Inattention symptom severity and cognitive processes in children at risk of ADHD: The moderating role of separation anxiety

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Abstract

Impairments in cognitive processes and their associations with dimensional measures of inattention, hyperactivity-impulsivity and anxiety were examined in children at risk of Attention-Deficit Hyperactivity Disorder.

Children referred by teachers for exhibiting ADHD-type problems (*n* = 116; 43 meeting full diagnostic criteria for ADHD; 4-8 years) completed computerised tasks measuring episodic memory, response inhibition, visuomotor control and sustained attention, while parents were interviewed (DAWBA) to assess ADHD and anxiety symptoms.

Of the 116 children assessed, 72% exhibited impaired cognitive processes; 47% had impaired visuomotor control, 37% impaired response inhibition, and 35% had impaired episodic memory. Correlational and hierarchical regression analyses using our final analytic sample (i.e., children who completed all cognitive tasks and a vocabulary assessment, *n* = 114) showed that poorer task performance and greater within-subject variability were significantly associated with more severe inattention symptoms but not with hyperactivity-impulsivity severity. Symptoms of separation anxiety, which were reported in over half of the sample, moderated associations between inattention and episodic memory, and between inattention and inhibition. Only children without separation anxiety showed significant correlations between ADHD symptoms and poor performance. However, separation anxiety had no moderating effect on associations between inattention and visuomotor control or sustaining attention.

Children exhibiting signs of ADHD show impairments across a range of cognitive tasks. Further research to improve our understanding of these processes may be useful in the development of early interventions. Our results suggest that separation anxiety should be taken into account when considering interventions to address emerging neuropsychological deficits associated with this disorder.

Keywords: Attention-Deficit/Hyperactivity Disorder, Episodic memory, Response inhibition, Comorbid anxiety.

Attention-deficit hyperactivity disorder (ADHD) is characterised by symptoms of inattention, hyperactivity and impulsivity (American Psychiatric Association [APA], 2013). These behavioural manifestations of ADHD can result in a range of difficulties in the school environment, including academic underachievement, off-task behaviour, and emotional dysregulation (Barry et al., 2002; Rapport et al., 2009; Shaw et al., 2014). ADHD is also highly comorbid with other disorders and associated with poorer outcomes in later life (Groenman et al., 2017). Because ADHD symptoms and information-processing deficits emerge early in life and can have a lasting impact on prosocial and academic development, early identification of the processes underlying the range of problems involved in ADHD symptomatology is important (Kalff et al., 2005; Rabiner et al., 2016). In the current study we examined cognitive processes in children with emerging ADHD symptoms in order to identify unique associations between different processes and ADHD symptom dimensions, taking into account the potential moderating role of anxiety in these relationships.

Individuals with ADHD show impairments in a range of cognitive processes that support the top-down coordination and control of other brain functions. These include executive function (EF) processes; (1) flexibly adapting to new situations, rules and perspectives, (2) inhibiting automatic responses; (3) updating and manipulating information in mind, and (4) sustaining and controlling attention (Willcutt et al., 2005; Zelazo, 2020). Estimates of impairment prevalence range from approximately one-third to one-half of children with diagnosed ADHD having difficulty in each domain (e.g., 30-37% of children have memory problems [Coghill et al., 2014]; 21-46% have impaired response inhibition [Kofler et al., 2019]). Impairments in EF are associated with greater severity of ADHD symptoms, and greater difficulties in daily life such as controlling attention and staying on task in the classroom (Antonini et al., 2013; Karalunas et al., 2017). Weaker performance on measures of cognitive functioning is also observed in young children at risk of ADHD (Coghill & Sonuga-Barke, 2012; Kalff et al., 2005; Slaats-Willemse et al., 2007), who may benefit from early intervention in this domain (Gau & Shang, 2010). Further, there is some evidence to suggest that training programs can improve these cognitive processes and even alleviate symptoms of ADHD (e.g., Kofler et al., 2020), although the evidence that cognitive training can reduce symptoms of the disorder is mixed (Cortese et al., 2015).

