Distinct Patterns of Emotional Processing in ADHD and Anxiety. Evidence from an Eye-Movement Go/No-Go Task

A. Manoli[a,b*], S.P. Liversedge[c], E. Sonuga-Barke[d] and J.A. Hadwin[e]

[a] Centre for Psychiatry and Mental Health, Wolfson Institute of Population Health, Queen Mary University of London, London, UK

[b] Cyprus University of Technology, Faculty of Health Sciences, Department of Nursing, Limassol, Cyprus

[c] School of Psychology, University of Central Lancashire, Preston, PR21 2HE, UK

[d] Department of Child and Adolescent Psychiatry, Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, SE5 8AF, UK

[e] School of Psychology, Liverpool Hope University, Hope Park, Liverpool, L16 9JD, UK

Athina Manoli: https://orcid.org/0000-0001-8500-7006

Simon P. Liversedge: https://orcid.org/0000-0002-8579-8546

Edmund Sonuga-Barke: https://orcid.org/0000-0002-6996-3935

Julie A. Hadwin: https://orcid.org/0000-0002-1776-7940

*****Corresponding author: Dr Athina Manoli, Queen Mary University of London, UK.

Email: a.manoli@qmul.ac.uk

Introduction

Attentional control and emotional processing are important cognitive functions in children's social and emotional development (Rueda et al., 2010). Both processes are interrelated, as attentional control influences the allocation of attentional resources to emotional stimuli, and this process impacts emotional processing and regulation (Pessoa, 2008, 2009). Research in psychopathology has increasingly focused on understanding the role of cognitive factors and emotion dysregulation as potential mechanisms underpinning the onset and maintenance of internalising and externalising disorders (Ahmed et al., 2015; Gin et al., 2021). Exploring the attentional mechanisms underlying psychiatric conditions will help to elucidate etiological factors linked to their onset, as well as in the development of new approaches to prevention and intervention.

Children with a diagnosis of Attention-Deficit/Hyperactivity Disorder (ADHD) and anxiety often experience challenges in both attentional control and emotional regulation. Recent estimates suggest that around 7.6% of children aged 3 to 12 years and 5.6% of adolescents aged 12 to 18 worldwide receive a diagnosis of ADHD (Salari et al., 2023). Anxiety is one of the most frequent mental health disorders in children and adolescents (Merikangas et al., 2022), with lifetime prevalence rates ranging between 6.5% to 25% in children and adolescents, worldwide (Polanczyk et al., 2015; Racine et al., 2021; Sacco et al., 2022). While ADHD and anxiety are distinct disorders diagnostically, they share symptoms of restlessness, sleep problems, increased distractibility and concentration difficulties (American Psychiatric Association, 2013). Studies have shown that the presence of anxiety disorders in young people with ADHD can delay diagnosis (Katzman et al., 2017), increase difficulties in daily functioning (Sciberras et al., 2014) and lower social competence (Becker et al., 2015). In addition, parents' reports of poorer social skills and more symptoms of inattention in young people diagnosed with both anxiety and ADHD, compared to those with ADHD only (Bowen et al., 2008), increase the need to further investigate unique and overlapping characteristics in both disorders to better inform more targeted and effective interventions (e.g., Katzman et al., 2017).

Our study is based on theoretical frameworks and empirical evidence suggesting that ADHD is characterised by deficits in executive functioning and self-regulation. These deficits often result in specific biases in processing emotional stimuli due to difficulties in inhibiting responses and modulating emotional reactivity. Emotional impulsivity and poor self-regulation frequently observed in individuals with ADHD can lead to a heightened sensitivity to emotional stimuli, particularly negative emotions like anger or fear (Barkley, 2015). This heightened sensitivity may cause a bias towards processing these emotional faces, exacerbating challenges in emotional regulation and increasing focus on negative emotional cues.

