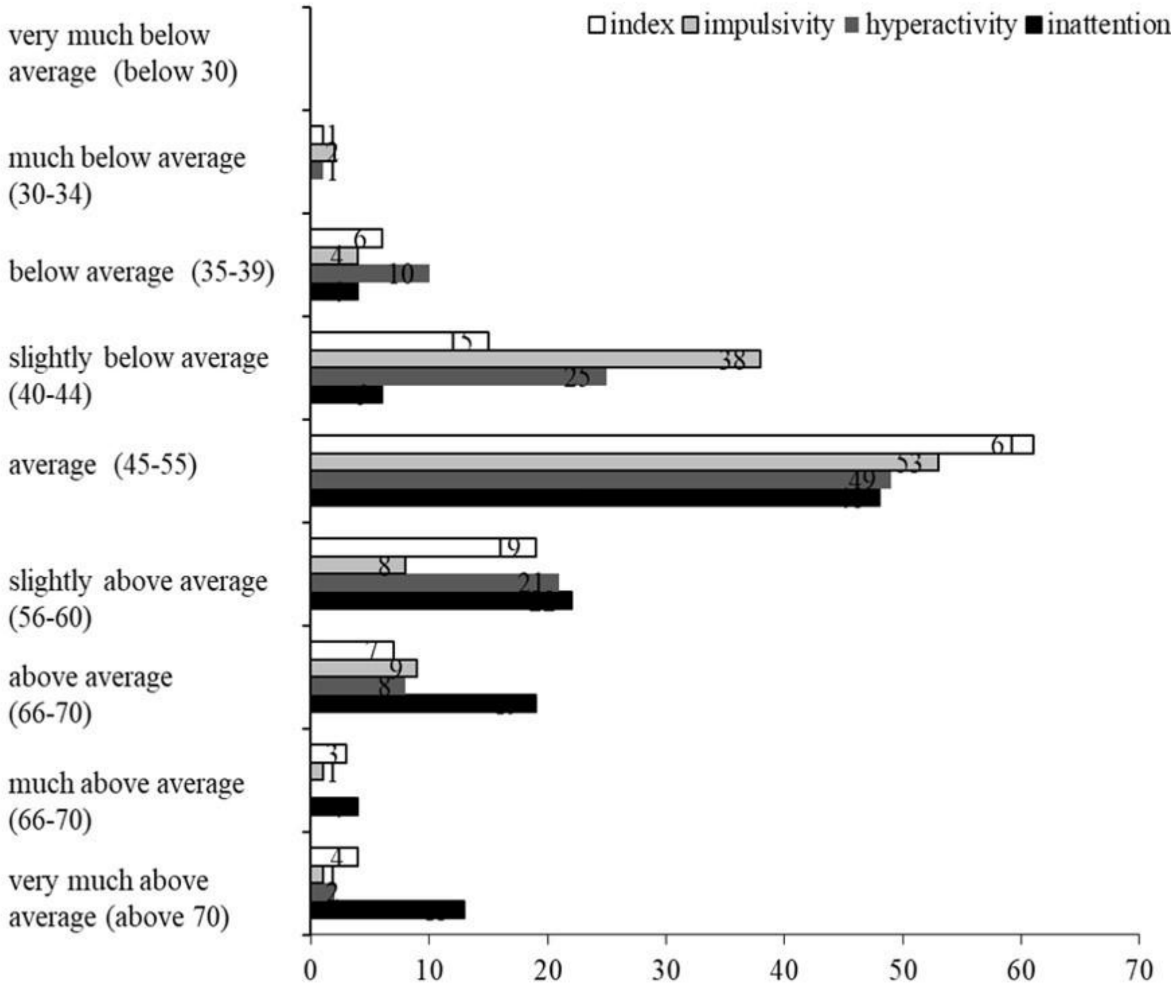

Figure 2. Number of participants falling into each category and the corresponding T-scores in brackets based on CAARS-S:S guidelines

Analysis of general switch costs

RTs for incorrect responses and trials following incorrect responses and the data points two standard deviation above and below the mean (1.4%) were removed before the analysis.

Predictable Task Switching Paradigm

We conducted a 2 (Condition: low load, high load) X 2 (Transition: repeat, switch) repeated measures ANOVA to evaluate the switch cost (see also Figure 3). A transition main effect indicated that overall RTs were higher on switch (*M* = 1189.76, *SE* = 22.05) than repeat (*M* = 785.31, *SE* = 9.94) trials [$F(1, 102) = 457.12$, $p < .001$, $\eta^2 = .82$] while the condition main effect was not significant, $F(1, 102) = 2.02$, $p = .158$, $\eta^2 = .02$. There was a significant Condition X Transition interaction, $F(1, 102) = 44.34$, $p < .001$, $\eta^2 = .30$. Bonferroni corrected paired samples t-tests revealed that in the low load condition, responses to switch trials (*M* = 1226.99, *SE* = 24.93) were slower than repeat trials (*M* = 738.74, *SE* = 10.46), $t(108) = 23.23$, $p < .001$. Same effect was observed in the high load condition [switch: *M* = 1156.29, *SE* = 27.51; repeat: *M* = 839.26, *SE* = 14.46), $t(106) = 13.91$, $p < .001$].We also found that in the high load condition, repeat trials were slower [$t(104) = 6.87$, $p < .001$] while switch trials were faster compare to the low load condition [$t(109) = 2.41$, $p = .017$]. However, this difference did not reach significance following Bonferroni correction ($P_{corrected} = .013$). To test the effect of WM load on task switching, we compared the switch cost across conditions. Paired samples t-tests revealed that switch costs were higher in the low load (*M* = 474.82, *SE* = 20.54) compared to the high load (*M* = 322.98, *SE* = 22.69) condition $t(101) = -6.54$, $p < .001$.

We next analysed the switch and repeat RTs for congruent and incongruent conditions separately. Bonferroni corrected paired samples t-tests revealed that RTs to switch trials were longer than repeat trials in all conditions: For low load, switch trials took longer than repeat trials for congruent [switch: *M* = 1192.78, *SE* = 25.41; repeat: *M* = 733.81, *SE* = 11.29, $t(110) = 21.64$, $p < .001$] and incongruent stimuli [switch: *M* = 1268.67, *SE* = 25.38; repeat: *M* = 751.95, *SE* = 12.19, $t(107) = 23.60$, $p < .001$]. Similarly, for high load, switch trials took longer than repeat trials for congruent [switch: *M* = 1116.60, *SE* = 28.78; repeat: *M* = 844.72 = 839.26, *SE* =

16.83, $t(109) = 11.17$, $p < .001$] and incongruent stimuli [switch: $M = 1221.20$, SE = 29.18; repeat: $M = 834.28$, $SE = 15.33$, $t(107) = 15.06$, $p < .001$].

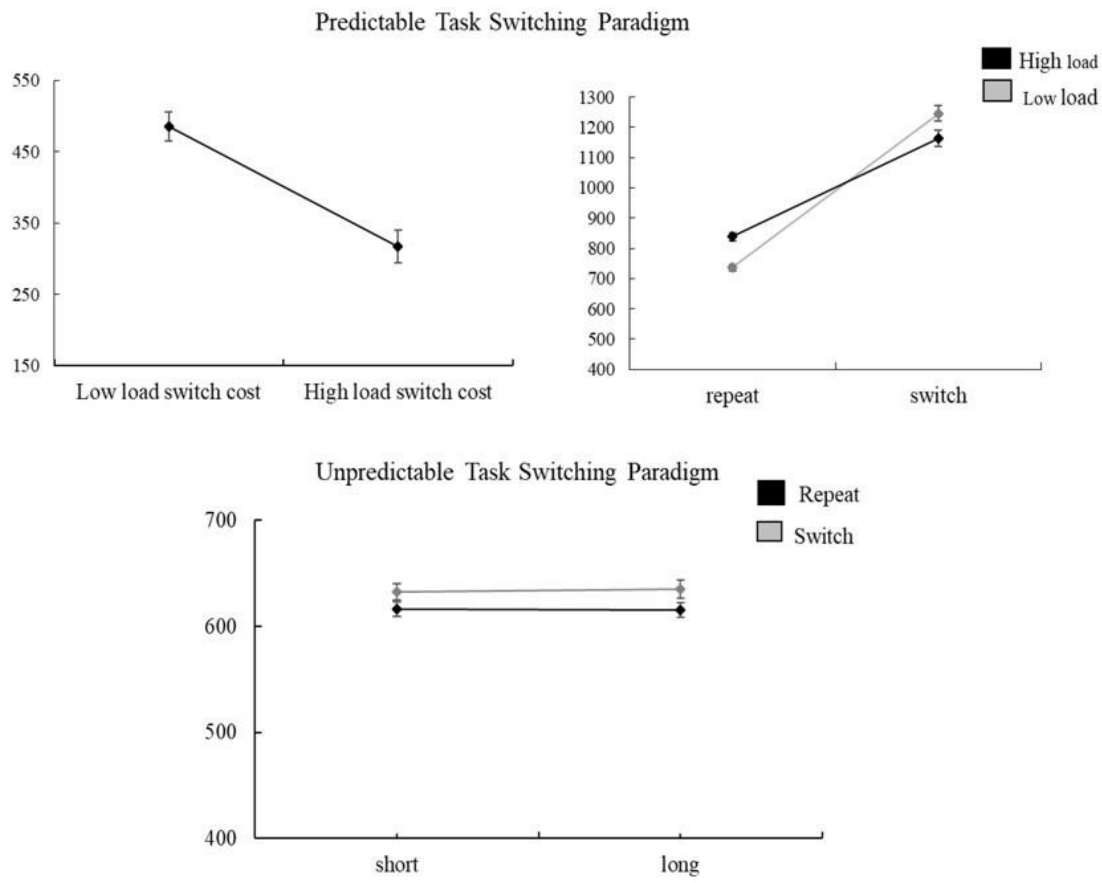

Figure 3. Average RTs based on the conditions of the stimuli in predictable and unpredictable task switching paradigms

Unpredictable Task Switching Paradigm

We conducted a 2 (RSI: short, long) X 2 (Transition: repeat, switch) repeated measures ANOVA to evaluate the switching cost and the effect of RSI. A transition main effect indicated that overall RTs were higher in switch ($M = 627.12$, $SE = 6.27$) than repeat ($M = 602.37$, $SE = 6.27$) condition, $F(1, 89) = 80.61$, $p < .001$, $\eta^2 = .48$. However, the RSI main effect [$F(1, 89) = .41$, $p = .525$, $\eta^2 = .01$] and RSI X transition interaction [$F(1, 89) = 2.69$, $p = .104$, $\eta^2 = .03$] were not significant, indicating that the RSI manipulation was not effective.

Inattention and Task Switching

We examined the bivariate correlations between the independent and dependent variables (Table 1). Pearson correlation coefficients revealed significant positive correlations between inattention scores and switch cost when the tasks were predictable. Inattention was correlated to predictable switch costs in low load ($r = .19$, $p = .05$) and high load ($r = .26$, $p < .01$) conditions. We also measured the switch costs separately for stimulus congruency: in the low WM condition, inattention significantly correlated with the switch costs when the stimuli were incongruent ($r = .22$, $p = .03$) but this correlation was no longer significant in the high WM load condition. In contrast, in the high WM condition, inattention was correlated with the switch costs of congruent ($r = .19$, $p = .05$) but not incongruent stimuli. Furthermore, inattention was not significantly correlated with the switch costs when the task order was unpredictable (short RSI: $r = .02$, $p = .88$; long RSI: $r = .08$, $p = .41$).

Table 1

Correlations between variables

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. Inattention	55.78	9.34	-											
2.Hyperactivity	49.65	8.21	.39**	-										
3. Impulsivity	48.02	7.86	.45**	.45**	-									
4. Index	51.24	8.46	.71**	.66**	.72**	-								
5. unpredictable switch cost (short RSI)	19.77	28.91	.02	.03	-.06	-.05	-							
6. unpredictable switch cost (long RSI) (log transformed)	1.43	.44	-.01	.14	.11	.11	.23*	-						
7. predictable switch cost (low load)	482.27	211.39	.19*	.04	.13	.08	-.01	.14	-					
8. predictable switch cost (high load)	317.03	235.74	.26**	-.03	.08	.11	.43**	.14	.24*	-				
9. congruent stimuli switch cost (low load; predictable)	458.97	223.45	.15	-.05	.09	.06	.12	.16	.95**	.42**	-			
10. incongruent stimuli switch cost (low load; predictable)	516.72	227.50	.22*	.10	.19	.12	.08	.12	.93**	.43**	.79**	-		
11. congruent stimuli switch cost (high load; predictable)	271.89	255.22	.19*	.02	.07	.13	.10	-.09	.31**	.87**	.27**	.31**	-	
12. incongruent stimuli switch cost (high load; predictable)	286.92	266.92	.15	-.07	.03	.06	.12	.05	.42**	.81**	.39**	.42**	.57**	-

*p<.01, **p<.05

We ran multiple regression analysis to investigate the role of ADHD traits when explaining switch costs. We also used Bayes Factors (B) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. We followed Dienes (2014) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. Where a Bayes Factor is given, we modelled the predictions of the theory of some evidence for a relationship with a half-normal whose mean and standard deviation values were taken from Cepeda et al. (2000); experiment 1 for predictable and experiment 2 for unpredictable TSPs due to the similarity of the procedure to our study. We used the value of r square (coefficient of determination) to calculate Bayes Factor where the regression model was non-significant (using BayesFactor package of R software, Liang, Paulo, Molina, Clyde, & Berger, 2008).

For predictable switch costs under high load, the multiple regression analysis revealed that the model (Table 2) explained 9% of the variation, $F(3, 106) = 3.27$, $p = .02$. Hyperactivity ($p = .131$, $B_{H(0, .422)} = 0.04$) and impulsivity ($p = .926$, $B_{H(0, .422)} = 0.04$) were non-significant predictors with Bayes Factors providing strong evidence for the null. Thus, inattention was the only predictor of the predictable switch cost under high WM load. The regression model where ADHD traits predict the switch costs in the low load condition of the predictable task was not significant and the Bayes Factor provided strong evidence for the null $F(3, 107) = 1.57$, $p = .20$, $B = 0.16$.

Table 2

Summary of regression model for inattention, hyperactivity and impulsivity scores on switch cost in high working memory load condition.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.09	.06	
Inattention	7.75	2.68	.32	2.89**			.27
Hyperactivity	-4.74	3.12	-.17	-1.52			-.15
Impulsivity	.31	3.33	.01	.09			.01

*p < .05, **p < .01

Due to the significant correlations, we ran multiple linear regression models to investigate whether inattention, hyperactivity and impulsivity predicted the switch cost to incongruent stimuli in the low load condition [$F(3, 107) = 2.13$, $p = .101$, $B = 0.31$], and, the switch cost to congruent stimuli in the high load condition [$F(3, 109) = 1.47$, $p = .227$, $B = 0.04$] which yielded non-significant results and Bayes values revealing strong evidence for the null hypothesis of no difference.

Discussion

We employed predictable and unpredictable task switching paradigms (TSPs) to investigate whether self-reported inattention is related to a general task switching impairment, a limitation in inhibition, or, in line with research showing a relationship between inattention and working memory (WM), an impairment specifically related to predictable task switching. The predictable TSP required participants to keep the task order available in WM and use this information to predict the next task to be performed, a form of proactive control. In the unpredictable TSP, the task order changed in a pseudo random order, not allowing participants to prepare or to use previous information to work out the upcoming task. Therefore, the unpredictable task primarily required reactive control.

Given the negative relationship between the WM capacity and inattention even in sub-clinical populations (Elisa et al., 2016; Lui & Tannock, 2007), we predicted that inattentive traits would be more related to the higher switch costs during predictable switching as the task requires the use of proactive control. Moreover, it was predicted that the relationship between inattentive traits and switch costs would be stronger when the task involved a higher WM load (in the cue-absent condition). As predicted, we found that inattentive traits predicted greater switch costs in the predictable TSP but only under high WM load conditions. Bayes values provided evidence towards no relationship between hyperactivity/impulsivity and the switch cost under predictable task switching conditions and for no relationship between the ADHD-related traits and switch costs in the unpredictable TSP.

It is interesting that inattention was related to poorer performance on what is essentially an easier task since the task changed in a predictable manner and thus it was possible to prepare the correct task set in advance. Such an impairment fits well with the problems with planning and organisation associated with inattention. To benefit from the preparation, participants had to keep the task order available in WM and use this information to identify the next task. Our results suggest that those with inattention are specifically impaired at this preparatory activity. Whilst we found that inattentive traits were positively correlated with switch costs in the cue-present condition, this relationship was not predictive.

We also measured switch costs separate for congruent and incongruent stimuli since the literature suggested that larger switch costs for ADHD may be driven by the switch costs for incongruent (RTs to incongruent switch trials – RTs to incongruent repeat trials) rather than congruent (RTs to congruent switch – RTs to congruent repeat trials) stimuli (Cepeda et al., 2000). As noted above the ADHD index score did not predict any switch costs in our study contrasting with the findings from Cepeda et al. (albeit in a sub-clinical population). However, our analysis revealed that inattention was correlated to incongruent trial switch costs, but only under low WM load. Inattention was also correlated with congruent trial switch costs, but only under *high* WM load. However, inattention did not predict the magnitude of either of these indicating that in our data at least inattention does not lead to increased switch costs as a result of trial congruency.