However, despite the consensus that cognitive deficits are highly prevalent in children with symptoms of ADHD, there is substantial variation between studies with respect to the type and severity of impairment found in children (e.g., Coghill et al., 2014; Kofler et al., 2019; Willcutt et al., 2005). Although most research has focused specifically on EF problems, individuals with ADHD also show impairments in cognitive processes that are closely related to performance on EF tasks, such as episodic memory and RT variability (Alderson et al., 2015; Cai et al., 2019). In addition, because factor analytic studies (e.g., Akshoomoff et al., 2018) have shown that EF are less clearly differentiated and overlap with other cognitive skills in young children (e.g., 3- to 6-year-olds), it may be beneficial for research in pre-diagnosed samples not to limit assessments to EF in order to improve our understanding of impaired cognitive processes that may be associated with developing ADHD symptoms. A further issue is that the comorbidity of ADHD with other conditions influences the prevalence and type of cognitive problems observed (Castagna et al., 2019). To improve understanding and inform a more targeted approach to intervention, it is important to examine associations between different cognitive impairments and ADHD symptoms, and to clarify the role of comorbid symptoms in children at risk.

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

Comorbidity is a key issue when examining cognitive problems in those with ADHD. Jensen et al. (2001) identified three clinical profiles in a large sample of children aged 7-10 with ADHD: ADHD with co-occurring anxiety and without any disruptive disorder; ADHD and disruptive disorders without anxiety; and ADHD with both anxiety and disruptive disorders, where “pure” ADHD was the exception rather than the rule. Because ADHD is most frequently comorbid with externalising symptoms of disruptive behaviour disorders (Jensen et al., 2001; Larson et al., 2011), comorbid anxiety has received less attention, despite estimates of comorbidity being as high as 40% (MTA Cooperative Group, 1999).

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

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

Current study

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

The sample consisted of young children (4-8 years) who had been referred by their schoolteachers for a range of emotional, cognitive and behavioural problems, including hyperactivity, impulsivity and inattention. Our analyses focused on the prevalence of cognitive impairments in these children, on the associations between cognitive processes and ADHD symptom dimensions, and on the way in which anxiety moderated these associations.

It was hypothesised: 1) that the sample would show impairments in cognitive processes, relative to norms and standard scores, indicating risk of cognitive problems; 2) that inattention symptoms of ADHD would be more strongly associated with poor cognitive function, with the exception of response inhibition, relative to hyperactivity-impulsivity symptoms; and 3) that anxiety would moderate relations between inattention and impaired cognitive processes by worsening working memory and improving response inhibition and attentional control.

Materials and Methods

Participants

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

Background information

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

Measures

ADHD Symptom Severity

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

Anxiety

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

Working and Episodic Memory

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

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

Response Inhibition

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

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

Visuomotor and Attentional Control

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

Sustained Attention

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

Vocabulary

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

Procedure

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

Data Analysis

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

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

The total valid N for the examination of prevalence rates was 116 (i.e., the number of children who completed all cognitive tasks). For our regression analyses, the total valid N was 114 (i.e., the number of children who completed all cognitive tasks and the vocabulary assessment).

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

further, the pick-a-point approach (Rogosa, 1980) was used to compare associations between ADHD and cognitive processes in children with low, mean and high anxiety scores. The Johnson-Neyman (J-N) technique was applied to derive regions of significance for the moderating effect of anxiety on associations between ADHD and cognitive processes (Preacher et al., 2007). This technique enabled us to define the ranges of values of anxiety which produce a statistically significant moderation effect. To apply this method, moderated regression analyses were repeated without mean centring of symptoms of inattention or anxiety. Previous studies have shown that the variance in cognitive processes accounted for by the interaction between ADHD and anxiety is small. For example, Castagna et al., (2019) found the interaction between inattention x anxiety accounted for a small proportion of variance in working memory ($\Delta R^2 = .05$, $p < .05$; Castagna et al., 2019). Therefore, interactions that were either significant ($p <. 05$) or marginal ($p <. 10$) were followed up with further analysis.

Results

Preliminary Analyses

Table 1 shows the DAWBA symptom scores for the sample. Forty-three children (37%) met the diagnostic criteria for ADHD (predominantly inattentive: $n = 7$, predominantly hyperactive-impulsivity: $n = 4$, combined: $n = 32$).

Seventy percent of the children in the sample had zero symptoms of social anxiety and 85% had zero symptoms of generalised anxiety. In contrast, symptoms of separation anxiety were exhibited in 54% of the sample and 23 children (20%) met DSM-5 diagnostic criteria (APA, 2013). The number of children meeting criteria for other anxiety disorders was low and very rarely occurred independently of separation anxiety (social anxiety: $n = 1$;

generalised anxiety: n = 5). Because separation anxiety is the most prevalent form of anxiety disorder in children of this age (Beesdo et al., 2009) and is associated with developing a variety of anxiety disorders later in life (Aschenbrand et al., 2003), we used separation anxiety scores to investigate interactions between ADHD symptom dimensions and anxiety on cognitive processes.