Recent theoretical frameworks, such as the Deficient Emotional Self-Regulation (DESR) model (Faraone et al., 2019) and the Dual-Pathway model (Sonuga-Barke, 2003), provide a foundation for understanding the unique attentional biases and emotional processing in children with ADHD. According to these models, ADHD is characterised not only by deficits in executive functioning but also by significant challenges in emotional regulation, which can manifest as heightened emotional impulsivity and difficulties in controlling emotional responses (Barkley, 2015; Sonuga-Barke, 2003). This heightened emotional reactivity may predispose individuals with ADHD to preferentially attend to negative emotional stimuli, such as anger or fear, which are often perceived as more salient and engaging (e.g., Nasab et al., 2022; Jakobi et al., 2022). Empirical studies have supported this notion, demonstrating that children with ADHD exhibit prolonged attentional engagement with negative emotional faces, such as angry expressions, compared to neutral or positive stimuli (Kochel et al., 2013; Manoli et al., 2020). Further empirical evidence from recent EEG studies reveals that children with ADHD show higher functional connectivity and longer shortest path lengths in the frontal and occipital lobes compared to healthy controls, especially during the processing of negative emotions like anger

(Nasab et al., 2022). Additionally, a recent study found that adults with ADHD, particularly those with higher levels of reactive aggression, show increased neural activation in regions such as the insula and hippocampus during emotion processing, which may reflect emotional hyper-reactivity and effortful regulation (Jakobi et al., 2022).

Moreover, ADHD is associated with distinctive neural circuit characteristics, involving critical regions for emotional processing and attentional control, such as the amygdala and prefrontal cortex (Faraone & Radonjic, 2023). These neural differences likely contribute to altered processing of emotional stimuli, particularly faces, due to impaired regulation of emotional arousal and attention (Karalunas et al., 2020). These findings suggest that the attentional biases in ADHD are intrinsic to the disorder, rather than merely a byproduct of comorbid conditions like anxiety. Understanding these specific biases in emotional processing can enhance our comprehension of the broader socio-emotional challenges faced by children with ADHD and inform more effective therapeutic strategies.

Children with a diagnosis of ADHD commonly exhibit challenges with attentional control, which can lead to difficulties in recognizing and regulating emotions. Some studies have found that poor executive control in ADHD was present regardless of the emotional content of the task (Van Cauwenberge et al., 2015), while others have demonstrated that increased difficulties with inhibitory control were most evident in the presence of emotional stimuli (Yarmolovsky et al., 2017) and particularly threat-related stimuli (i.e., angry faces) (Kochel et al., 2013; Manoli et al., 2020). For example, Kochel et al., (2013), examined emotional Go/No-Go performance across happy, angry, sad and neutral faces in boys with (n=16) and without (n=16) a diagnosis of ADHD. Participants had to either execute (75% Go trials) or inhibit (25% No-Go trials) a button press. Children with a diagnosis of ADHD showed poor inhibitory control as reflected in higher commission errors (i.e., incorrect responses to No-Go cues) for angry (versus neutral) faces when compared with children who had no diagnosis. No difference was found for commission errors in happy-neutral and sad-neutral faces between the two groups. The findings support the proposition that children with ADHD may exhibit heightened challenges in managing their responses to emotional and threat-related stimuli, indicating challenges with emotional self-regulation.

Decreased attentional control in anxiety has been demonstrated in the context of internal (i.e., uncontrollable worry) or external threats (review by Richards et al., 2014). Children with a diagnosis of anxiety often exhibit attentional biases towards threat-related stimuli, reflecting heightened vigilance to potential dangers (Dudeney et al., 2015). These biases may impact emotional processing, as attention is selectively directed towards threatening stimuli, leading to increased sensitivity and intensified emotional responses. Research has consistently found that increased symptoms of anxiety are associated with disrupted cognitive performance in the presence of threat-related social stimuli (Cisler & Koster, 2010; Dudeney et al., 2015). Specifically, elevated anxiety has been linked to sensitivity to threat, including faster orientation (attentional capture) towards threatening stimuli, increased hypervigilance for threat (e.g., (Pavlou et al., 2016), difficulties disengaging from and attentional avoidance of threat (Barry et al., 2015; Richards et al., 2012). Investigating attentional control and emotional processing in children with anxiety can provide valuable insights into how attentional biases contribute to the development or maintenance of anxiety symptoms in childhood and adulthood.