Consistent to Liefooghe et al. (2008), switch costs were modified by WM. In the predictable TSP, responses to the repeat trials were longer in the high compare to the low WM load condition, indicating an effect of WM load in the expected direction. However, responses to the switch trials were quicker in the high (cue absent) compare to the low (cue present) WM load condition. We also found that the switch costs decreased in the high compare to low WM load condition (Figure 3). This could be due to the type of control executed by the participants. The cue-present condition involved proactive and/or reactive control depending on the strategy (keeping track of the order or benefiting the cue) to perform the task; keeping track of the task order allowed participants to prepare in advance as they figure out the next stimuli from the maintained task order and this could happen before the next stimulus appears. Utilising the cue did not allow advanced preparation. That is, in the cue-present condition, participants could choose from the two strategies for responding. The cue-absent (high WM load) condition, however, forced participants to keep track of the order which may have encouraged advance preparation, thereby reducing response times to the switch trials in the cue-absent (high WM load) compare to the cue-present (low WM load) condition. This supports the notion that inattentive traits uniquely predicted the switch costs when WM was needed to perform proactive control for advanced preparation (cue-absent condition of predictable TSP).

To summarise the results from Study 1, we found that only inattentive traits significantly predicted task switching performance. This was only observed when switching was predictable and trial order was not indicated by a cue, suggesting that it was the requirement to track task order and utilise proactive control that lead to larger switch costs in those with high levels of inattention. Furthermore, none of the ADHD related tendencies were correlated to switch costs in an unpredictable TSP. These findings indicate that the impairment in WM associated with inattention can lead to task switching impairments and that the failure to observe a consistent relationship between ADHD and task switching performance in previous studies is likely due to the failure to consider the differential influence of the core symptoms of inattention, hyperactivity and impulsivity. However, these conclusions are mitigated by certain limitations in the experimental design. First, the ability to keep track of the task order and use proactive control were confounded in the present study. Second, the predictable and unpredictable paradigms differed in several ways: 1) The stimuli in the predictable TSP were bivalent while the unpredictable TSP had univalent stimuli; 2) The RSI was manipulated in the unpredictable TSP only leading to differences in time constraints between the predictable and unpredictable tasks. Finally, whilst there are a number of participants falling into each category that is spread normally (see Figure 2), the hyperactive and impulsive scores were numerically more restricted than the inattention scores, which could have reduced the likelihood of observing a relationship between these symptoms and task switching performance (although assuming a linear relationship, we believe this would not have had a significant impact on the results).

Study 2

Study 1 revealed that self-reported inattentive traits uniquely predicted higher switch costs in a predictable task switching paradigm in which working memory (WM) was needed to track task order while unpredictable switching was not related to any of the ADHD symptoms. However, the tasks differed more than in predictability. Therefore, in the present study we addressed the methodological issues raised above by using bivalent stimuli in both the predictable and unpredictable TSP and eschewing an RSI manipulation. In addition, the present study also sought to identify factors that might lead to a relationship between inattention and predictable task switching performance.

For those participants high in inattention the factor limiting performance in Study 1 was either the need to keep track of the order of repeat and switch trials or the need to utilise preparatory proactive control when the order was known. Given the predictable and basic nature of the sequence, the participants should have been able to take advantage of the simple sequence to improve their performance and proactively prepare for each upcoming trial. Inattention did not predict performance when there was environmental support for tracking task order. Clearly when the location cued the task was to be performed, the need for a contribution from working memory to track task order was reduced. Such a result could be explained by either an impairment in working memory or in the use of proactive control. In Study 1 these factors were confounded.

In the present experiment, participants were asked to complete five blocks of task switching where task order was either predictable (a trackable sequence engaging WM) or it was unpredictable. The task was cued with two frames (an advanced cue presented before the stimulus and stimulus cue presented with the stimulus) in either black, red or blue. The coloured cue indicated which task to perform while black cue was uninformative. Moreover, in some blocks coloured advanced cue enabled participants to engage in proactive control and some blocks included a coloured stimulus cue that permitted participants to utilise reactive control to select the correct task set. The five block types were the following: 1) a predictable task switching order with black advanced cue on any trial but a coloured stimulus cue indicating the task to be performed; this condition is referred to as Order PC/RC because the predictable order permitted the use of proactive control and the stimulus colour cue permitted the use of reactive control; 2) a random task switching order with coloured advanced cue on every trial and a coloured stimulus cue indicating the task to be performed; this condition is referred to as Random PC/RC because the order was random and the advanced cue permitted the use of proactive control and the stimulus colour cue permitted the use of reactive control; 3) a predictable task switching order with black advanced cue and black stimulus cue indicating the task to be performed; this condition is referred to as Order PC because the predictable order permitted the use of proactive control (this condition is the condition most similar to the high WM load condition of Study 1); 4) an unpredictable task switching order with a coloured advanced cue on every trial but black stimulus cue indicating the task to be performed; this condition is referred to as Random PC because the order was random and the advanced cue permitted the use of proactive control; 5) an unpredictable task switching order in which a a coloured stimulus cue permitted the use of reactive control; the condition is referred to as Random RC. This design permits the de-confounding of working memory load and proactive control. If inattention was related to impairment in the use of proactive control, it would be related to performance in any block that presents an advanced cue (Random PC/RC or Random PC). If inattention was related to working memory impairments, it would be related to performance in any block/condition that has a predictable sequence and involves the need to keep track of the order of switch and repeat trials (Order PC/RC or Order PC), but especially Order PC where no other cue is provided about which task to perform (thereby replicating Study 1). If inattention was related to an impairment in reactive control it would affect performance most clearly in the Random RC block.

The de-confounding of working memory and proactive control is a necessary step in identifying the determining factor producing the relationship between predictable task switching and inattention. However, in the present study we also considered another potential contributor to this result. Specifically, Elisa, Balaguer-Ballester and Parris (2016) reported a relationship between working memory performance and sub-clinical symptoms of ADHD. The only working memory related task that was uniquely related to inattention was a letter monitoring task that measured the tendency for goal neglect. In goal neglect, although instructions are understood and not forgotten (a representation of the task is created; Duncan et al., 1996; Duncan et al., 2008) participants behaviourally fail to follow these instructions (Duncan et al., 1996).

Duncan et al. explained the occurrence of goal neglect with reference to competition in the task model: In order to perform complex tasks, individuals need a body of knowledge composed of all relevant facts and instructions (*the task model)* where the cue-action mappings with sufficient saliency are constructed. The model should be organised into small chunks of information to be retrieved when relevant triggering conditions occur. As the information in the task model is increased (e.g., by increasing the complexity in the task instructions), multiple task components compete to be represented. Due to limited capacity in some individuals, some of the task components are too weakly represented to be used when needed, resulting in goal neglect (Duncan et al., 1996; Duncan et al., 2008). When asked, participants can re-report the instructions in full, but it is the use of components of the task model during task performance that is impaired. Goal neglect has been linked to the lapses in WM (Duncan et al., 2012; Kane & Engle, 2003) and fluid intelligence which is related to cognitive control functions (Duncan et al., 1995; Kane & Engle, 2003; Marshalek et al., 1983; Oberauer et al., 2003). Along with various measures of WM, Elisa at al. (2016) also measured the link between inattention, hyperactivity and impulsivity and goal neglect based on the notion that those with inattention have problems receiving verbal instructions. They showed that inattention was uniquely related to goal neglect even when controlling for fluid IQ.

The original conception of goal neglect has been influential and other researchers have extended the concept. De Jong (2001) proposed the notion of the *failure to engage hypothesis* and referred to this as goal neglect. De Jong argued that the residual switch cost, a cost, even after being given time to prepare for an upcoming trial, remains because participants occasionally fail to engage and maintain goal-related preparation (but see Mayr & Keele, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer,

& Evans, 2001 for an alternative view). According to the failure to engage hypothesis, individuals sometimes fail to take the opportunity to perform preparation. Given the link between inattention and increased reports of goal neglect, we hypothesised that the link between inattentive traits and increased predictable switch costs could be moderated by goal neglect. If this is supported by the data, then it would support the notion that goal neglect is an important contributor to the experience of inattention.

Method

Participants

As with Study 1 we collected data from 120 (different) individuals (*M* = 20.55, *SD* = 2.31). Rather than a power analysis, we included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1. Participants aged between 18 and 33 with normal or corrected vision from non-clinical samples were recruited through Bournemouth University's research participation system and through advertisements. Participants were mainly undergraduate and postgraduate students. Undergraduate students received course credits for their involvement.

Materials

Adult ADHD Self Report Scale (ASRS):

We used ASRS to measure ADHD related traits (Adler et al., 2006; Kessler et al., 2005). ASRS includes total of 18 items consisting the ADHD symptoms of Diagnostic and Statistical Manual of Mental Disorders Fourth edition (DSM-IV). There are nine items indicating inattentive symptoms (1,2,3,4,7,8,9,10,11) and nine items indicating hyperactive/impulsive symptoms (5,6,12,13,14,15,16,17,18). ASRS asks participants how often a particular symptom of ADHD has occurred to them over the past six months on a five-point response scale ranging from “never” (0), “rarely” (1), “sometimes” (2), “often” (3), to “very often” (4). The ASRS was scored by averaging the participants’ ratings across the responses in each symptom cluster, providing us a continuous scale (Overbey et al., 2011; Whalen et al., 2003).

Task Switching Paradigm:

The task required participants to perform two types of tasks: participants were required to decide if the digit was even or odd (even/odd task) or if the digit was lower or higher than five. Available responses (‘z’ and ‘m’) counterbalanced across participants. The task comprises two conditions where the pure condition required only one type of task throughout the block while the mixed condition required frequent switches between two tasks. There were two blocks for the pure condition (one block for each type of task) presented in random order. Pure blocks were designed to make participants familiar with each type of task and learn stimulus-response associations. It was also aimed to test participants’ ability to perform each task. Participants performed total of 16 practice and 64 experimental trials for the pure condition. The Mixed Condition included five blocks presented in random order. Each block included 16 practice and 96 experimental trials. Stimuli consisted of digits between one to nine except five, presented in Courier New Bold in 36 points (bold). Before the stimulus presentation, a square with 2.8 cm length appeared as a cue (advanced cue) and stayed on the screen as a frame for the stimulus (stimulus cue). Depending on the block, the frame was either red, blue or black. The colours red and blue indicated the task to be performed (counterbalanced across participants). At the beginning of each block, participants were asked to make a key press when they were ready. A 2000ms blank screen followed the key press. Each trial started with the square frame, then, the stimulus was presented inside the frame after 250ms. The stimulus was present until the response (maximum response duration was 5000ms). Following an error, a reminder for the rules appeared on the screen for 1200ms. Please see Figure 4 for a depiction of the sequence of events.

In the *Random PC/RC block*, both the advanced cue and the stimulus cue was coloured indicating the task to be performed. Hence, participants had the opportunity to attend the advanced cue or the stimulus cue. The advanced cue allowed advanced preparation and the use of proactive control, while the stimulus cue did not. Instead, the stimulus cue required participants to engage in reactive control where the cognitive processes are triggered by the stimulus presentation. The tasks were presented in a random order.

The *Order PC/RC block* followed the same procedure as the previous blocks, except that the tasks were presented in a set order (AABB…). The stimulus cue was presented in red or blue, indicating the task to be performed. Therefore, participants could either keep track of the task order or wait for the stimulus cue to figure out the required task. Keeping track allowed advanced preparation (proactive control) while attending the stimulus cue required reactive control.

In the *Random PC block*, the advanced cue was presented in red or blue, indicating the upcoming task. The frame then turned to black. Since participants had to focus on the advanced cue to figure out the next task, they were strongly encouraged to engage in advanced preparation. The tasks were presented in a random order.

The *Order PC block*, similar to Order PC/RC block, the tasks were presented in a set order (AABB…). Both the advanced cue and the stimulus cue was always black, forcing participants to keep track of the task order to find out the task to be performed. Keeping track of the task order allowed participants to know the upcoming task before stimulus presentation, hence strongly encouraging advanced preparation.

Finally, in the *Random RC* condition, tasks were in random order and were indicated by the stimulus cue, allowing only the use of reactive control. Therefore, this block involved unpredictable switching.

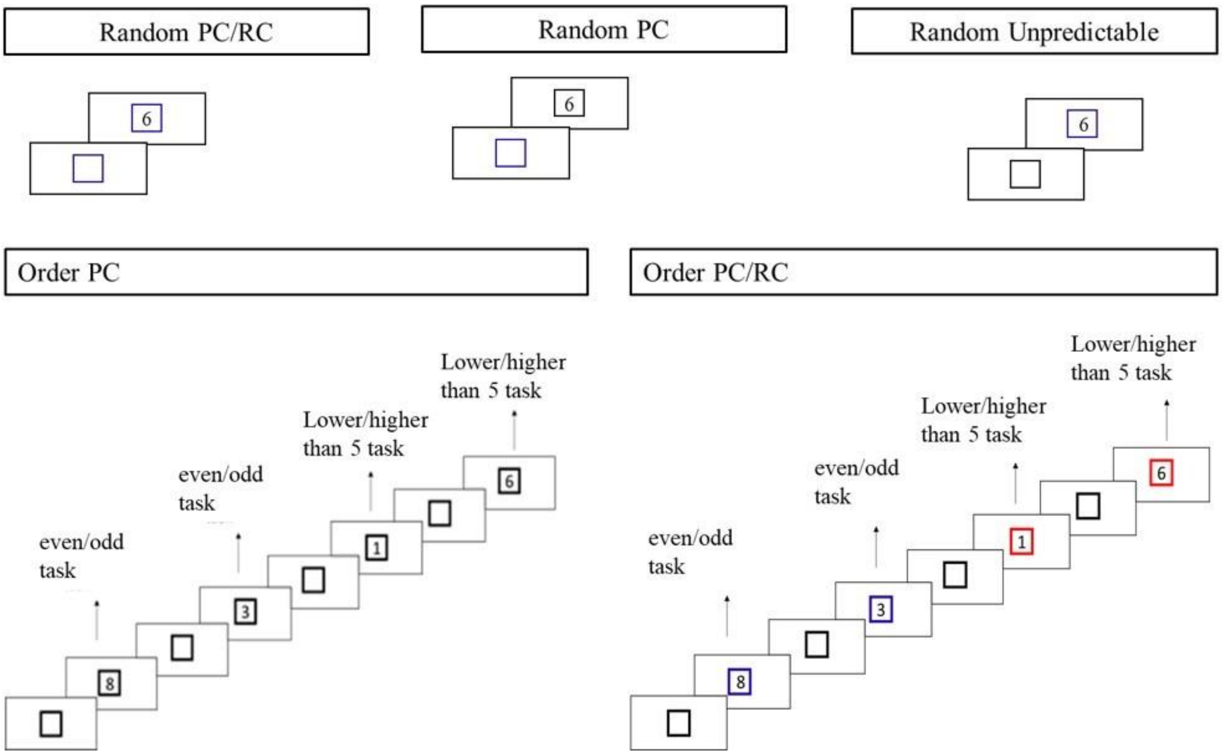

Figure 4. Example demonstration for the blocks of mixed condition in the task switching paradigm.

Automated Operation Span Task:

Automated version of Operation Span task taken from Unsworth, Heitz, Schrock and Engle (2005) was used as a measure of working memory capacity. The task required participants to remember the letters solve mathematical problems in between as the distraction (Unsworth et al., 2005). Mathematical problems and letters were presented one at a time in the centre of the screen. Participants reported the sequence of letters by choosing among possible letters from a 4 by 3 matrix of possible letters (F, H, J, K, L, N, P, Q, R, S, T, and Y). For the mathematical operations, participants were told to solve the mathematical operation as quickly as possible and press a mouse button when ready. Next, participants were asked to report if the number presented on the screen is the correct solution of the mathematical problem by clicking on either the true or the false button.

Participants completed a practice session with simple letter span following another block of 15 mathematical problems only. In the experimental condition, letters appeared on the screen for 800ms while recall phase was untimed. After the recall, an accuracy feedback for both operations was provided. Following the practice sessions for letter recall and mathematical problems, participants had a final practice combining both operations, identical to the experimental condition. In the experimental condition, sequences of mathematical problems and letters were presented. There were three sets from each possible set size (3 to 7 letters to remember and mathematical problems to solve). Thus, total number of 75 letters and 75 mathematical problems were presented. Scores are calculated by adding the number of letters recalled in the correct order (also known as the partial score; Turner & Engle, 1989). Participants below the 85% accuracy were not included in the analysis to ensure that participants were attempting to perform both operations.