Impaired cognitive processes in children at risk of ADHD

Table 2 shows the prevalence of impairments on each cognitive task. Overall, 72% of the sample demonstrated a below average performance in at least one cognitive domain. Impaired visuomotor control was exhibited by 47%, 37% were impaired in response inhibition, and 35% had impaired memory on at least one of the two memory tasks (working or episodic).

Associations between age, vocabulary scores and cognitive processes are shown in Table 3. Age was associated with higher picture sequence memory scores, faster and more accurate inhibition, better sustained attention, and lower within-subject variability (ANT-ROO inhibition response times and ANT-Pursuit distance from target). Independent samples t-tests showed that there were no sex differences in ADHD or separation anxiety symptom scores. Girls demonstrated significantly slower response inhibition ($t(114) = -2.50$, $p = .01$). Vocabulary scores were associated with faster and more accurate response inhibition and lower within-subject variability (ANT-ROO and ANT-Pursuit) (Table 3).

Associations between impaired cognitive processes and specific ADHD symptom dimensions

As shown in Table 3, in the whole-group correlational analysis, inattention was correlated with poor visuospatial episodic memory, more variable inhibition (response times) and visuomotor control, and worse sustained attention. Hyperactivity-impulsivity was correlated with higher inhibition variability. Our sensitivity analysis showed that, when children with separation anxiety were removed from correlational analyses, inattention was additionally associated with worse response inhibition (slower, more errors) (Table S1 in Supplementary information).

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

Our sensitivity analysis indicated that removing children with separation anxiety strengthened correlations between ADHD symptoms and impaired cognitive processes. To examine the potential moderating effect of anxiety, we looked at whether adding interactions between ADHD symptoms and separation anxiety in the third step of moderated hierarchical regression models improved model fit.

Episodic and Working Memory

No significant associations were found between performance on the AWMA backwards digit task and ADHD symptom dimensions. Associations between greater separation anxiety and poor working memory were not significant (b = -.17, p = .07).

On the picture sequence task, greater inattention was associated with poorer episodic memory. As shown in Table 4, the addition of individual symptom severity scores in Step 2 resulted in a significant increase in R^2 (ΔR^2 = .06, p = .04), where greater inattention was a significant predictor of worse performance (b = -.24, p = .01). We examined whether separation anxiety moderated this relationship by entering the interaction term between separation anxiety and inattention in Step 3 of the hierarchical regression model. When this term was added, the increase in R^2. was marginal (ΔR^2 = .03, b = .43, p = .06). This interaction was probed further by exploring the association between inattention and episodic memory at different levels of separation anxiety, and by calculating the region of significance (Hayes et al., 2017). The region of significance suggested that the association between inattention and episodic memory shifted from significant to non-significant as separation anxiety scores increased beyond a score of 1.50. Inattention was significantly associated with poorer episodic memory for children with the lowest separation anxiety scores[1], *b* = -10.05, *SE* = 3.19, *t* = -3.15, *p* <.01, and mean levels of separation anxiety, *b* = -5.96, *SE* = 2.79, *t* = -2.14, *p* = .03, but not for children with high separation anxiety scores (+1 SD), *b* = -.12, *SE* = 4.51, *t* = -.03, *p* = .98 (see Figure 1). Together, these results indicate that children with high inattention and high separation anxiety performed better on this assessment of visuospatial episodic memory than children with high inattention and low separation anxiety symptoms.

Inhibition

Our correlational analyses showed that associations between inattention and poor response inhibition (greater RT variability, more errors and slower response times) shifted from non-significant to significant when children with separation anxiety were removed from the sample (Table S1). We examined this potential interaction between separation anxiety and inattention using a moderated hierarchical regression analysis (see Table 4). This showed that the interaction between inattention and separation anxiety accounted for a significant proportion of variance in response times ($\Delta R^2 = .02$, *b* = -3.043, *p* = .03). Examination of the significance region showed that this association shifted from non-significant to a significant negative association for children with higher separation anxiety symptom scores; above 5.14, indicating that separation anxiety was associated with faster inhibition response times in children with high inattention. We found that the association between inattention and inhibition was not significant at low and mean levels of separation anxiety. Children with high separation anxiety (+ 1 SD) showed a marginal association between inattention and faster inhibition (*b* = -.51, *SE* = .29, *t* = -1.73, *p* = .09).