Research has provided substantial evidence highlighting both overlapping and distinct characteristics associated with diagnoses of ADHD and anxiety. Overlapping features include difficulties in attentional control, such as problems with sustained attention, shifting attention, and inhibitory control. Both ADHD and anxiety also share challenges with related cognitive functions, such as working memory and cognitive flexibility. However, distinct characteristics exist as well. Characteristics more clearly associated with ADHD include hyperactivity, impulsivity, and restlessness. Anxiety has been linked with excessive worry and rumination, fear, and heightened arousal in response to perceived threats. Moreover, individuals with a diagnosis of ADHD typically display difficulties across various contexts, while anxiety disorders often manifest in specific situations or with specific triggers. Neurobiological studies have also revealed differences in brain structures and functioning between the two disorders (Arnsten, 2009; Craske et al., 2017; Faraone et al., 2024; Shin & Liberzon, 2010). Collectively, this evidence underscores the need for further research to more clearly understand the overlapping and unique features of ADHD and anxiety in children and that can more clearly inform targeted support.

Research findings focusing on the comparison of cognitive and affective processing in ADHD and anxiety are limited. Moreover, few studies have examined the interactive effects of behaviours associated with ADHD and anxiety in tasks that involve attention and inhibitory control, or that have considered how performance is impacted by emotional stimuli. A recent study (Manoli et al., 2020), asked children, adolescents and adults to complete a Go/No-Go task with neutral and emotional (happy and angry face) with an eye-movement methodology. In this task, centrally presented face and non-face stimuli (coloured squares) required moving (Go cues) or inhibiting No-Go cues) eye movements to a peripheral target. The results showed that individuals with elevated anxiety were faster to move their eyes to peripheral targets from centrally presented angry (versus happy) face Go cues, supporting previous findings of threat avoidance (Stirling et al., 2006). In contrast, elevated ADHD symptoms were linked to slower eye movements to peripheral targets in the context of angry face Go cues, indicating difficulties disengaging from threat. Moreover, the effect of anxiety symptoms on emotional processing that indicated avoidance of threat prevailed in individuals with elevated symptoms of ADHD and anxiety. Manoli et al. (2020) extended a growing body of work suggesting that symptoms of anxiety can modulate attentional processes in ADHD, highlighting a cognitive profile characterized by threat avoidance in the context of co-existing increased symptoms of anxiety and ADHD.

The research reported by Manoli et al., (2020) included individuals whose self-reported symptoms of anxiety largely fell within a typical range. The current paper aimed to replicate and extend this set of findings to examine the impact of social-emotional threat on attentional processing and inhibitory control in children and adolescents who met the diagnostic criteria for ADHD, anxiety, and typical controls. Following Manoli et al., (2020), we employed an eye-movement Go/No-Go paradigm and compared inhibitory control (measured via eye-movement commission errors on No-Go trials) and sustained attention (measured via saccade latency and missed saccadic responses (omission errors) to the target on Go trials) between groups for social and non-social stimuli. Irrespective of the participants' diagnostic group, we predicted that basic attentional processing would be modulated by the presence of the emotional faces compared to the neutral stimuli so that slower attentional disengagement (longer saccade latencies) in Go trials will be observed for emotional faces compared to neutral stimuli, but also for angry compared to happy faces (Manoli et al., 2020). We also anticipated that emotional faces be associated with more attentional hold on No-Go trials so that better inhibitory control (i.e., fewer commission errors) would be found for emotional faces compared to neutral stimuli. With regards to the participant group, we predicted that young people with ADHD would show attentional disengagement (increased omission errors and longer saccade latencies) in the presence of angry faces compared to young people with anxiety and TD children/adolescents (see Manoli et al., 2020; Weissman et al., 2012). We also predicted that disrupted attentional performance in young people with anxiety would manifest with faster saccade latencies in Go trials for angry compared to happy faces, indicating threat avoidance.