Letter Monitoring Task:

The letter monitoring task was taken from Duncan et al. (1996) as a measure of goal neglect. In the letter monitoring task, participants receive series of pairs of letters and digits on the left and right side of a central dot. The task is to ignore the digits and read aloud the letters on the attended side. Digits were chosen from the set 1-8, and letters were randomly chosen without replacement from the letters of the alphabet except D, I, O, V, and W. Following the instructions of Duncan et al., participants were then asked if they were ready to start the task prompted by the "READY?" message. Following the participant's verbal report, the experimenter made a key press to initiate a 500ms blank interval followed by the practice session. Practice session started with the presentation of the instruction "WATCH LEFT/RIGHT" for 1 second indicating the side participant is required to report the letters. The message was followed a by a further 1 second interval for participant to get ready for the stimulus sequence. Each trial had s sequence consisted of pairs of numbers and letters presented for 200ms and a blank interval of 200ms. In the first part of the trial, there were ten pairs (5 letters and 5 digits). After the 10^{th} pair, a "+" or "-" symbol was presented in the center of the screen for 200ms. A "+" sign indicated to attend right while "-" sign indicated to attend left side of the dot (letters only). Following a further 200ms, three more pairs were presented for the second part of the trial. For the second part of the trial, the first pair was always digits and the rest were letters. A scoring sheet with correct answers was prepared for experimenter to manually record responses of the participant. Please see Figure 5 for an example trial.

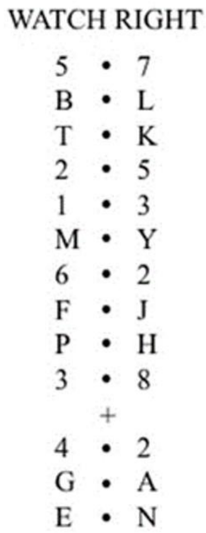

Figure 5. An example demonstration of a letter monitoring task trial taken from Duncan et al. (1996). Starting from the top to bottom, “Watch RIGHT” message (1s) is followed by the pairs. Each pair is presented in a separate screen for 200ms with a blank interval of 200ms.

To ensure that the cue was remembered correctly, pieces of papers were placed on the appropriate side of the screen with “PLUS” (for the right) and “MINUS” (for the left) written on them. All participants received the same following instructions: (1) read aloud the letters and ignore the numbers (2) start on the side instructed by the message on the screen (3) use the cue (+ or -) to attend the correct side for the second part of the trial. The task was devised of three blocks of 12 experimental trials with 3 sub-blocks (4 trials each) within each block. Participants also received a practice trial which was repeated until at least one letter was reported from either (correct or incorrect) side and the “+/-“ cue was reported accurately. In each successive trial of four there were one “WATCH LEFT” followed by a “-“ cue, one “WATCH LEFT” followed by a “+” cue, one “WATCH RIGHT” followed by a “-“ cue, and, one “WATCH RIGHT” followed by a “+” cue presented in random order. Therefore, in half of the trials, cue required participants to stay on the attended side as the message while on the other half the cue indicated to switch side. Participants were asked to repeat the rule again between each block. Instructions for the task were provided following Duncan et al.'s (1996)(1996) instructions.

Scoring. Participants received a score of 1 for each letter reported from the correct side (in the second part of the trial). A perfect trial included a score of two with two letters reported from the correct side. A valid trial would include at least 3 letters reported from the appropriate side indicated by the initial message (the first part). Participants also had to report at least one switch and one repeat trial to pass each sub-block. Final score was computed by the sum of the each passed sub-block. Scores indicate to what extend a participant's score was affected by the cue.

Raven's Standard Progressive Matrices (SPM; Shortened Version):

In the shortened Raven SPM (Bouma, Mulder, & Lindeboom, 1996), three sets of items from the original version (Sets B, C, and D) were administered as an indicator of fluid intelligence. Each item consisted of a matrix of black and white elements composing an overall pattern (rule). Participants were asked to complete this pattern by choosing the correct missing element among multiple possible options. There was no time limit in completing the test. Each item was scored either 1 (correct) or 0 (incorrect). Administration and scoring were carried out based on the guidelines provided in the SPM manual (Raven, 1938).

Procedure

The present study included: the ASRS for measuring ADHD related tendencies, Task Switching Paradigm, OSPAN as a working memory measure, Letter Monitoring Task as a measure of goal neglect and SPM as a control measure of fluid abilities for the goal neglect measures. After providing the participant information sheet and the informed consent, tasks were administered in counterbalanced order.

Results

Scores from ASRS ranged between zero to four. Mean scores and standard deviations for ASRS are reported in Table 3. The mean scores of inattention were again higher than those for hyperactivity/impulsivity and total ADHD scores but this difference was within 1 standard deviation above and below the mean. Outliers 2SD above and below the mean were removed for SPM (3.33%), Random PC/RC (5%), Order PC/RC (5%), Random PC (5.8%), Order PC (5.8%), Random RC (5%) due to non-normal distributions. For OSPAN, data for the participants scoring below 85% accuracy on math questions were also removed (7.5%).

Analysis of switch costs

RTs for incorrect responses and trials following incorrect responses were not analysed. We found switch costs for all conditions (Figure 6). Bonferroni corrected paired samples t-tests revealed that responses to switch trials [Random PC/RC: M = 1187.01, SD= 253.83; Order PC/RC: M = 1256.18, SD = 222.33; Random PC: M = 1201.34, SD = 314.13; Order PC: M = 989.48, SD = 278.25; Random: M = 1226.58, SD = 199.17] were slower than repeat trials [Random PC/RC: M = 796.63, SD = 145.49; Order PC/RC: M = 829.20; SD = 178.52; Random PC: M = 1008.13, SD = 231.93; Order PC: M = 763.19, SD = 163.34; Random: M = 884.62, SD = 125.24] in Random PC/RC [$t(102) = 17.47$, $p < .001$], Order PC/RC [$t(104) = 23.95$, $p < .001$], Random PC [t(102)

= 10.51, $p < .001$], Order PC [$t(104) = 10.68$, $p < .001$], Random [$t(102) = 21.94$, $p < .001$].

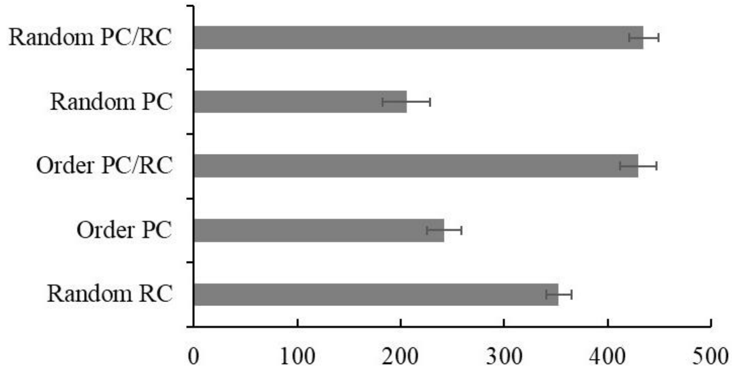

Figure 6. RTs of the switch costs in each condition. Error bars indicate standard error.

Pearson correlation coefficients revealed significant positive correlations (Table 3). Inattention was correlated with letter monitoring ($r = -.19$, $p = .04$) and OSPAN ($r = -.29$, $p = .002$) scores. Inattention was also correlated to switch costs in random PC/RC ($r = .20$, $p = .04$) and order PC/RC ($r = .22$, $p = .018$) conditions. Composite scores of ADHD were also correlated to OSPAN ($r = -.29$, $p = .002$). Scores of SPM was correlated with letter monitoring ($r = .31$, $p = .001$), task switching in random ($r = .20$, $p = .038$) and order PC ($r = .40$, $p < .001$) conditions.

We used Bayes Factors (B) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. We followed Dienes (2014) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. Where a Bayes Factor is given, we modelled the predictions of the theory of some evidence for a relationship with a half-normal whose mean and standard deviation values were taken from the variable inattention in the model

Table 3

Correlations between variables.

	N	M	SD	1	2	3	4	5	6	7	8	9	10	11
1. Inattention	120	2.06	0.69	-										
2. Hyp/Imp	120	1.45	0.73	.509**	-									
3. ADHDtotal	120	1.76	0.62	.860**	.877**	-								
4. SPM	116	31.27	2.67	-0.02	-0.02	-0.02	-							
5. Letter Monitoring	120	4.48	4.27	-.187*	-0.02	-0.11	.307**	-						
6. OSPAN	111	55.45	11.70	-.285**	-.215*	-.287**	0.07	.291**	-					
7. Random PC/RC	114	434.80	246.58	.20*	-.01	-.01	-.02	-.26**	-.13	-				
8. Order PC/RC	114	429.51	219.33	.222*	0.09	0.18	0.15	-.221*	-0.11	.37**	-			
9. Random PC	113	205.44	223.09	-0.03	-0.08	-0.07	-0.06	0.10	0.06	.31**	.209*	-		
10. Order PC	113	241.81	236.81	0.05	0.04	0.05	.401**	0.07	-0.02	0.05	.310**	0.04	-	
11. Random	114	352.69	207.48	0.09	-0.02	0.04	.197*	-0.17	-0.10	.44**	.525**	.211*	0.17	-

*p<.01, **p<.005

Inattention and Goal Neglect

We ran multiple regression analysis where inattentive and hyperactive/impulsive traits were used as predictors for letter monitoring performance (Table 4). The model explained 14% of the variation in, $F(3, 115) = 5.98$, $p < .001$. SPM and inattention were the significant predictors where hyperactivity/impulsivity was non-significant with Bayes Factors providing evidence for the null ($p = .292$, $B_{H(0, .636)} = 0.26$). The prior was taken from the variable inattention from the same model.

Table 4

Summary of regression model for inattention and hyperactivity/impulsivity scores on letter monitoring scores when controlling for SPM scores.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.14	.12	
SPM	.49	.14	.30	3.46**			.31
Inattention	-1.52	.65	-.25	-2.39*			-.22
Hyperactivity /Impulsivity	.63	.60	.11	1.06			.10

*p < .05, **p < .01

Inattention and Working Memory

We ran multiple regression analysis where inattentive and hyperactive/impulsive traits were used as predictors for Operation Span Task performance (Table 5). The model for random PC/RC explained 10% of the variation in, $F(3, 106) = 3.81$, $p = .012$. Inattention was a significant predictor whereas hyperactivity/impulsivity ($p = .592$, $B_{H(0,}$

$_{1.801)}$ = 0.17) and SPM (p = .609, $B_{H(0,\ 1.801)}$ = 0.04) were non-significant with Bayes Factors providing evidence for the null.

Table 5

Summary of regression model for inattention and hyperactivity/impulsivity scores on OSPAN scores when controlling for SPM scores.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.10	.07	
SPM	.21	.41	.05	3.46			.05
Inattention	-4.59	1.80	-.28	-2.55*			-.24
Hyperactivity /Impulsivity	-.89	1.66	-.06	-.54			-.05

*p < .05, **p < .01

Inattention and Task Switching

Due to the significant correlation, we ran multiple regression analysis to investigate the role of ADHD traits when explaining switch costs for the random PC/RC and order PC/RC conditions where the use of both proactive control and reactive control was possible.

The multiple regression analysis revealed that the model explained 6% of the variation, $F(2, 106) = 3.18$, p = .046 (Table 6). Hyperactivity/Impulsivity (p = .159, $B_{H(0,\ 30.03)}$ = 0.12) was non-significant with Bayes Factors providing evidence for the null. Thus, inattention was the only predictor of the predictable switch cost.

Table 6

Summary of regression model for inattention and hyperactivity/impulsivity scores on random PC/RC condition.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.08	.05	
Inattention	75.70	30.03	.28	2.52*			.24
Hyperactivity /Impulsivity	-39.98	28.20	-.16	-1.42			-.14

*p < .05, **p < .01

The multiple regression analysis revealed that the model for the order PC/RC switch costs explained 8% of the variation, $F(3, 110) = 2.92$, $p = .037$ (Table 7). Hyperactivity/Impulsivity **(**$p = .722$, $B_{H(0, 34.926)} = 0.12$) and SPM ($p = .110$, $B_{H(0, 34.926)} = 0.14$) were non-significant predictors with Bayes Factors providing evidence for the null. Thus, inattention was the only predictor of the predictable switch cost. Since SPM was correlated with switch costs in random PC/RC, it was included in the model as a control variable.

Table 7

Summary of regression model for inattention and hyperactivity/impulsivity scores on order PC/RC condition when controlling for SPM scores.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.08	.05	
SPM	12.25	7.61	.15	1.61			.15
Inattention	80.41	34.93	.25	2.30*			.22
Hyperactivity /Impulsivity	-11.73	32.85	-.04	-.36			-.04

*p < .05, **p < .01

We also ran a mediation analysis using PROCESS Version 3.0 (Hayes, 2013), to investigate a potential mediating role for letter monitoring performance on the relationship of inattention scores with switch costs on random PC/RC and order PC/RC conditions when controlling for hyperactivity/impulsivity and SPM scores. We found inattention was no longer a significant predictor after accounting for the letter monitoring scores, and, letter monitoring was a significant predictor for random (β = -.25, p = .020) and order (β = -.26, p = .011) PC/RC conditions. Thus, letter monitoring scores mediated the link between inattention scores and the switch costs on PC/RC conditions when the use of both proactive and reactive control was possible (Figure 7).

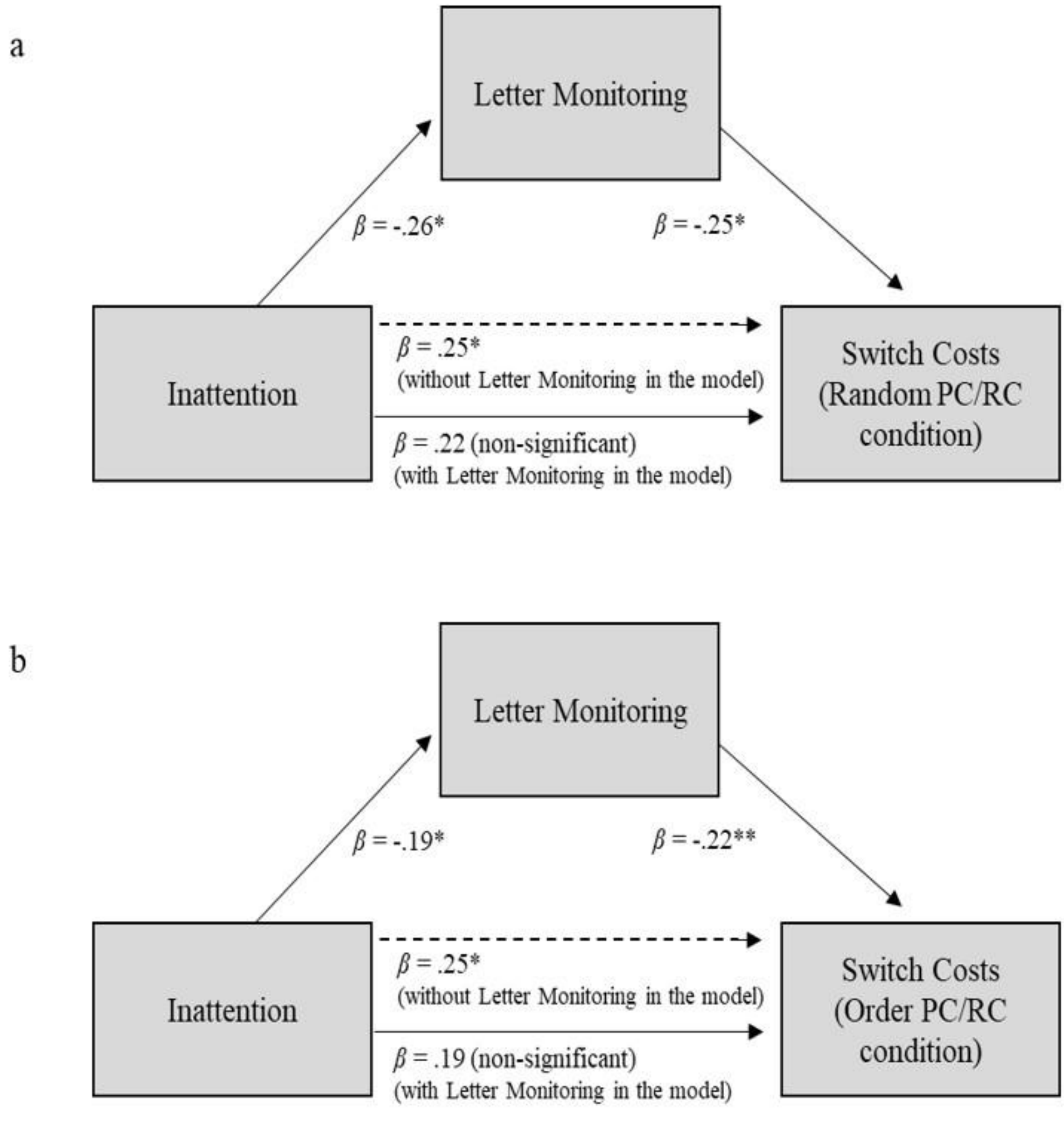

Figure 7. The mediation effect of Letter monitoring performance on the link between inattention scores and switching performance of random (a) and order (b) PC/RC. Bootstrapping was used to calculate a 95% confidence interval around the indirect effect using 1000 resamples.