Attention and within-subject variability

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

Hierarchical regression models predicting sustained attention and within-subject variability (inhibition response times, tracking performance on the ANT-Pursuit), showed that inattention was the only significant symptom predictor of variance in these domains (Table 5). The addition of inattention symptom severity resulted in a significant change in R^2 in the following models predicting impaired performance on cognitive tasks: inhibition response time variability (ΔR^2 =.08, B = .30*,* p <.01); variability in tracking distance on the ANT-Pursuit task (ΔR^2 = .05, B = .22, p = .03), and sustained attention (ΔR^2 = .08, B.= .24*,* p = .01).

Discussion

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

Cognitive impairments the sample

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

Dimensional associations between ADHD symptoms and cognitive processes

Consistent with predictions, poor performance on assessments of visuospatial episodic memory, visuomotor control and sustained attention was associated with inattention symptom severity, but not with hyperactivity-impulsivity severity. This suggests that these specific cognitive impairments are predominantly associated with difficulties controlling and focusing attention in young children at risk of ADHD, as opposed to hyperactive and impulsive behaviour (Cai et al., 2019; Loo et al., 2009; Toplak et al., 2005). The hypothesised association between inhibition errors and hyperactive-impulsive symptoms was not found. Instead, measures of poor inhibition performance (slow response times, errors) correlated with inattention. Our study is not the first to find that inhibition is associated with inattention rather than hyperactive-impulsive symptoms, which highlights the need to distinguish between cognitive inhibition, associated with performance on neuropsychological tasks, and behavioural disinhibition problems (i.e., difficulty regulating gross motor activity) (Chhabildas et al., 2001). The only variable that was significantly associated with hyperactive-impulsive symptoms was variability in response times, which was associated with both dimensions of ADHD symptomatology. Previous research has shown that children at risk of ADHD show higher gross motor activity during cognitively demanding tasks (Burley et al., 2021). Instead of being directly related to weaker cognitive function, it may be that hyperactivity reflects a compensatory behaviour to up-regulate arousal and sustain neural activity (Rapport et al., 2009). Because RT variability is associated with lapses of attention, this association between parental ratings of hyperactivity and RT variability may reflect how children increase movement to up-regulate arousal when they are losing focus (Antonini et al., 2013; Sarver et al., 2015). This may explain why hyperactivity was not directly associated with poor performance but was associated with more frequent lapses of attention on the task.

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

The moderating effects of separation anxiety on associations between ADHD dimensions and impairments in cognitive processes was broadly in line with predictions. In contrast to children in groups with low and mean anxiety scores, children in the high separation anxiety group (4-10 symptoms), did not show a significant association between inattention and episodic memory. For response inhibition, associations between inattention and response inhibition were not significant within each anxiety group. Our moderation analysis indicated that children with very high separation anxiety (6-10 symptoms) showed a significant association between high inattention and faster inhibition response times. Our sensitivity analysis showed that when children with clinically significant separation anxiety were removed from the sample, inattention was associated with more inhibition errors. This association was not significant in the full sample. Together, this indicates that the faster response times associated with comorbid separation anxiety did not compromise accuracy.

The finding that separation anxiety dampened associations between inattention and poor inhibition, and between inattention and poor visuospatial episodic memory, suggests that in children with high inattention symptoms, separation anxiety was associated with better performance on these cognitive assessments. Therefore, comorbid separation anxiety may mitigate these specific cognitive problems in ADHD. There are several proposed ways in which comorbid anxiety could influence cognitive processes, such as increasing inhibition or reducing impulsivity (Bloemsma et al., 2013; Newcorn et al., 2001). We found that the moderating effect of separation anxiety was not restricted to inhibition and our findings are therefore more consistent with a general mechanism, with separation anxiety increasing aspects of attention, motivation and/or arousal (Vance et al., 2013; Vloet et al., 2010). This may compensate for the under-activation of brain regions associated with impaired EF in ADHD and improve performance across multiple domains of cognitive functioning (Bellgrove et al., 2004; Loo et al., 2009; Rubia, 2018).

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

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

Implications

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

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

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

Limitations

Age-related differences in the prevalence of anxiety disorders are well-documented in the anxiety literature; separation anxiety has an earlier age of onset and is more common than social and generalised anxiety in preadolescence (Kessler et al., 2005; Lijster et al., 2017).

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

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

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

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

Conclusion

The current findings indicate that young children with emerging ADHD symptoms, specifically those with symptoms of inattention, exhibit impairments in cognitive processes. However, comorbid separation anxiety may improve specific cognitive processes –

visuospatial memory and response inhibition – in children with high levels of inattention problems. The cognitive benefits of anxiety in ADHD may be less detectible on tasks requiring high levels of attentional processing, on which children demonstrated the greatest prevalence of impairment, regardless of level of separation anxiety. These results suggest that targeting visuomotor and attentional control for early intervention is likely to be useful in reducing the cognitive and behavioural problems associated with developing ADHD. This approach would also benefit children with additional anxiety problems, who may show fewer impairments in other cognitive processes.