Furthermore, in this study, we acknowledge the prevalence of comorbidity between ADHD and externalizing disorders, as well as the co-occurrence of anxiety with Major

Depressive Disorder. Recognizing the potential impact of these comorbidities on our findings, we have included these symptoms as covariates in our analyses, to control for their influence.We anticipate that the severity of ODD, CD, and MDE symptoms may introduce variability in attentional and inhibitory control measures. For instance, higher symptom counts for ODD or CD may coincide with alterations in attentional processing and inhibitory control, while MDE symptomatology might introduce differences in these patterns, potentially leading to slower disengagement from emotional stimuli. By considering these covariates we can better elucidate the interplay between diagnostic categories and comorbid symptomatology, thus enhancing our understanding of attentional processing in youth.

In our study, we utilized an eye-movement go/no-go paradigm to investigate saccade latencies and saccadic accuracy in the attentional processing of facial emotional expressions and neutral, symbolic stimuli. This approach was selected due to its significant advantages over traditional behavioural reaction-time tasks in studying attentional processes. The eye-movement go/no-go paradigm offers a direct and objective measure of attentional engagement and disengagement, providing insights with higher precision and sensitivity compared to manual response-based tasks. It allows for the examination of immediate attentional shifts without the confounds of motor response delays, thereby offering a more accurate reflection of cognitive processing (Armstrong & Olatunji, 2012; Clauss et al., 2022). This method is particularly effective in reducing motor response artefacts and in capturing the dynamic nature of attentional shifts in real-time.

Material and Methods

Participants

Seventy-one (38 males) children and adolescents aged between 8-15 years old (*M* = 11.37, *SD* = 2.03) participated in this study. Participants were recruited from the community, primary and secondary schools. We recruited a subset of children and adolescents with a diagnosis of

ADHD via the South Hampshire ADHD Register (SHARe) at the University of Southampton. The SHARe is a clinical database for children and adolescents with ADHD living in the South Hampshire area and has been a source of well-characterised volunteer families for a number of neuroscience studies conducted in the School of Psychology at the University of Southampton. The SHARe steering group committee approved the recruitment process (through the SHARe database), for the current study.

All participants were screened for ADHD (including inattention, impulsive/hyperactive and combined subtypes) and/or anxiety disorder(s) (Specific Phobia (SP), Social Phobia (SoP), Separation Anxiety Disorder (SAD), Panic Disorder (PD) and Generalised Anxiety Disorder (GAD)) according to the Diagnostic Interview Schedule for Children (DISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Twenty-one participants (15 males) met the diagnostic criteria for ADHD (M_{Age} = 11.00, SD_{Age} = 2.12). Of those, 10 participants also met the criteria for at least one anxiety disorder. Twenty-one children and adolescents (9 males) met the criteria for at least one anxiety disorder (M_{Age} = 11.09, SD_{Age} = 1.64), and 29 (14 males) participants did not meet the criteria for either ADHD or any anxiety disorder (M_{Age} = 11.82, SD_{Age} =2.19). For the subgroup of children and adolescents with ADHD and anxiety, there were 6 males and 4 females. For those without anxiety, there were 9 males and 2 females. All participants had an estimated IQ score > 70, and a comparison of IQ, age and gender showed no significant group differences (Table 1).

<Table 1 about here>

Medication information was collected from a short demographics form that parents/guardians completed for children and adolescents prior to the day of testing. No participant was medicated with anxiolytic or long-acting psychostimulants, had severe learning difficulties, or had special educational needs. Children and adolescents who had been given a diagnosis of ADHD and who were being treated with short-acting stimulant medications were required to refrain from their medication 48 hours prior to the study. Estimated IQ score was measured using the block design and vocabulary check subscales of the Wechsler intelligence scale for children (WISC- IV; 4^{th} *Ed*, (Wechsler, 2003). Children and adolescents provided written assent to participate, and a parent or legal guardian provided written consent. Ethical approvals were obtained from the Research Ethics Committee of the School of Psychology, at the University of Southampton and the South-Central Berkshire Research –B Ethics Committee.