Discussion

The present study had two aims: 1) To de-confound aspects of the design of Study 1 that rendered it difficult to interpret the relationship reported between predictable task switching and inattention (stimulus valency, the presence of an RSI manipulation design permits the de-confounding of working memory load and proactive control); 2) to investigate whether the relationship between inattention and predictable task switching is moderated by goal neglect. It was noted that if inattention were related to impairment in the use of proactive control it would be related to performance in any block that presents an advanced cue (Random PC/RC or Random PC). Alternatively, if inattention were related to working memory impairments it would be related to performance in any block;/condition that has a predictable sequence and involves the need to keep track of the order of switch and repeat trials (Order PC/RC or Order PC), but especially Order PC where no other cue is provided about which task to perform. Finally, if inattention were related to an impairment in reactive control it would affect performance most clearly in the Random RC block. We also conducted Operation Span Task and Letter Monitoring Task to measure the role of WM and goal neglect on the relationship between inattentive traits and predictable switching performance.

Consistent with previous research (Elisa et al., 2016), inattentive traits were unique predictors of the letter monitoring and OSPAN scores when controlling for hyperactive/impulsive traits. However, the results from the order PC and random PC blocks did not replicate those of Study 1. A replication of the results from Study 1 would have been represented by a relationship between inattention and the Order PC condition. This was not observed. Given we observed no relationship between inattention and the Order PC, Random PC and Random RC blocks and inattention (or any of the other ADHD symptoms) our data suggest that those high in inattention do not experience difficulties with keeping tracking of task order, the use of proactive control or the use of reactive control, respectively. The difference between the Order PC/RC and Random PC/RC conditions, for which a relationship with inattention was observed, and all other conditions was the possibility of using both types of control on each trial our results suggest that one or other forms of control (proactive or reactive) was selected of the other. Our findings showing that the impairments in switching were mediated by the tendency for goal neglect permit us to conclude that it is likely that inattentive participants were neglecting proactive control and relying on reactive control to complete the task.

The relationship between inattentive traits and switch costs in random PC/RC and order PC/RC is consistent with the literature reporting that individuals with low WM capacity use proactive control less compared to those with high WM capacity (Engle & Kane, 2003; Redick et al., 2011; Unsworth et al., 2004). Given the negative relationship between inattentive traits and measures of WM in the current study (OSPAN scores) and in the literature (e.g., Gathercole et al., 2008; Lui & Tannock, 2007), it is reasonable to expect the decreased use of proactive control as the scores of inattentive traits increase. However, it is important to note that OSPAN scores were not correlated to the switch costs in any of the blocks. Thus, the present findings stress the role of goal neglect in the failure to appropriately weight all aspects of task instructions in the task model, rather than the OSPAN performance, involving maintenance plus manipulation of information on the trial in task switching performance.

Consistent with Verbruggen, Liefooghe, Vandierendonck, and Demanet (2007) who reported successfully eliminated switch costs when use of the advanced cue was strongly encouraged, the presence of an advanced cue or trackable order in the absence of any other cue appears to have encouraged those high in inattention to prepare in advance. In the random PC and order PC conditions, the screen only contained a black frame and a digit which could indicate either of the tasks. Therefore, the only way to know the next task was to keep track of the task order (in order PC) or focusing on the advanced cue (in random PC). Therefore, the goal of attending the cue was reinforced in these conditions.

It is unclear why the Order PC condition did not replicate the high WM condition of Study 1. However, a key difference between the two conditions was the presence of an empty black square 250ms prior to the onset of the stimulus in Study 2. It is possible that this square served as a cue to withdraw the previous event from memory and remind them of the need to prepare in time for the upcoming trial; we consider this especially likely given that in other conditions the square could be informative. That is, the pseudo-cue in Study 2 acts as a nudge to prevent goal neglect. There is some precedence for this in the goal neglect literature. Duncan et al. (1996) noted that verbal prompts were enough to prevent the occurrence of goal neglect in the letter-monitoring task. Likewise, Parris et al. (2012) also used goal-related primes to prompt the goal of responding quickly and accurately during Stroop performance which resulted in the elimination of Stroop interference. These studies suggest that it is possible that a stimulus that has previously acted as a cue to prepare for an upcoming trial might serve as a reminder of the need to prepare, even if that cue was not being utilized efficiently when it was informative.

General Discussion

In two studies, we conducted predictable and unpredictable task switching paradigms (TSPs) to investigate the link between inattentive traits and task switching performance. Study one revealed that inattentive traits uniquely predicted higher switch costs when there was a set task order that needed to be tracked to permit preparatory control. Study 2 revealed that it was not the ability to perform preparatory processes per se that led to the association between switch costs and inattention, but instead, it was the tendency for those high in inattention to neglect preparatory processes, especially when reactive control options were available. Importantly, the task switching impairment in those high in inattention was related to performance on a goal neglect task. This indicates that the lack of preparatory control was related to a newly reported capacity limit reported by Duncan and colleagues (1996; 2008) that they have linked to the episodic buffer component of working memory. Another way to understand the present results are as a failure to engage in preparatory control despite the capacity to do so (De Jong et al., 1999). The finding that task switching performance is linked to the tendency for goal neglect in only inattentive participants is consistent with previous work showing that goal neglect is unique to inattention (Elisa et al., 2016).

Consistent with the mixed findings on the relationship between ADHD and task switching performance reviewed in the introduction, our composite scores of ADHD tendencies (CAARS-S:S -index in study one and ASRS-total in study two) were not related to switch costs. It is interesting that inattentive tendencies alone were related to predictable switch costs whilst composite tendencies of ADHD were not. Such a finding highlights the importance of considering the role of individual symptoms when investigating ADHD, at least at sub-clinical levels. Indeed, the idea of measuring

ADHD as a continuum has been proposed. The idea is that a clinical diagnosis represents the extreme end of the inattention, hyperactivity and impulsivity continuums (Barkley & Murphy, 1998). Our findings are consistent with previous studies measuring sub-clinical ADHD traits on a continuous scale (Elisa et al., 2016; Lui & Tannock, 2007; Overbey et al., 2011; Seli, Smallwood, et al., 2015) and as with those studies, have implications for clinical level inattention.

Consistent with other studies in the literature (Gathercole et al., 2008; Lui & Tannock, 2007) our results showed that OSPAN scores do not correlate with switch costs (see also Kane et al., 2007; Logan, 2004 for no relationship between WM measures and task switching performance) and is thus supportive of the notion that working memory is independent of task switching capacity (Miyake et al., 2000). However, it has been argued that goal neglect is related to an impairment in the episodic buffer of Baddeley's (2000) working memory model (Duncan et al., 2008) indicating that there might be aspects of working memory that are related to task switching performance.

In summary, in two studies, we measured the link between task switching performance and self-reported ADHD traits. In both studies we report increased switch costs in those high in self-reported inattention. We have concluded that the increased switch costs are due to the frequent failure to engage in preparatory proactive control, especially when the ability to use reactive control is available. The mediation of the impairment in the use of proactive control by goal neglect indicates that the proactive component of the instructions was under-weighted as part of the task goal.

Chapter 5: Trait Inattention, Proactive Control and Goal Neglect

Chapter 4 revealed that task switching performance was uniquely impaired in those with inattention but only under predictable switching conditions where the use of proactive control was advantageous for performance. The results indicated a tendency for those with inattention to not use proactive control to their fully capacity when reactive control mechanisms were possible. Chapter 5 addresses whether this tendency to avoid proactive control is observed outside of the task switching context. Here, we used a version of the Stroop task designed to measure an individual's tendency to use proactive control (Gonthier, Braver, & Bugg, 2016) and the Letter Monitoring Task to test if goal neglect is the reason for the limited use of proactive control for those with inattention.

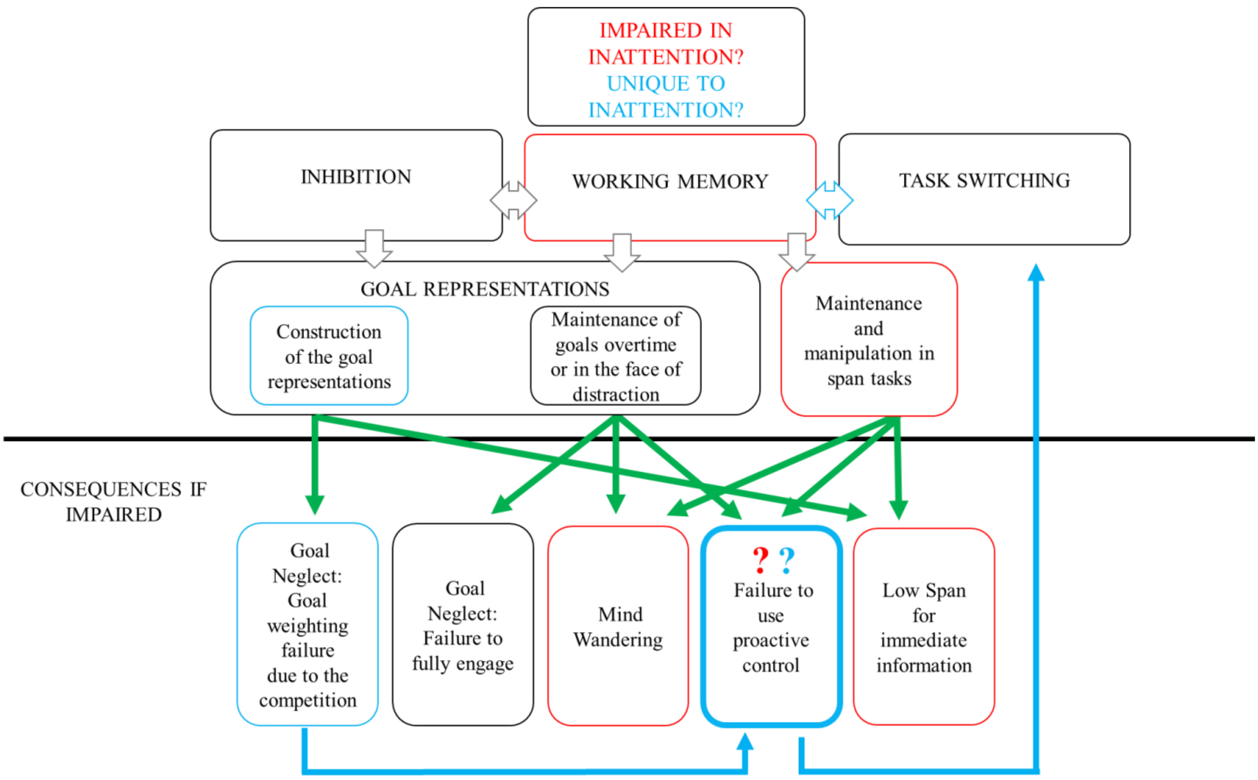

Figure D. A depiction of the role of working memory in goal-oriented behaviour showing the aim of the Chapter 5 (highlighted in bold)

Abstract

Both clinical and sub-clinical (trait) levels of inattention have been linked to impairments in working memory. In the present work, we set out to investigate which components of working memory are impaired in inattention. Here we tested whether inattention was associated with impairments in proactive control and goal neglect. 63 undiagnosed adults who self-rated inattention and other ADHD-related tendencies completed a version of the Stroop task employing list wide and item-specific congruency manipulations designed to measure the use of proactive and reactive control, respectively. Participants also completed a letter monitoring task that measures their tendency for goal neglect, a relatively new attentional capacity associated with working memory and inattention that measures the ability to appropriately weight competing components of task instructions. The results showed that inattentive traits uniquely predicted reduced use of proactive control but only for those with frequent experiences of goal neglect. None of the self-reported ADHD traits were related to the use of reactive control. Findings are consistent with previous research relating inattention to impairments in working memory but extends this finding showing that proactive but not reactive control is affected. It is the use of a poorly structured goal representation that likely exemplifies the trait and symptom of inattention.

Keywords: Inattention; Dual Mechanisms of Control; Proactive Control; Goal Neglect; Working Memory

Trait inattention, characterised by the inattentive symptoms of Attention Deficit/Hyperactivity Disorder, has been shown to exist on a continuum with a core cognitive limitation in working memory (Elisa et al., 2016; Hinshaw, 1992; Lui & Tannock, 2007; Nigg, 2001, 2006) and goal neglect (Chapter 4; Elisa et al., 2016), which is thought to result from an impairment in the episodic buffer component of working memory (Duncan et al., 2008). In the present work we set out to investigate which components of working memory are impaired in inattention and whether they are unique to inattention or are also associated with the other core symptoms of ADHD. For example, mind wandering is associated with working memory and represents a failure to maintain focus on the current goal. However, whilst frequent experiences of spontaneous mind wandering have been shown to be associated with inattention, such experiences are also associated with hyperactivity and impulsivity (Arabacı & Parris, 2018; Franklin et al., 2017; Seli, Smallwood, et al., 2015). The aim of the present work was to refine our knowledge about inattention by looking at specific functions of components of working memory.

Proactive vs. Reactive control

Braver (2007) proposed two distinct types of control attributable to working memory, namely, proactive and reactive control. Proactive control refers to an early selection process based on the goal-related information that is actively maintained to bias responding to a future critical event (Miller & Cohen, 2001). Reactive control is triggered following the critical event with no previous information (Jacoby, Kelley, & McElree, 1999). Hence, proactive control depends on anticipation and prevention of interference while reactive control is involved only after the conflict has occurred (Braver, 2012). Therefore, proactive control requires sufficient goal construction and active goal maintenance serving as a top-down mechanism to bias and facilitate the mechanisms dealing with the upcoming event (Braver, 2012). To our knowledge, there are no studies investigating the link between proactive control, a component of working memory, and inattention.

Research into proactive control has revealed that working memory capacity plays an important role (Braver et al., 2007). Braver et al. found that individuals with higher working memory capacity are more able to use proactive control when it is beneficial to performance. As already noted above, separate lines of research also revealed that inattentive symptoms predict poor performance on working memory tasks in clinical and sub-clinical samples (Carr, Henderson, & Nigg, 2010; Elisa et al., 2016; Hinshaw, 1992; Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2007; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; Lui & Tannock, 2007; Martinussen et al., 2005; Nigg, 2001, 2006; Nigg, Butler, et al., 2002) which would affect the tendency to use proactive control for those with inatentive traits.

It is possible to utilise proactive control to deal with expected upcoming interference in Stroop Task (Braver, 2012; Gonthier et al., 2016). For example, activating the colour-naming goal in advance is expected to enhance the detection of the colour feature and reduce the interference from the irrelevant incongruent word (Braver, 2012). Gonthier, Braver and Bugg (2016) manipulated the use of proactive and reactive control mechanisms in picture-naming version of the Stroop task by manipulating the congruency proportion at both the list and item levels. List-wide and item-specific congruency effect are thought to reflect proactive and reactive control, respectively (Bugg, 2012; Hutchison, 2011). The list-wide (LW) proportion congruency is related to the well-known finding that the Stroop congruency effect is reduced when the task involves mostly incongruent trials as opposed to mostly congruent block (e.g., Bugg, 2014; Bugg, Jacoby, & Chanani, 2011; Hutchison, 2011; Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982). When participants are faced with many incongruent trials, they form a global control strategy of driving their attention away from word reading as it is too often the irrelevant and therefore interfering dimension (Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982 see also Blais & Bunge, 2010; Bugg, Jacoby, & Toth, 2008; Schmidt, 2013, 2014 for alternative views). That is, participants anticipate that they will encounter incongruency and adjust their responses accordingly, which is, by definition, proactive control (Gonthier et al., 2016). Similarly, item-specific (IS) manipulates proportion congruency but only for particular colour-word combinations (e.g., *red* in green is presented more often than *red* in red, but *yellow* in blue is presented as often as *yellow* in yellow). Following this, item-specific manipulation interference is reduced only for the colour-word combinations for which congruency proportion is uneven (Bugg & Hutchison, 2013; Bugg et al., 2011; Bugg et al., 2008; Hutchison, 2011; Jacoby, Lindsay, & Hessels, 2003). This indicates a local and not global form of control.

The IS effect is referred as an item-level control mechanism and can only work via recognition of the particular colour-word combination when it is presented on any give trial; hence reflecting the use of a reactive control mechanism (Bugg, 2012; Hutchison, 2011). Gonthier et al. (2016) argued that LW and IS effects in the Stroop task reflect proactive and reactive control, respectively. Consistent with their argument, Gonthier et al. found distinct behavioural signatures of proactive and reactive control for the same participants measured in list-wide and item-specific ways.

Goal neglect

Roberts and Pennington (1996) argued that to be able to bias future behaviour on the goals of the task (use proactive control), the goal-relevant information must be easily accessible. Indeed, influential models of Stroop task performance hold that good performance mostly depends on maintenance of task goals in the face of competition from habitual responding (Cohen, Dunbar, & McClelland, 1990; Cohen & Servan-Schreiber, 1992). When goal maintenance fails, it is not possible to block habitual responding, therefore, greater levels of Stroop interference results. That is, blocking is performed by the "active maintenance of intention" (Braver & Cohen, 2000; Kane & Engle, 2003; O'reilly, 2006). Kane and Engle (2003) further suggested that working memory is required not only for maintaining the representations of the external stimuli active but also for maintaining the goal representations in an easily accessible manner to allow biasing future behaviour (see also Miller, 2000). They referred to the failure to maintain a goal, goal neglect.