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Tables

Table 1

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

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

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

Table 2

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

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

Note. WM = Working Memory. AWMA= Automated Working memory Assessment - Backwards Digit Recall. PSM = Picture Sequence Memory. RT = response time. To profile the sample's performance on working memory tasks (PSM, AWMA), we used age-corrected standard scores, for which the normative mean is 100 and standard deviation is 15 (Alloway, 2007; Zelazo et al., 2013). To profile response inhibition and executive attention, we used norm values produced by the ANT software for the ANT-ROO and ANT-Pursuit (De Sonneville, 1999), for which the normative mean is 0 and standard deviation is 1. Because this is calculated using errors, reaction times, and distance from the target, a score of above +1 indicates weaker performance (i.e., below the norm), whereas a score of below -1 is considered above the norm.

Table 3

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

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

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

Table 4

Hierarchical Regressions Estimating Performance on Cognitive Tasks

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

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

Table 5

Hierarchical Regressions Estimating Within-subject variability

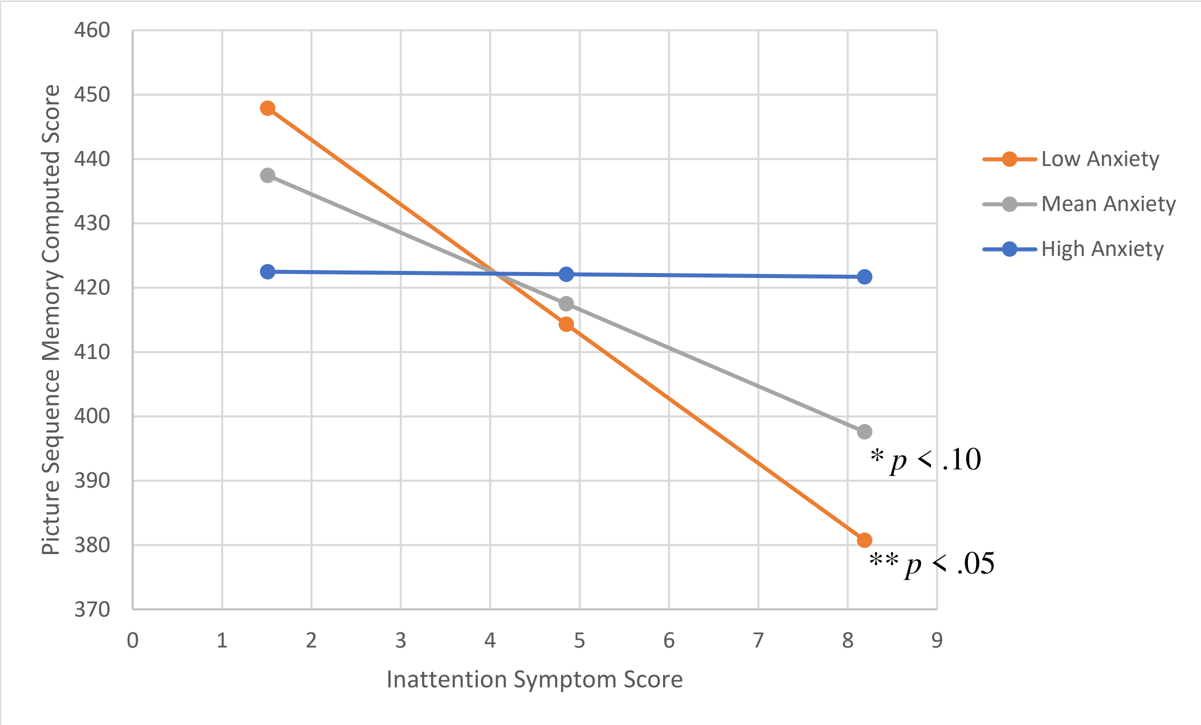
Measure	Step/Variable	R^2	ΔR^2	B	SE B	β	t	95% CI
ANT-	Step 1	.110	.110**					
ROO	Age			-.016	.018	-.097	-.892	[-.052, .020]
	Sex			-.016	.032	-.044	-.486	[-.037, .023]
	BPVS			-.003	.001	-.266*	-2.444	[-.081, -.008]
	Step 2	.194	.084**					
	Inattention			.015	.005	.304**	3.359	[.021, .081]
	Sep Anx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

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

Figures

Figure 1

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



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