Measures

ADHD and Anxiety

The Diagnostic Interview Scale for Children—Fourth Edition (DISC-IV; Shaffer et al., 2000) is based on established diagnostic criteria. It was used to measure symptoms of ADHD and anxiety. This measure includes a parent-reported, structured diagnostic interview designed to identify clinically elevated symptoms in children and adolescents aged 6–17 years old. Most of the questions are recorded and coded as “yes” (1), “no” (0), “not applicable” (8), or “don’t know” (9). The DISC has moderate to good diagnostic reliability and validity for the parent interview (Schwab-Stone et al., 1996). Test-retest diagnostic reliability of the DISC-parent report for ADHD is 0.60 for and for any anxiety disorder 0.56 (κ- statistics).

Comorbid Symptoms

The Conners Comprehensive Behaviour Rating Scale-Parent (CBRS-P; (Conners, 2008) was used to assess co-occuring behavioural, emotional, academic and social challenges. The CBRS-P is a parent report that consists of 123 items designed for use parents of children and adolescents aged 6-18 years of age. Parents are asked to judge the frequency of behaviours on a 4-point Likert format (0 = never/seldom - 3 = very often/very frequently). In this study, we used the symptom count of the CBRS-P subscales to understand behaviours associated with Conduct Disorder (CD), Oppositional Defiant Disorder (ODD) and Major Depressive Episode (MDE).

Means and standard deviations of CBRS Symptom Counts can be found in the supplementary table S1.

Go/No-Go Task

Following Manoli et al., (2020) the eye-movement version of the Go/No-Go task (see *Figure 1*) was made up of four experimental blocks that included non-face stimuli (blue and orange squares) represented Go and No-Go cues) and facial emotional stimuli (happy and angry faces). Non-face and facial stimuli represented Go and No-Go trials that were each reversed between two blocks. Each experimental block consisted of 200 trials (80% Go trials and 20% No-Go trials presented in random order), with each block preceded by 15 practice trials (see (Manoli et al., 2020)).

Children and adolescents were asked to look at a central fixation cross presented at the centre of the screen (2000ms) and respond to Go cues as quickly as possible, with an eye movement towards a peripheral target (white square) and bring their eyes back to the centre after the central fixation cross appeared again. The target was presented either to the left or to the right side for 600ms. They were also asked to maintain central fixation in the presence of No-Go cues. A randomised inter-trial interval (ITI) of 1500 – 2500ms was added between the initial fixation cross and the target screen. An automatic recalibration was added every 25 trials throughout each block to minimise data loss due to the continuous presence of the trial sequences. Data visualisation indicated noise due to artefacts in the first trial after every automatic recalibration and thus it was removed from the dataset for all the participants.

The face stimuli (modelled by one male and one female) were taken from the NimStim face set (Tottenham et al., 2009). Eye movements were recorded using an EyeLink 1000 Plus Desk Mount eye-tracking system (SR Research Ltd) housed in a department research laboratory. The experiments were created and implemented using Experiment Builder software (SR Research Ltd.) and presented on a 23-inch monitor (1920 x 1080 resolution). The eye-movement data were extracted in the form of saccadic reports from the EyeLink Data Viewer software (SR Research Ltd).

<Figure 1 about here>

Power Analysis

A power analysis was conducted using Power Analysis for GEneral ANOVA designs (PANGEA; (Westfall, 2016) to determine the minimum sample size required to test the study hypothesis for the number of commission errors. Results indicated the required sample size to achieve at least 80% power for detecting a medium effect (d = .45), at a significance criterion of α = .05, was N = 36 for the interactive effects between cue condition and participant group that were set as fixed factors and participants (nested within participant group) and trials were set as random factors.

Data Analysis

We first examined differences in age and estimated IQ using Kruskal Wallis rank sum test and gender using a Chi-square test, among the ADHD, anxiety and TD control groups.

We performed linear mixed-effects (LME) models using the lmer function from the lme4 package (Bates et al., 2015) in R (R, Core Team, 2017) to examine the group differences in young people with ADHD, anxiety and TD controls on saccade onset latency in the presence of facial emotional expressions and non-face/neutral stimuli. The saccade onset latency was measured on correct Go trials, and it was defined as the time elapsed from the presentation of the Go cue until the first correct saccade landed in the interest area of the target. Saccade latencies below 80ms were excluded from the dataset. Saccade latencies were log-transformed to ensure normal distribution.