Duncan et al. (2008) explained the occurrence of goal neglect by referring to a *task model* where all the relevant set of instructions to perform the task is constructed. The task model is also where the rules/instructions are turned into goals by establishing stimulus-response relationships to perform the task (Duncan et al., 2008). When the number of instructions increase at a level more than the individual is capable of bearing, each set of instructions competes with each other to be represented in the task model, resulting in the loss, or weaker representation, of some of the components from the task model (Duncan et al., 2008, experiment 4).

Duncan et al. (2012) argued that the task model differs from traditional forms of working memory: The task model is the storage of information over an extended period while traditional measures of working memory such as complex span tasks ask participants to maintain some information over a relatively short time period while performing a second task. The difference is that the participants know that after a few trials, they are asked to report the information maintained and after that, they no longer need that information so that they can expunge it. Therefore, although traditional measures require the maintenance of information that is relevant to the task on trial n, they do not involve to information that has a bearing for the entire task duration. Duncan and colleagues proposed that the task model is stored in the component of working memory known as the episodic buffer. Since goal neglect has been shown to be uniquely associated with inattention (Elisa et al., 2016) and likely has an as yet unidentified relationship with proactive control we included a measure of goal neglect in the present work.

In summary, inattention is associated with a deficit in working memory, but working memory is theorised to comprise multiple functions and it is not clear from which of these functions inattention results. Here we investigated whether unique to inattention are impairments related to maintenance of some competing components of the task model including those related to the use of proactive control. Presumably the latter requires the former, but impairments in the latter could occur despite no impairments in the former. Indeed, a core definitional concept associated with goal neglect is the capacity to report on goals, suggesting an intact representation, but a failure to use or weight the information appropriately. Here we explored whether inattention is associated with impairments in proactive control, and if so, whether that impairment is itself related to goal neglect. We hypothesised that inattention reduces the capacity to utilise proactive control due to reported problems with goal maintenance (Elisa et al., 2016). In order to test this, we employed the same three conditions as Gonthier et al. (LW-mostly congruent, LW-mostly incongruent and IS proportion congruency) to permit the measurement of proactive and reactive control use. We also measured the tendency for goal neglect using the letter monitoring task by Duncan et al. (2008).

Method

Participants

Data was collected from 63 individuals. Sample size was based on availability and sensitivity of tests were determine by Bayes Factors. Participants were native speakers of English aged between 18 and 35 (*M* = 22.85, *SD* = 4.08) with normal or corrected vision. Data was collected from non-clinical samples recruited through Bournemouth University's research participation system and through advertisements. Participants were mainly undergraduate and postgraduate students. Participants were compensated with £20 or course credits.

Materials

Connors' Adult ADHD Rating Scale: Short Version (CAARS-S:S):

CAARS-S:S (Conners et al., 1999) was used to measure ADHD tendencies. Participants rated their frequency of experiences on the 26 items (symptoms) using a four-point rating scale. Raw scores for each symptom was transformed into T-scores allowing a comparison across participants. T-scores range between 28 (lowest) to 90 (highest) calculated based on the age and gender.

Letter Monitoring Task:

Letter monitoring task was taken from Duncan et al. (1996) as a measure of goal neglect. In the letter monitoring task, participants receive series of pairs of letters and digits on the left and right side of a central dot. Participants were asked to report only the letters on the attended side. Digits were chosen from the set 1-8, and letters were randomly chosen without replacement from the letters of the alphabet except D, I, O, V, and W. Before the start of the practice trials and the experimental trials, a “READY?” message was used to confirm if the participant was ready to start the trial. Following the participant’s verbal report, the experimenter made a key press to initiate a 500ms blank interval followed by the practice session. The task started after a 500ms blank interval. Each trial started with a 1 second presentation of the instruction “WATCH LEFT/RIGHT” (indicating the side participant is required to report the letters), followed by a further 1 second interval for participant to get ready for the stimulus sequence.

Each trial had a sequence consisted of pairs of numbers and letters presented for 200ms and a blank interval of 200ms. In the first part of the trial, 5 letters and 5 digits (total of 10 pairs) were presented. After the 10th pair, a “+” or “-“ symbol was presented in the center of the screen for 200ms. A “+” sign meant that for the last part of the trial, participants needed to attend right side of the dot (letters only), while “-“ sign indicated to attend left. This symbol was followed by a further 200ms blank screen, three more pairs were presented for the second part of the trial. In the second part of the trial, the first pair was always digits while the last two pairs were letters. A perfectly correct trial included 5 letters from the appropriate side following the initial message (the first part) and 2 letters from the side following the cue (second part). The researcher manually recorded responses of the participant using a prepared scoring sheet with correct answers (see Figure 1 for an example trial).

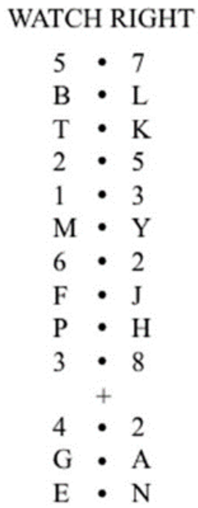

Figure 1. An example demonstration of a letter monitoring task trial taken from Duncan et al. (1996). Starting from the top to bottom.

To help the participant remember the cue correctly, pieces of papers were placed on the appropriate sides of the screen with “PLUS” (for the right) and “MINUS” (for the left) written on them. Instructions for the task were provided following (Duncan et al., 2008). The experimental trials were consisted of three blocks of 12 trials and practice trials. Practice trial were repeated until one letter was reported from either the correct or incorrect side, and, the “+/-“ cue was reported accurately. Each block was divided into four sub-blocks with one “WATCH LEFT” followed by a “-“ cue, one “WATCH LEFT” followed by a “+” cue, one “WATCH RIGHT” followed by a “-“ cue, and, one “WATCH RIGHT” followed by a “+” cue in random order. Hence, in two trials the cue required participants to stayed on the initially attended side while the cure indicated a switch from the initially attended side for the rest two trials. Participants were asked to repeat the rules of the task before and after the task.

Scoring. A valid trial required at least 3 letters reported from the correct side for the first part of the trials (first 10 pairs). The reason for identifying invalid trials were to ensure that participants were already attending the letters in the first part of the trial, allowing a switch/repeat by using the cue information. Participants received 1 point for every letter reported correctly. Scores indicated how much of a participant's score was affected by the cue. Each participant received a score computed by the total scores of the valid trials.

Picture–Word Stroop task:

Picture-Word Stroop task was take from Gonthier et al. (2016). All participants completed three versions of the picture-word Stroop task with animal names and pictures. The list-wide mostly congruent block (LWmc) had 75 per cent of congruent (PC75) with 25 per cent incongruent trials while the list-wide mostly incongruent block (LWmi) included 25 per cent of congruent (PC25) with 75 per cent incongruent trials. The third block included item-specific proportion congruency (ISPC) with some items with PC25 and some with PC75. Each block also consisted of PC50 items indicating the unbiased assessment of transfer benefits.

Stimuli is consisted of eight black-and-white drawings of animals (Bugg & Chanani, 2011). In two sets. The first set of four animals (frog, cow, pig, seal) were used as unbiased PC-50 items in all three task blocks (LWmc, LWmi, and IS). The second set of four animals (cat, dog, bird, fish) that were used as biased items in various proportion of congruency (PC75 for LWmc and PC25 for LWmi). In ISPC block, two animal pictures from the set (e.g., bird, cat) were used as PC75 items while the other two were used for PC25 items (counterbalanced across participants). Each animal picture was presented with a word of an animal name. On congruent trials, the word matched the animal picture but not in incongruent trials. In incongruent trials, the word could be an animal name from the same set. For example, a picture of a bird could be presented the words fish, dog or cat, but not with the word frog, while a picture of the frog could not be presented with the word bird. The stimuli were presented at the center of the screen until a voice response. The voice response was detected by CEDRUS voice key. Following the voice response, a blank screen was presented until the experimenter made a key press (manually coding the participant's answers on a keyboard). Thus, an experimenter was present throughout the task to press the corresponding key following the participant’s verbal response. The experimenter coded the trial as invalid when the voice response was unclear, or the voice input did not trigger with the participant’s answer. There was a 1000 ms inter-stimulus interval between the experimenter’s key press and the presentation of the new stimulus.

There were total of 384 trials in the LWmc block (96 PC50 trials and 288 PC75 trials), 384 trials in the LWmi block (96 PC50 trials and 288 PC25 trials), and 432 trials in the ISPC block (192 PC75 trials, 192 PC25 trials, and 48 PC-50 trials appearing only in the second half of the block3). A short break was offered halfway through each task and in between the tasks. There were 22 practice trials preceding each block with the same congruency proportion as the corresponding block. Following Gonthier et al., participants completed the LWmc block, the LWmi block and the IS block, in order.

Matrix Reasoning:

Wechsler Adult Intelligence Scale-Fourth Edition (Wechsler, 2008) was administered as a measure of fluid abilities. Participants were asked to perform Matrix Reasoning subtest following the instructions provided in the manual.

Procedure

Following the participant information sheet and after receiving informed consent, all participants completed the Stroop task, the letter monitoring task and the CAARS:S in a counterbalanced order. This study was approved by the Bournemouth University Ethics

Committee. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Results

Mean scores and standard deviations for CAARS scores are reported in Table 1. Due to the issues with data collection, one participant's data for the Stroop Task was missing while another participant only had the scores from the Stroop Task. Outliers were removed from the variables of CAARS-impulsivity (3.2%), Matrix (9.5%), Letter Monitoring (9.5%), LWMC cost in PC50 condition (7.9%) and the MC-MI (11.1%; the difference in the Stroop effect in LWMC and LWMI conditions) due to non-normal distributions and residuals. Please see Figure 1 for detailed participant characteristics on CAARS scores.

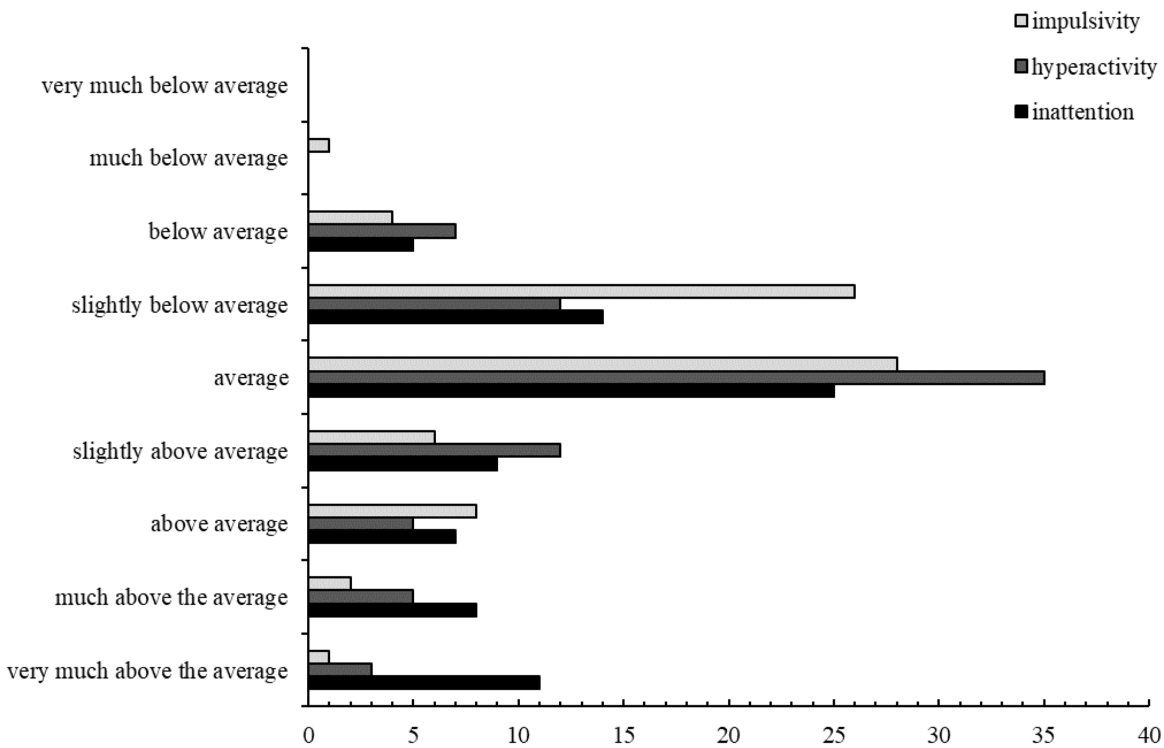

Figure 2. Number of participants falling into each category based on CAARS guidelines

Analysis of the Stroop Effect

Bonferroni corrected paired samples t-tests revealed that responses are longer for the incongruent compared to the congruent trials for LWMC [$t(61) = 17.64$, $p < .001$], LWMC_PC50 [$t(61) = 13.95$, $p < .001$], LWMI [$t(60) = 9.95$, $p < .001$], LWMI_PC50 [$t(60) = 10.52$, $p < .001$], ISPC_MC [$t(61) = 12.19$, $p < .001$], ISPC_MI [$t(61) = 11.98$, $p < .001$], ISPC_PC50 [$t(61) = 9.96$, $p < .001$].

Table 1.

Mean reaction times and standard deviations (in parenthesises) for the congruent and incongruent conditions of each type of proportion congruency.

	LWMC	LWMC_PC50	LWMI	LWMI_PC50	ISPC_MC	ISPC_MI	ISPC_PC_50
Congruent	679.77	713.56	727.66	750.49	724.76	726.15	730.71
	(12.22)	(12.62)	(15.90)	(16.72)	(15.92)	(17.39)	(18.11)
Incongruent	820.48	841.40	813.65	845.11	838.83	818.70	855.90
	(16.39)	(17.75)	(18.71)	(19.64)	(20.85)	(20.44)	(24.34)

Considering the indicators of proactive control and reactive control, Bonferroni corrected paired samples t-tests also revealed that the Stroop effect in the LWMC was larger than in the LWMI condition, $t(60) = 8.23$, $p < .001$. Additionally, interference in the LWPC_MC50 condition was larger than in the LWMI_PC50 condition, $t(60) =$ 3,73, $p < .001$. The Stroop effect was also larger in the ISPC_MC condition compared to the ISPC_MI condition, $t(60) = 2.63$, $p < .011$.

Correlations between variables

We examined the bivariate correlations between the independent and dependent variables (Table 1). Inattention was correlated with letter monitoring (r = -.31, p = .02). Letter monitoring was correlated with Matrix scores (r =.36, p = .009) and the Stroop effect LWMC condition (r = -.28, p = .038). LWMI cost was also correlated with inattention (r = .27, p = .048) and impulsivity (r = .32, p = .021) while hyperactivity was just shy of significance (p = .052). MC-MI difference (the use of Proactive Control) was also negatively correlated with inattention (r = -.28, p = .036), hyperactivity (r = -.34, p = .012) and impulsivity (r = -.27, p = .05).

We used Bayes Factors (B) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. We followed Dienes (2014) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. Where a Bayes Factor is given, we modelled the predictions of the theory of some evidence for a relationship with a half-normal whose mean and standard deviation values were taken from the variable inattention in the model.

Table 2
Correlations between variables.

	N	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1.Inattention	62	56.61	11.38	-											
2.Hyperactivity	62	52.02	9.36	.55**	-										
3.Impulsivity	61	48.43	8.95	.40**	.64**	-									
4. index	62	53.76	10.85	.76**	.58**	.64**	-								
5.Matrix	57	16.97	2.85	.01	.10	.11	-.05	-							
6.Letter Monitoring	57	47.05	19.15	-.31*	-.01	.08	-.11	.36**	-						
7.LWMC Stroop effect	62	140.72	62.80	-.03	-.01	.01	-.04	-.24	-.28*	-					
8.LWMI Stroop effect	57	83.06	55.79	.07	.15	.16	.06	-.25	-.19	.67**	-				
9.ISPC_MC Stroop effect	62	114.07	73.70	.01	.01	.12	.02	-.28*	-.16	.62**	.56**	-			
10.ISPC_MI Stroop effect	62	92.56	60.81	-.15	-.11	-.12	-.18	-.10	-.16	.58**	.67**	.55**	-		
11.LW_MC-MI (use of Proactive Control)	56	55.68	50.55	-.28*	-.34*	-.27	-.24	-.01	-.12	.40**	-.39**	.02	-.06	-	
12.ISPC_MC-MI (use of Reactive Control)	62	21.51	64.54	.16	.12	.24	.19	-.24	-.03	.16	.01	.62**	-.31*	.08	-

*p<.01, **p<.005

Letter Monitoring and Inattention

We ran multiple regression analysis where inattentive, hyperactive and impulsive traits were used as predictors for letter monitoring performance. The model explained 24% of the variation, $F(4, 51) = 3.80$, $p = .009$. Matrix and inattention scores were the significant predictors whereas hyperactivity ($p = .605$, $B_{H(0, .27)} = 0.29$) and impulsivity ($p = .327$, $B_{H(0, .27)} = 0.51$) were non-significant. The Bayes Factor for hyperactivity provided evidence for the null while Bayes Factor for impulsivity was insensitive. The prior was taken from the variable inattention from the same model.

Table 3

Summary of regression model for inattention, hyperactivity and impulsivity scores on letter monitoring scores when controlling for Matrix scores.

Variable	*b*	SE*b*	β	*T*	R^2	Adjusted R^2	Semi-partial correlation
					.24	.18	
Matrix	.2.32	.93	.32	2.51*			.34
Inattention	-.70	.27	-.38	-2.59*			-.35
Hyperactivity	.19	.37	.11	.521			.07
Impulsivity	.38	.38	.16	.99			.14

*p < .05, **p < .01

A multiple regression model with inattention, hyperactivity and impulsivity scores predicting the Stroop effect in the LWMI condition yielded non-significant results with

Bayes values revealing strong evidence for the null hypothesis of no difference, $F(3, 52) = 2.17$, $p = .103$, $B = -0.64$.

In order to investigate the role of letter monitoring scores on the relationship between inattention traits and MC-MI (the use of Proactive control), we ran a moderation analysis using PROCESS Version 3.0 (Hayes, 2013) using Bootstrapping to calculate a 95% confidence interval around the indirect effect using 1000 resamples. The model explained 33% of the variation, [$F(6, 44) = 3.64$, $p = .01$] and revealed that inattentive traits predict decreased use of proactive control only for those with low letter monitoring scores, $\beta_{low} = -.61$, $p = .01$ while inattention ($p = .21$), hyperactivity ($p = .36$) and impulsivity ($p = .64$) scores were non-significant.

Discussion

The aim of the present study was to investigate which components of working memory were uniquely related to inattention. Consistent with previous research (Elisa et al., 2016; Chapter 4), we found inattentive traits uniquely predicted frequent experiences of goal neglect, indicating a limitation with appropriately weighting components of the task model in those with inattentive traits. Moreover, inattentive traits were related to an impairment in the use of proactive control (LWMC-LWMI) but not reactive control (ISPC-MC-MI). However, it was also observed that goal neglect moderated this relationship. That is, inattentive traits predicted an impairment in proactive control only for those with frequent experiences of goal neglect. Overall these results suggest that it is the use of poorly structured goal representations that likely exemplifies the trait and symptom of inattention.

The letter monitoring task with its focus on appropriate weighting of components of task instructions, a function argued to be related to the episodic buffer of the working memory model of Baddeley (2000), seems to capture the cognitive limitations associated with inattention better than other functions related to the use and maintenance of goal representations (e.g., mind wandering and proactive control failure). Goal neglect is unique in that it is, as measured here, the capacity to deal with competition from separate components of a task model at the construction stage of the goal representation. In the present study we have shown that this relatively understudied form of attentional capacity (Duncan et al., 2012) is also related to the efficacy of other preparatory control mechanisms.

In the present data, goal neglect was not related to the use of proactive control (Table 1). Given the need for goal representations in proactive control use (Braver & Cohen, 2000; Kane & Engle, 2003; O'reilly, 2006), one would expect that those who are more able to construct coherent goal representations would be better able to use proactive control. However, whilst execution of proactive control requires goal representations to be sufficiently constructed and maintained, sometimes, this demand is relatively low. For example, in our tasks, the use of proactive control was based on frequently encountering congruent stimuli in LWMC and incongruent stimuli in LWMI, which reinforce the goal representations needed to perform proactive control. Therefore, the use of proactive control may have placed a relatively low demand on the goal representations. However, for those with frequent experiences of goal neglect the goal representations were likely not sufficiently well described for proactive control.

Consistent with previous research suggesting the importance of treating inattention as a separate dimension (Barkley, 2001; Diamond, 2005; Hinshaw, 2001; Toplak et al., 2009), the composite score of ADHD was not correlated to any of the conditions. Studies using confirmatory factor analysis (Dumenci et al., 2004; Toplak et al., 2009) and taxometric studies (Haslam et al., 2006; Salum et al., 2014) found that symptoms of ADHD are continuous with inattention being a separate dimension. Further research reported that inattention and hyperactivity/impulsivity present distinct cognitive impairments which could be overlooked when combining both dimensions as a unitary construct using combined or composite scores of ADHD (Barkley, 2001; Diamond, 2005; Hinshaw, 2001).

In summary, we found that inattentive traits uniquely predicted reduced use of proactive control and this association was moderated by goal neglect. That is, inattentive traits were related to impairments in proactive control but only for those experiencing goal neglect frequently. Thus, it is the use of a poorly structured goal representation that likely exemplifies the trait and symptom of inattention.

Chapter 6: High-Frequency rTMS Stimulation of left DLPFC mitigates Goal Neglect

The work in this thesis consistently revealed an impairment in constructing goal representations in inattention. Chapter 4 and Chapter 5 revealed that whilst impaired performance was observed under proactive control and task switching conditions, this was driven by goal neglect (a failure in goal representations). Thus, in this final chapter, we set out to investigate if goal neglect can be alleviated using high-frequency Transcranial Magnetic Stimulation over left DLPFC, a neural region that has been consistently associated with working memory (e.g., Burgess et al., 2010).

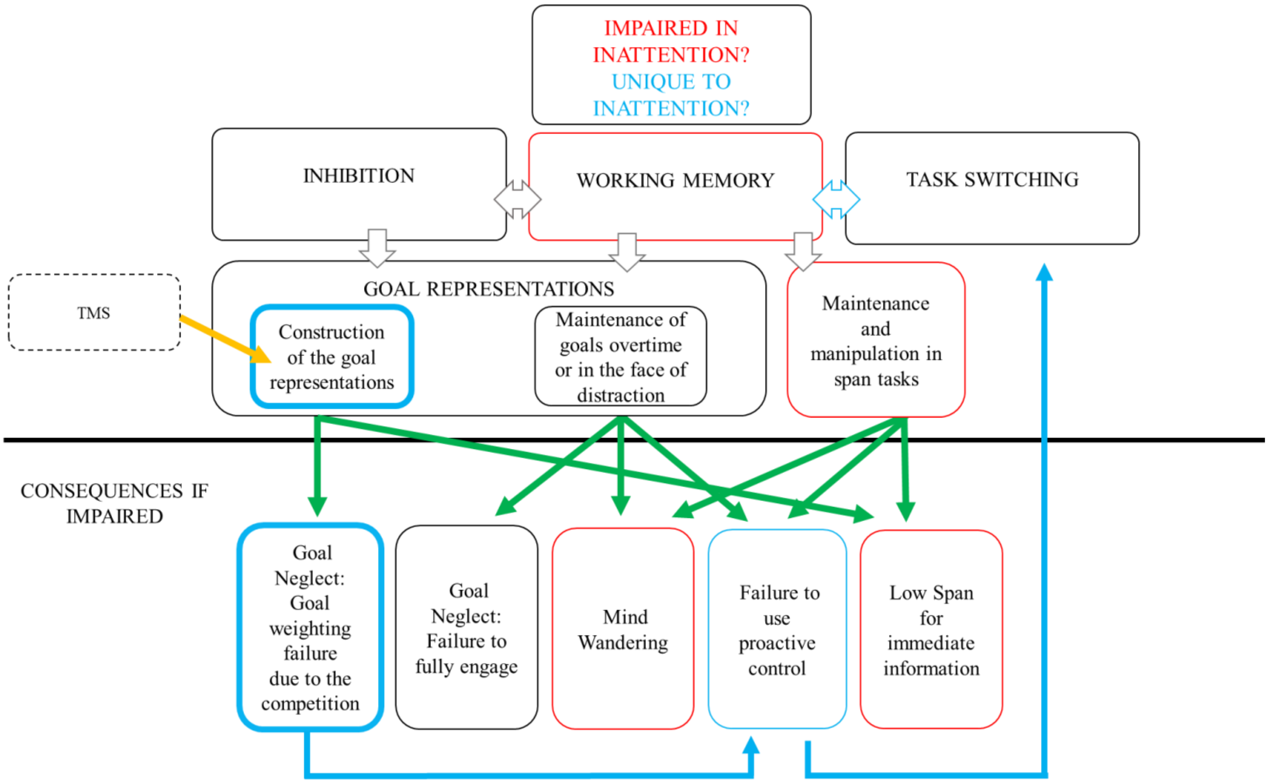

Figure E. A depiction of the role of working memory in goal-oriented behaviour showing the aim of the Chapter 6 (highlighted in bold)

Abstract

Individuals neglect some task instructions due to increased competition in working memory for goal representations. In an attempt to improve working memory capacity and alleviate goal neglect, we used high-frequency repetitive Transcranial Magnetic Stimulation to the Dorsolateral Prefrontal Cortex. Twenty-two participants completed a measure of goal neglect following 20mins stimulation (active and sham sessions were run on separate days). We found that participants had less goal neglect in the active compare to sham condition, providing support for the link between the Dorsolateral Prefrontal Cortex and goal neglect. Results are evaluated in the context of potential use to alleviate symptoms of disorders related to goal neglect.

Keywords: High-Frequency rTMS; Goal Neglect; DLPFC; Working Memory

High-Frequency rTMS Stimulation of left DLPFC mitigates Goal Neglect

Transcranial Magnetic Stimulation (TMS) offers a non-invasive technique for direct intervention to human brain (Luber & Lisanby, 2014) via the modulation of the neurons in the targeted brain area. Repetitive TMS (rTMS) refers to the long-term stimulation via trains of stimulation with intervals between the trains (inter-train interval: ITI). The intensity of rTMS is known to affect the direction of the cortical excitability. The lower frequencies (< 1 Hz) is known to disrupt cortical functioning while higher frequencies (>1 Hz) lead to an enhancement (motor cortex stimulation: Pascual-Leone & Hallett, 1994). The effect of rTMS has been shown to last post-stimulation for several minutes and up to one hour (Brunoni & Vanderhasselt, 2014; Fregni & Pascual-Leone, 2007; Maeda, Keenan, Tormos, Topka, & Pascual-Leone, 2000; Peinemann et al., 2004; Tegenthoff et al., 2005). Although initially used for therapeutic purposes in psychiatry and neurology (Hoy & Fitzgerald, 2010; McKinley, Bridges, Walters, & Nelson, 2012), using TMS on healthy populations is a promising avenue for exploring underlying brain function permitting as it does the discovery of causal links between brain and behaviour (Luber & Lisanby, 2014).

TMS stimulation of the brains of healthy individuals has been shown to successfully improve cognitive functioning (visual spatial attention: Hilgetag, Théoret, & Pascual-Leone, 2001; Thut, Nietzel, & Pascual-Leone, 2004; visual search: Hodsoll, Mevorach, & Humphreys, 2008; mental rotation: Klimesch, Sauseng, & Gerloff, 2003; analogical reasoning: Boroojerdi et al., 2001; phonological recall: Kirschen, Davis-Ratner, Jerde, Schraedley-Desmond, & Desmond, 2006; drawing abilities: Snyder et al., 2003; Young, Ridding, & Morrell, 2004; mathematics, calendar calculating and proofreading: Young et al., 2004). In particular, high-frequency rTMS to the dorsolateral prefrontal cortex (DLPFC) has been shown to improve performance on a variety of cognitive tasks (Hwang, Kim, Park, Bang, & Kim, 2010; Vanderhasselt, De Raedt, Leyman, & Baeken, 2009). For example, Vanderhasselt, De Raedt, Baeken, Leyman, and D'haenen (2006) reported decreased reaction times on the Stroop task following high-frequency rTMS stimulation at 10 Hz compare to a sham condition. In their sham condition, the same parameters were set but the stimulation region of the TMS coil did not touch the scalp; instead the figure of 8 coil was rested on the scalp on its edge. Hence, the actual stimulation does not occur, but participants' experience in the two conditions is very similar. TMS has frequently been used for cognitive enhancement (Andrews, Hoy, Enticott, Daskalakis, & Fitzgerald, 2011; Dresler et al., 2013; Fregni et al., 2005), and, high-frequency rTMS has been shown to be a promising technique for working memory enhancement (Brunoni & Vanderhasselt, 2014; Esslinger et al., 2014; Gaudeau-Bosma et al., 2013; Guse et al., 2013).

DLPFC and working memory

Working memory is one of the three core components of executive functions along with inhibition and switching (Friedman & Miyake, 2017). Working memory refers to the limited abilities in activating and maintaining information that is not available in the environment for as long as the information is needed (Baddeley & Hitch, 1994). Some definitions also include resisting interference from irrelevant information to enable the maintenance of relevant information (Conway & Engle, 1994; Kane & Engle, 2000, 2002).

Models of working memory suggest that DLPFC is involved in monitoring and manipulating cognitive representations (Duncan & Owen, 2000; Koechlin et al., 2003; Miller & Cohen, 2001; Owen et al., 1996; Petrides, 2000, 2005; Petrides et al., 2012).

fMRI studies have revealed increased DLPFC activity during various working memory processes such as: 1) when the information to be maintained constrains short term memory capacity; 2) during delay intervals when no information is provided (Courtney, Ungerleider, Keil, & Haxby, 1997; Zarahn, Aguirre, & D'Esposito, 1999); 3) when the manipulation of maintained information is required (D’Esposito & Postle, 1999; Postle, Berger, & D’Esposito, 1999; Rypma & D’Esposito, 1999); 4) when participants needed to maintain information during a delay period (D’Esposito et al., 2000; Postle et al., 1999; Rypma & D’Esposito, 1999), and; 5) before selecting an appropriate response following stimulus presentation and task-set maintenance (posterior DLPFC: Burgess et al., 2010).

The link between the working memory and DLPFC has also been investigated with brain stimulation studies. Researchers have reported increased performance on working memory tasks following high-frequency rTMS procedures. Using 10 Hz rTMS to left and right DLPFC, Bagherzadeh, Khorrami, Zarrindast, Shariat, and Pantazis (2016) reported improved performances on verbal working memory tasks (digit span and a visuo-spatial 2-back tasks). Combined with fMRI, Esslinger at al. (2014) used 5 Hz rTMS to the right DLPFC during the 2-Back Task. They found faster responses following stimulation compared to the sham condition. While the stimulation did not modify the DLPFC activation itself, significantly increased connectivity within the working memory network during the N-back task was found. Preston et al. (2010) further conducted 10 Hz rTMS to left or right DLPFC and found increased RT performance in the Sternberg paradigm following stimulation compare to the pre-stimulation baseline.

In summary, research has revealed a role for DLPFC in working memory performance (e.g., Burgess et al., 2010). TMS studies have also showed that high frequency stimulation of DLPFC results in increased performance in various working memory tasks (e.g., Bagherzadeh et al., 2016; Koch et al., 2005).

Goal neglect and working memory

Duncan et al. (2008) introduced what they referred to as a different form of attentional capacity that they theoretically linked to working memory, specifically the episodic buffer of working memory system. Duncan et al. suggested that the instructions of a task need to be translated into goals and all goal-relevant information has to be accessible throughout the task in the *task model*. Due to the limited capacity of the task model, as the complexity of the instructions increase, some of the information is lost or inappropriately weighted, leading to *goal neglect*, especially in those with lower fluid intelligence.

In goal neglect, despite being able to report the instructions before and after the task, participants neglect some of the instructions during task performance. Using a letter monitoring task, the occurrence of goal neglect has been reported in older adults with lower fluid intelligence and in frontal lobe patients with impaired fluid intelligence (Duncan et al., 2008) but also in younger adults with inattention even when fluid intelligence was controlled (Elisa et al., 2016). Researchers have also investigated goal neglect using a variations of goal neglect tasks (Altamirano et al., 2010; Duncan et al., 1996; Duncan et al., 2008; Piek et al., 2004; Towse et al., 2007). Importantly for present purposes, Duncan et al. linked the new attentional capacity to the frontal lobes by showing that goal neglect was pronounced in frontal lobe patients. Whilst Duncan et al. did not describe where in the frontal lobes the patients' lesions were their later contention that goal neglect is a component of working memory capacity predicts a role for the left DLPFC. Given the link between working memory performance and high-frequency stimulation of DLPFC, in the present study we aimed to investigate whether high frequency TMS can alleviate goal neglect. Although goal neglect has been shown on patients with frontal lobe damage, the direct link between left DLPFC and the goal neglect would represent a novel and theoretically important finding.

Method

Participants

Twenty-two participants (10 females) aged between 19 and 35 (M = 25.77, SD = 4.79). Participants provided written informed consent and TMS screening form (Rossi, Hallett, Rossini, Pascual-Leone, & Group, 2009) following the information about the TMS procedure and participant information sheet. The data is conducted in accordance with the ethical approval from Bournemouth University Ethics Committee. None of the subjects had any medical condition or contraindications to rTMS (Rossi et al., 2009; Wassermann, 1998).

Materials

Letter Monitoring Task:

To measure goal neglect, we used letter monitoring task taken from Duncan et al. (1996). Participants saw series of pairs of letters and digits with a central dot in the middle. The task was to ignore the numbers and read aloud the letters on the attended side. Following a “READY” message, a 500ms blank interval was initiated. The session was started with a “WATCH LEFT/RIGHT” instructions presented for 1 sec. This message indicated the side participant is required to report the letters. A further 1 second interval allowed participants to get ready before seeing the stimulus sequence.

Each sequence had pairs of numbers and letters presented for 200ms and a blank interval of 200ms. First part of the trial was consisted of 10 pairs (5 letters and 5 digits). After the 10th pair, participants saw a cue which may indicate to switch the attended side. A “+” sign indicated to attend right while “-“ sign indicated to attend left side of the dot (letters only). Following a further 200ms interval, three more pairs appeared. 11th pair was always digits while the last two pairs were letters. A valid trial would include at least three letters reported from the attended side indicated by the initial message (for the first part). A scoring sheet with correct answers was prepared for experimenter to manually record responses of the participant. Please see Figure 1 for an example trial. Pieces of papers with plus and minus signs written on them were placed on the appropriate side of the screen. All participants received the same following instructions: (1) read aloud the letters and ignore the numbers (2) start on the side instructed by the message on the screen (3) use the cue (+ or -) to attend the correct side for the second part of the trial.

WATCH RIGHT

5 • 7
B • L
T • K
2 • 5
1 • 3
M • Y
6 • 2
F • J
P • H
3 • 8
\+
4 • 2
G • A
E • N

Figure 1. An example demonstration of a letter monitoring task trial taken from Duncan et al. (1996). Starting from the top to bottom, “Watch RIGHT” message (1s) is followed by the pairs. Each pair is presented in a separate screen for 200ms with a blank interval of 200ms.

Each block had 12 experimental trials. Participants first completed practice trial which was repeated until at least one letter was reported from either (correct or incorrect) side and the "+/-" cue was reported accurately. Each successive trial of four (each sub-block) had one "WATCH LEFT" followed by a "-" cue, one "WATCH LEFT" followed by a "+" cue, one "WATCH RIGHT" followed by a "-" cue, and, one "WATCH RIGHT" followed by a "+" cue presented in random order. Thus, half of the trials required participants to stay on the same side after seeing the cue while the other half required to switch. Participants were asked to report the instructions before and after the task. Instructions for the task were provided following Duncan et al.'s (1996) instructions. Digits were chosen from the set 1-8, and letters were randomly chosen without replacement from the letters of the alphabet except D, I, O, V, and W.

Scoring. Participants received a score of 1 for each letter reported from the correct side (in the second part of the trial). A valid trial would include at least 3 letters reported from the appropriate side indicated by the initial message (the first part). Participants also had to report at least one switch and one repeat trial to pass each sub-block. We then computed the sum of the each passed sub-block. Final scores were transformed into percentages. Scores indicate to what extent a participant's score was affected by the cue.

The Profile of Mood States (POMS):

We used abbreviated version of POMS to measure the effect of TMS on the mood (Vanderhasselt et al., 2006). Administration of POMS required participants to rate how they feel ''at this moment'' using five-point scale (0–4). POMS includes 40 items with the subscales of tension, anger, fatigue, depression, esteem-related affect, vigour and confusion. A total mood disturbance is calculated by subtracting the totals for the positive subscales from the sum of negative subscales.

TMS Parameters

The stimulation procedure was carried out using a MAGSTIM high-speed stimulator (Magstim Company Limited, Wales, UK) with a figure-8-shaped coil. High frequency rTMS procedure was used to stimulate left DLPFC. We used 10-20 electrode positioning system to locate F3 for left DLPFC (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003). Before each condition (active and sham), resting Motor threshold was determined for each participant through the electrodes over the right abductor pollicis brevis muscle. Stimulus intensity was 110% of rMT using 10 Hz stimulation frequency. There were total number of 40 four-second trains with 26 sec inter-train-interval. The stimulation procedure lasted 20mins with total number of 1600 stimulations. The sham condition involved programming the same parameters, but the coil was held at an angle of 90 degrees, only resting on the scalp with one edge (as per Vanderhasselt et al., 2006).

Design and Procedure

Participants initially completed a block of the Letter Monitoring task to make sure they were familiar with the task. We then asked each participant to complete three blocks of the Letter Monitoring Task following 20 mins of rTMS or sham condition. The order of conditions (active vs sham) was counterbalanced across participants and was single blind. Therefore, a single blind, within-subjects design was used. Participants were also asked to complete the POMS at the end of each session.

Results

Following Dienes (2014), we used Bayes Factors (B) to assess the strength of evidence in support of hypotheses when the p value for the predictors was not significant. Where a Bayes Factor is given, we modelled the predictions of the theory of some evidence for a relationship with a half-normal. The mean and standard deviation values were taken from the pairwise comparison between the active and the sham conditions for the Letter Monitoring scores. $B_{H(0, X)}$ refers to the Bayes Factors testing each hypothesis, where 'H' indicates a half-normal distribution, 0 indicates the mean and 'X' the predicted standard error of the mean of this half-normal.

First, a pairwise t-test revealed that there were no significant mood differences between active (M = 11.10, SD = 12.97) and sham (M = 11.70, SD = 2.93) stimulation conditions, $t(19) = -.40$, $p = .698$. Supporting the notion that goal neglect can be reduced via high-frequency stimulation of the left DLPFC a paired samples t-test revealed that participants' letter monitoring scores were better in the active compared to the sham condition, $t(19) = 2.185$, $p = .042$, $d = 3.75$. A further t tests revealed that whilst the scores on the initial Letter Monitoring Task were improved in both the active [$t(17) = 4.65$, $p < .001$, $d = 1.23$] and sham [$t(17) = 3.50$, $p = .003$, $d = 0.78$] conditions, reflecting the effects of practice, this improvement was greater in the active than in the sham condition, $t(17) = 2.44$, $p = .026$, $d = 0.36$.

Independent samples t-tests was run to measure the effect of task order on the active and sham conditions. The analysis yielded non-significant results for the active [$t(14) = -.27$, $p = .789$, $M_{diff} = -4.69$,] and sham [$t(14) = .75$, $p = .464$, $M_{dif} = 11.81$,] conditions. The Bayes value for the active condition provided evidence for the null

($B_{H(0, 9.58)} = 0.29$) while the Bayes for the sham condition was insensitive $B_{H(0, 9.58)} = 1.20$. Please see Table 1 for means and standard deviations.

Table 1.

Mean percentage of accuracy and standard deviations of the Letter Monitoring Scores for each condition.

	Initial practice	Active	Sham
Mean	47.92	83.40	73.82
Standard Deviation	37.19	16.92	28.35
N	18	20	20

Discussion

This study investigated the effects of high-frequency rTMS over left DLPFC on goal neglect. We used 10 Hz stimulation over left DLPFC for 20mins. In a different session, the same participants also underwent a sham stimulation where the exact parameters were employed but the TMS coil did not touch to the scalp in a way that would enable active stimulation. We measured goal neglect following active and sham sessions individually.

We found that participants experienced less goal neglect (indicated by higher scores for the letter monitoring task) following the stimulation of left DLPFC compared to the sham condition. This provides support for a link between the DLPFC and this new attentional capacity: the ability to construct, maintain and appropriately weight all components of goal representations over an extended period and hence not to neglect the goal. This finding is consistent with Duncan et al. (2008) suggesting that working memory is needed to maintain the goal-related information in the task model. Duncan et al. suggested that, unlike traditional working memory measures which focus on keeping information readily accessible while performing a secondary task, Duncan et al. refers to keeping the goals available throughout the task and the ability to handle competition between different aspects of the task model. They suggested that, to be able to perform the task, instructions must be turned into task goals where stimulus-response associations are established. When these goals or components of them, are lost from the task model, participants fail to follow the goal despite being able to describe it. This type of behaviour was originally reported on frontal lobe damage patients (Luria, 1966; Milner, 1963).The current study demonstrates that the occurrence of goal neglect can be alleviated following high-frequency DLPFC stimulation, hence providing a direct link between left DLPFC and goal neglect.

In addition to the significant difference between active and the sham conditions, the initial goal neglect performance increased regardless of the stimulation condition. Thus, there was an effect of practice. However, this increase in performance was greater in the active than in the sham condition, suggesting an increase attributable to more than just the practice effect. We also found that there was no difference in goal neglect performance between the participants who received the active stimulation first and those who had the sham condition first. However, the Bayes values for the sham condition were insensitive. Nevertheless, the order of the conditions was counterbalanced indicating that this is not responsible for the observed effects.

Finally, we would like to point out a possible limitation regarding the use of sham stimulation. Following previous research (e.g., Bagherzadeh et al., 2016; Bridges et al., 2018; Vanderhasselt et al., 2009), in our sham condition, participants received the same parameters at the same brain sight (F3) but the coil was positioned in a way that participants did not receive the actual stimulation. Therefore, although the same stimulation noise was produced, the sensation of the stimulation was absent. Whilst we acknowledge that this could have been a clue for the participants that the stimulation effect would be different, participants were oblivious to the TMS/sham procedures as well as, moreover, the actual potential effect of stimulation, which could have been either harmful or beneficial to performance. Thus, we suggest the effect of this commonly used sham procedure on our findings are limited. Future research using alternative sham techniques such as a specific sham TMS coil may be useful.

In summary, we found that goal neglect was mitigated following high frequency rTMS of the left DLPFC. Our findings are consistent with the previous research reporting improvement in the performances on cognitive tasks following high-frequency rTMS (Andrews et al., 2011; Bagherzadeh et al., 2016; Dresler et al., 2013; Fregni et al., 2005; Vanderhasselt et al., 2009). The present findings suggest there is potential to alleviate goal neglect in clinical disorders where it might contribute to reported symptoms such as in inattention (Elisa et al., 2016) and following frontal lobe damage after stroke or atrophy during ageing (Duncan et al., 1996).

Chapter 7: Thesis Discussion

Summary of the aims and theoretical background

The aim of this thesis was to identify impairments that are unique to inattention. The approach of the thesis was to explore the theoretically proposed link between inattention and working memory with a focus on the role of the construction and maintenance of goal representations (as per Figure 1) in executive function tasks. This was done using a sub-clinical population given evidence showing inattention and hyperactivity/impulsivity exist on a continuum where the extreme end forms a clinical ADHD diagnosis (Dumenci, McConaughy, & Achenbach, 2004b; Smith Jr & Johnson, 1998; Toplak et al., 2009).

Summary of the Studies and Main Findings

Chapter 2. **Inattention and probe-caught mind wandering.** Chapter two measured the associations of trait level inattention and mind wandering measured by probes during easy and difficult versions of a sustained attention task. Chapter 2 revealed that inattention predicted spontaneous mind wandering only when the task was cognitively challenging while hyperactivity and impulsivity predicted spontaneous mind wandering independent of task difficulty. That is, inattention was linked to frequent spontaneous mind wandering only when there was a working memory load to maintain goal representations to stay on task (Figure 1). This is consistent with the literature suggesting that mind wandering occurs due to the failures in working memory for goal maintenance (e.g., McVay & Kane, 2009), an impairment specifically linked to inattention (Diamond, 2005; Elisa et al., 2016).

Given that DSM-V refers to mind wandering only under inattentive symptom list (APA, 2013), the findings that inattention was linked to frequent mind wandering only under difficult task conditions while hyperactivity and impulsivity were also linked to mind wandering (and in both easy and difficult conditions) are somewhat inconsistent with the approach to the diagnosis of ADHD. Furthermore, only spontaneous mind wandering was linked to ADHD symptoms while deliberate mind wandering was not. Thus, our findings suggest the need for a modification of the symptoms listed against each of the core symptoms in the DSM-V such as the inclusion of mind wandering in the hyperactivity/impulsivity symptom lists and introducing the effects of intentionality and task difficulty/cognitive load. Given the implications of the present findings Chapter 3 set out to replicate the current findings using a different measure of mind wandering.

Chapter 3. Inattention and daily-life mind wandering. Chapter 2 revealed that inattention was linked to spontaneous mind wandering only when it needs to be controlled to ensure task performance, while hyperactivity/impulsivity was associated with frequent mind wandering regardless of task difficulty. This was a somewhat surprising finding that contrasted with the notion that in most, if not all, assessments of ADHD, mind wandering is strongly associated with inattention only. The work in this chapter investigated the link between mind wandering and inattention using daily-life measures of mind wandering across a much larger sample. Once again, inattention, hyperactivity and impulsivity predicted spontaneous mind wandering. In contrast to the probe-caught method, using the daily-life measure, both inattention and hyperactivity predicted deliberate mind wandering while impulsivity scores were not conclusive. To sum, consistent across two studies (Chapter 2 and Chapter 3), findings revealed that all symptoms of trait level ADHD are related to mind wandering, despite the clinical diagnosis listing mind wandering items specifically under inattention (APA, 2013). Chapter 3 also revealed that, across 652 undiagnosed adults (only 15 participants had ADHD diagnosis), inattention, hyperactivity and impulsivity traits were normally distributed, supporting the dimensional approach to ADHD symptomatology (e.g., Haslam et al., 2006).

Chapter 4. Inattention and Task Switching. The previous chapters established that mind wandering, an impairment associated with working memory, was not uniquely associated with inattention. The work in this chapter aimed to test whether inattention predicted poor performance in one of the other core executive functions, task switching, either independently of any working memory involvement or only when working memory was implicated. Thus, Study 1 used predictable and unpredictable task switching paradigms to tease apart the switch-related processes such as preparation and task-set inhibition. We found that inattentive traits uniquely predicted the switch costs in a predictable task switching paradigm in which advanced preparation was needed for successful performance. Research has revealed the need for working memory capacity to bias future behaviour based on the task goals, a control mechanism known as *proactive control* (Braver, 2012; Braver et al., 2007). Study 2 addressed some of the limitations of Study 1 and also included measures of active maintenance (Operation Span Task) and goal neglect (the Letter Monitoring Task). Replicating the findings of the Study 1, inattention was uniquely linked to the poorer predictable switching. However, Study 2 further revealed that inattention was a unique predictor only when the use of proactive control was optional while it was non-significant when the need for proactive control was not optional. Furthermore, the frequency of goal neglect during the Letter Monitoring Task mediated the link between inattention and the switch costs while the active maintenance component (Operation Span Task scores) was unrelated.

Thus, Study 1 and Study 2 revealed a tendency for those with inattention to avoid the use of proactive, effortful control, and that this tendency was related to goal neglect.

Chapter 5. Proactive Control and Goal Neglect. Following the findings from Chapter 4 (linking inattention to goal neglect and proactive control in the context of switching), Chapter 5 aimed to investigate the tendency to avoid proactive control outside of the task switching context. To measure proactive control, a picture-naming version of the Stroop task was used where stimulus congruency was manipulated in a list-wide and item-specific manner. Participants again performed letter monitoring task as a measure of their tendency for goal neglect. The findings revealed that inattention was the unique predictor of poor proactive, but not reactive, control use. Moreover, this was once again moderated by the tendency for goal neglect; only those with inattention who frequently experience goal neglect were less likely to use proactive control. The findings from this chapter supported the notion that the core impairment in those with inattention was the increased tendency for goal neglect.

Chapter 6. Goal neglect and DLPFC. Using Repetitive Transcranial Magnetic Stimulation (rTMS), this chapter aimed to investigate whether the levels of goal neglect can be reduced following the stimulation of the left DLPFC, the part of the brain strongly associated with working memory capacity (e.g., Burgess et al., 2010). This study used high-frequency rTMS, which is thought to improve the activation of the stimulated area. Results revealed that participants experienced less goal neglect following active stimulation compared to a sham condition (a condition where the real stimulation does not occur, but the participant is oblivious to this). Thus, findings of Chapter 6 showed that goal neglect can be reduced via the link between the left DLPFC and goal neglect.

Interim summary

The results from this thesis point to a core deficit in the construction of suitable goal representations in inattention. As shown in Figure 1 this leads to various other impairments associated with the use of goal representations such as in proactive control. However, inattention was also associated with other working memory impairments which were not unique to inattention.

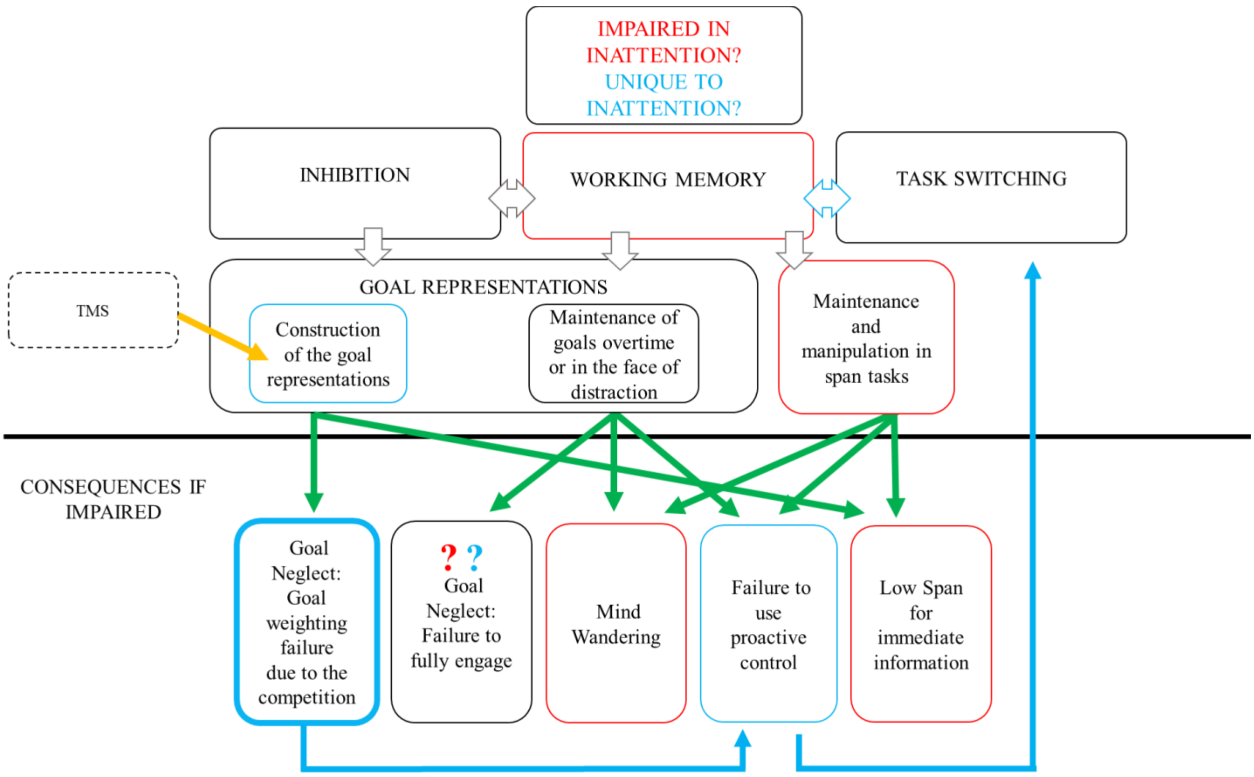

Figure 1. Figure explaining the main findings

Theoretical Implications of the findings for Inattention

Inattention and Working Memory

Diamond (2005) claimed that a working memory impairment is specific to inattention rather than hyperactivity/impulsivity (see also Alloway et al., 2010; Elisa et al., 2016; Kim, 2004 for studies revealing impaired working memory for inattention). The findings from this thesis and the existing literature suggest that hyperactivity and impulsivity are also associated with impairments in working memory (and/or processes associated with working memory). However, this thesis also presents evidence for unique impairments in specific processes associated with working memory.

Inattention and maintenance and manipulation in span tasks

Elisa et al. (2016) found that only inattention predicted working memory scores of Digit Span Backward and Operation Span tasks but revealed insensitive Bayes values for non-significant hyperactivity and impulsivity, making the results relating to these latter core symptoms inconclusive. In contrast, the results from Chapter 4 (Table 5) revealed that inattention was the unique predictor of Operation Span Task performance with Bayes values for hyperactivity and impulsivity providing evidence for the null. However, Elisa et al. (2016) also reported that only impulsivity was linked to a spatial working memory impairment. These results indicate that inattention is associated with impairments in verbal working memory (e.g., Digit Span Backward and Operation Span tasks). Indeed, the Operation Span Task is designed to measure verbal working memory capacity via the active maintenance of information during an interference from a secondary task (Unsworth et al., 2005). Given that scores on this task were not related to impaired proactive control in inattention (during predictable task switching), it is likely that an impairment in active maintenance of goal representations is impaired in inattention but is not unique to it.

Inattention and Goal Neglect

The verbal working memory impairment in inattention may be related to the commonly reported problems in following instructions (APA, 2013; Diamond, 2005). Indeed, our findings reported consistent impairments in what Duncan and colleagues have referred to as an episodic buffer like component of working memory used for the integration and construction of task instructions/goals (Chapter 4, Study 2 and Chapter 6 see also Elisa et al., 2016). This tendency for goal neglect was related to poor use of proactive control (Chapter 4 and Chapter 5) and led to the impaired task performance in predictable task switching (Chapter 4, Study 1 and Study 2). Thus, the present results suggest that inattention is related uniquely to impairments in working memory for goal representations (Duncan et al., 2008), involving the episodic buffer component (Baddeley, 2000) as well as the maintenance and manipulation issues that are common to the other core symptoms.

The work in the thesis did not directly address the association between inattention and the form of goal neglect leading to a failure to fully engage in a task - i.e., there was no experiment utilising the response-stimulus interval (RSI) manipulation employed by De Jong et al. (1999). However, there is evidence that points towards a potential tendency for this type of goal neglect in inattention. Whilst the initial task switching study indicated an impairment in the use of proactive control in inattention, the second study revealed an intact capacity to utilise proactive control but a tendency to neglect proactive control when reactive control mechanisms were available. This indicates that those with inattention are indeed failing to fully engage their full control capacity. However, both the second task switching study (Chapter 4) and the conceptual replication of a unique proactive control impairment in inattention in the congruency proportion manipulated Stroop task (Chapter 5), showed that the tendency to neglect proactive control use was accounted for by performance on the letter monitoring task. This indicates that these two forms of goal neglect are related. In Chapter 6, it was shown that rTMS to the left DLPFC can relieve goal neglect. This work indicates that goal neglect in inattention could also be mitigated by rTMS.

Inattention and Mind wandering

Inattention was not uniquely related to mind wandering, although it was the strongest predictor of mind wandering in the present data (Chapter 2 and Chapter 3). During task performance, inattention was a significant predictor only when the task was difficult; that is, when the experiences of spontaneous mind wandering needed to be controlled due to working memory load (Rummel & Boywitt, 2014). This fits with the proposed relationship between working memory and mind wandering suggesting a need for working memory to maintain task goals, hence stay on task (e.g., Smallwood & Schooler, 2015). However, we also found that mind wandering was also linked to hyperactivity and impulsivity, suggesting that it is not a unique characteristic of inattention, and might be linked to other impairments such as inhibition.

Inattention and proactive control

It was interesting that the link between proactive control and task switching relied on how much the goal representations for the use of proactive control was reinforced. Inattentive traits predicted neither the predictive switching (Chapter 4, Study 2) nor interference inhibition (Chapter 5) where the use of proactive control made limited demands on goal representations. In Chapter 4, there was no relationship between inattention and predictable switching when participants had to focus on the advanced cue (Random PC) and the task order (Order PC) to be able to work out the next task. It suggests that, if the participant's focus is drawn to advanced information, this may facilitate the goal representations for the preparation instruction. As a result, in Random PC and Order PC conditions, the use of proactive control to prepare for the upcoming task did not have a high demand for preparation-related goal representations, which seems to be impaired by inattention.

Similarly, in Chapter 5, the tendency to use proactive control was measured using the Stroop task with list-wide congruency manipulation. Participants performed mostly congruent and mostly incongruent versions of this task. Although the index for the use of proactive control (the difference in the Stroop effect between mostly congruent and mostly incongruent blocks) was predicted by inattention, the Stroop effect (an index of interference inhibition) was not related to inattention for either block (or any other ADHD-related traits). This suggests that the limitation in proactive control did not reflect in interference resolution in the Stroop task. Similar to the Chapter 4, it is possible to argue this could be due to the limited demands on goal representations. The idea is that, to use proactive control (expect and prepare for the congruency of the next stimulus), participants need to reinforce the congruent instruction in mostly congruent block and incongruency instruction in mostly incongruent block - the commonly used instruction. Common use of an instruction helps reinforce the representations of this instruction, therefore, the use of proactive control involves relatively low demand on goal representations (McVay & Kane, 2009). As a result, whilst goal neglect moderates the link between inattentive traits and decreased use of proactive control, this is only the case for those who goal neglect frequently, and, the impaired use of proactive control does not lead to an impairment in dealing with the Stroop interference effect.

Inhibition, working memory and inattention

Despite the consistently reported response inhibition impairment in hyperactivity/impulsivity and the combined presentations of ADHD (Barkley, 1997; Nigg, Blaskey, et al., 2002), studies employing the Stroop task as a measure of interference inhibition have revealed inconsistent findings (King et al., 2007), and little is known about the role of interference inhibition impairments in inattention. It is clear that some of the present findings including increased spontaneous mind wandering and increased competition between components of goal representations (or task models) in inattention could be explained by an impairment in interreference inhibition. Whilst the present thesis did not directly address the potential role of inhibition in producing inattention, Chapter 5's employment of the Stroop task permits some conclusions to be drawn on this matter. The present findings on inattention and Stroop task performance join studies reporting a non-significant relationship between inattention and interference inhibition (Chapter 5, Table 2; Nigg, Blaskey, et al., 2002; Van Mourik, Oosterlaan, & Sergeant, 2005). Moreover, the present data also provide evidence supporting no relationship between interference inhibition and hyperactivity and impulsivity, suggesting inhibition impairments in these two core symptoms might related specifically to response inhibition.

Consistency across ADHD measures

The CAARS and ASRS scales revealed similar effects in all domains in which they were compared. Across a relatively large sample, scores from both CAARS and ASRS revealed a consistent pattern of distributions (Chapter 3, Figure 2) and correlations (Chapter 3, Table 1). The two measures consistently linked ADHD symptoms to spontaneous and deliberate mind wandering. Moreover, Chapter 4 revealed that using CAARS (Study 1) and ASRS (Study 2) yielded similar associations between inattention and predictable switching while unpredictable switching was non-significant. Together, the similar pattern of results reveals the consistency between CAARS and ASRS as measure of ADHD symptoms.

Future Aims

Findings in this thesis revealed frequent levels of goal neglect in inattention. However, the strength of this relationship was moderate (14% in Chapter 4 and 24% in Chapter 5). Whilst the letter monitoring task proved to be a useful measure of goal neglect (Duncan et al., 2008; Chapter 4, Chapter 5 and Chapter 6), further work manipulating the demands on the task model construction might reveal a stronger relationship between inattention and goal neglect and would be beneficial in clarifying the nature of goal neglect and its relation to inattention. Alternatively, goal neglect might only be a piece of the puzzle, and to explain inattention in its entirely might take a collection of tasks. It has already been noted that the span tasks pose a challenge to those with inattention, but no more so than for those high in hyperactivity/impulsivity. Nevertheless, this thesis has taken the approach that identifying unique impairments in inattention is the best way to understand inattention. Future work should further consider issues associated with goal maintenance overtime by, for example, comparing performance at short and long RSIs (De Jong et al., 1999).

It was shown in Chapter 6 that rTMS to the left DLPFC successfully decreased goal neglect. Whilst this is the first work linking DLPFC to goal neglect, the use of brain stimulation is relatively costly and can only be administered with special training. The persistency of the rTMS effect is also yet to be evidenced (Thut & Pascual-Leone, 2010). Future work should aim to ameliorate goal neglect using methods that are transferable to daily life strategies. There is some work suggesting the reduction in goal neglect following practice (Duncan et al., 2008, Experiment 3), feedback and prompting (Duncan et al., 1996), however, this work is yet to be investigated in the context of inattention. There is also a possibility that the failure to engage in goal relevant processes (producing goal neglect) is due to the low levels of effort/motivation (De Jong et al., 1999). The link between cognitive effort/motivation and performance on executive tasks has been shown and might be at the heart of the problems associated with inattention (Castellanos et al., 2006; Sergeant & Van der Meere, 1990; Sergeant et al., 1999). Hence, further studies exploring the impact of motivation on goal neglect would be useful.

Moreover, the existing measures of inattentive symptoms all belong to ADHD scales (e.g., CAARS and ASRS), making it difficult to treat inattentive traits individually. Hence, large scale studies aiming to improve the existing measures of inattention and development of inattentive traits questionnaire would be useful. The development of such a measure would be useful in assessing inattention in other clinical disorders such as schizophrenia and depression.

This thesis has considered the cognitive impairments associated with inattention but did not consider its socio-emotional impact. Whilst there are many studies showing the negative impact of adulthood ADHD traits on socio-emotional functioning (Barkley et al., 2002; DuPaul et al., 2009; Johnston, 1998; Johnston et al., 2012), the literature on inattentive traits is limited. There is some work showing problems with internalisation (Goodyear & Hynd, 1992; Hinshaw, 2002; Wheeler Maedgen & Carlson, 2000) and coping with stress and self-concept (Overbey et al., 2011), but most of these studies are comparing ADHD-I to ADHD-HI or ADHD-C. Given the existence of inattentive traits in the general population, and the cognitive impairments that come with it, more work on the socio-emotional impact of trait inattention is important and could be as influential as work on trait anxiety.

Thesis Conclusion

Based on evidence differentiating inattention from hyperactivity/impulsivity (Diamond, 2005) and evidence showing that such symptoms are present at subclinical levels (Haslam et al., 2006; Salum et al., 2014), the studies in this thesis set out to discover the unique impairments in inattention and their impact on complex cognitive tasks. Focussing on how impairments in working memory affect the effectiveness of the construction and maintenance of goal representations, this thesis has explored impairments in complex cognition in a variety of experimental contexts. The key finding was the consistent replication of the unique link between inattention and goal neglect frequency (Elisa et al., 2016, Chapter 3, Chapter 5), and the role that goal neglect plays in producing impairments in proactive control use.

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Appendices

Appendix A. Connors Adult ADHD Rating Scale-Self-Report: Short Version (Connors, Edhardt & Sparrow, 1999)

Instructions: Listed below are items concerning behaviors or problems sometimes experienced by adults. Read each item carefully and decide how much or how frequently each item describes you recently. Indicate your response for each item by circling the number that corresponds to your choice. Use the following scale: 0 = Not at all, never; 1 = Just a little, once in a while; 2 = Pretty much, often; and 3 = Very much, very frequently.

	Not at all, never	Just a little, once in a while	Pretty much, often	Very much, very frequently
1. I interrupt others when talking.	0	1	2	3
2. I am always on the go, as if driven by a motor.	0	1	2	3
3. I'm disorganized.	0	1	2	3
4. It's hard for me to stay in one place very long.	0	1	2	3
5. It's hard for me to keep track of several things at once.	0	1	2	3
6. I'm bored easily.	0	1	2	3
7. I have a short fuse/hot temper.	0	1	2	3
8. I still throw tantrums.	0	1	2	3
9. I avoid new challenges because I lack faith in my abilities.	0	1	2	3
10. I seek out fast paced, exciting activities.	0	1	2	3
11. I feel restless inside even if I am sitting still.	0	1	2	3
12. Things I hear or see distract me from what I'm doing.	0	1	2	3
13. Many things set me off easily.	0	1	2	3
14. I am an underachiever.	0	1	2	3
15. I get down on myself.	0	1	2	3
16. I act okay on the outside, but inside I'm unsure of myself.	0	1	2	3
17. I can't get things done unless there's an absolute deadline.	0	1	2	3
18. I have trouble getting started on a task.	0	1	2	3
19. I intrude on others' activities.	0	1	2	3
20. My moods are unpredictable.	0	1	2	3
21. I'm absent-minded in daily activities.	0	1	2	3
22. Sometimes my attention narrows so much that I'm oblivious to everything else; other times it's so broad that everything distracts me.	0	1	2	3
23. I tend to squirm or fidget.	0	1	2	3
24. I can't keep my mind on something unless it's really interesting.	0	1	2	3
25. I wish I had greater confidence in my abilities.	0	1	2	3
26. My past failures make it hard for me to believe in myself.	0	1	2	3

Appendix B. Adult ADHD Self-Report Scale (Adler et al., 2006; Kessler et al., 2005)

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months. Please give this completed checklist to your healthcare professional to discuss during today's appointment.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
					Part A
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					

Appendix C. Chapter 2, Study 1 Supplementary Material

Table 1

Demographic information, CAARS t-scores and mind wandering scores for each participant

					CAARS scores				Standard SART probe responses			Sequential SART probe response		
Participant number	Age	Occupation	Gender	Previous diagnosis	Inattention	Hyperactivity	Impulsivity	Index	On Task	Deliberate	Spontaneous	On Task	Deliberate	Spontaneous
1	22	postgraduate	female	no	51	49	55	53	9	11	0	11	3	6
2	21	undergraduate	male	no	61	47	51	60	12	8	0	7	5	8
3	19	undergraduate	male	yes	74	59	51	70	9	1	10	6	4	10
4	19	undergraduate	male	no	64	56	42	53	13	1	6	17	1	2
5	20	undergraduate	female	no	63	57	46	73	19	1	0	12	1	7
6	22	undergraduate	male	no	70	59	58	68	4	8	8	8	5	7
7	26	postgraduate	female	no	45	40	43	47	18	1	1	16	3	1
8	27	postgraduate	female	no	63	54	61	61	9	3	8	18	0	2
9	21	undergraduate	male	no	57	59	48	53	3	3	14	0	2	18
10	24	postgraduate	male	no	51	34	38	45	11	4	5	7	8	5
11	36	postgraduate	male	no	59	47	52	48	10	1	9	8	3	9
12	20	undergraduate	male	no	57	51	79	61	14	3	3	9	7	4
13	24	postgraduate	female	no	47	53	48	45	6	3	11	4	2	14
14	21	undergraduate	female	no	75	63	61	71	10	1	9	10	4	6

15	18	undergraduate	female	no	60	72	61	65	5	5	10	0	7	13
16	20	undergraduate	male	no	80	74	77	90	5	10	5	3	8	9
17	20	undergraduate	female	no	48	43	46	48	10	3	7	10	2	8
18	20	undergraduate	male	no	54	47	42	43	8	6	6	2	13	5
19	18	undergraduate	male	no	47	44	40	36	2	17	1	3	17	0