Generalised linear mixed-effects (gLME) models using the glmer function from the lme4 package in R were also used to examine group differences across facial and neutral stimuli in saccadic accuracy (saccadic error rates; binary variable: 1 = error, 0 = no error). Saccadic accuracy was measured via the number of (1) omission errors, defined as the number of misses (absence of a saccade when one is required) in the presence of Go cues, and (2) commission errors, defined as the number of incorrect saccades executed in the presence of No-Go cues.

The models included participant group (ADHD, anxiety, TD), and cue condition (happy face, angry face, and non-face stimuli) as fixed factors. Details of the participant group characteristics are provided in the Results section below. We also examined the effects of Age, Gender, estimated IQ and the possible comorbidities via a symptom count of the CBRS-P (Conners, 2008) ODD, CD and MDE that were added covariates in the models of the main analyses.

Age showed a significant negative association with saccadic omission errors ($\beta = -0.19$, SE =.06, $z = -3.32$, $p < .001$), indicating that younger children/adolescents were more likely to fail to move their eyes to the target in Go trials. Males made more omission errors than females ($\beta = -.77$, SE =.23, $z = -3.32$, $p < .001$). The symptom counts of ODD, CD, and MDE along with Estimated IQ did not have a significant effect on any of the outcome measures (*p's* > .05); hence, they were removed from the final analyses to enhance the parsimony of the models (see Supplementary Table S2). Participants and trial numbers were included as random factors in a maximal structure, with different intercepts and different slopes for the effect of cue condition and groups for the random effect of trial number. The models were trimmed in a top-down method until convergence (Barr et al., 2013). The random structure of the final model used for saccade latency, omission and commission errors included different intercepts and slopes for the cue condition for the random effect of participants and different intercepts and slopes for the cue condition and participant group for the effect of trials (no interaction between the slopes).

The models were adjusted for multiplicity using the “mvt” (i.e., multivariate t) adjustment from the emmeans package (Lenth, 2021) for all pairwise comparisons between Group and Cue condition in the models. Due to the characteristics of our participant group as a whole, we carried out additional exploratory analyses to examine attentional processing in ADHD participants with (n = 10) and without (n = 11) anxiety. Thus, we performed the same LME and gLME models for saccade latencies and errors, respectively, with the fixed factor of group (as a binary variable) split for ADHD with anxiety vs ADHD without anxiety.

Results

General Task Performance

Sacadde Latencies

We examined saccadic performance via saccade latencies, saccadic omission and commission errors to eccentric targets in response to centrally presented emotional (happy and angry faces) and non-face cues. We found a significant main effect of the emotional valence of the cues on all outcome measures. Considering saccade latencies, contrast comparisons showed that the emotional (angry and happy) faces were associated with longer saccade latencies to the target (i.e., slower attentional disengagement from face cues) compared to non-face cues. Angry faces were also associated with slower disengagement (i.e., longer latencies) compared to happy faces. Collectively the data indicate that centrally presented facial emotional Go cues were linked with slower responses than the processing of centrally presented non-face stimuli, and additionally disengagement was longer for angry compared with happy faces.

Saccadic Errors

Omission Errors. Saccadic omission errors were higher for emotional faces compared to neutral/non-face stimuli. However, the number of omission errors did not differ between happy and angry faces showing that although participants were slower to move their eyes away from angry (versus happy) face cues response accuracy was not affected by emotional face cue.

Commission Errors. Considering commission errors, as expected, the results showed that participants made more commission errors (i.e., failed to inhibit an eye-movement to the target) for central, non-face stimuli compared to both happy and angry faces. Commission errors were also significantly higher for happy compared to angry faces. Collectively, the results suggest that angry faces were more likely to hold attention compared to happy faces, which in the current task was reflected in increased inhibitory control (i.e., fewer commission errors) for angry compared to happy faces (see Tables 2 and 3).

<Table 2 about here>

<Table 3 about here>

Group Differences and Task Performance

We examined group differences (ADHD, Anxiety and TD) and their interactions with cue conditions (happy, angry faces and non-face stimuli) on saccade latencies, saccadic omission, and commission errors.

Saccade Latency

We found no significant main effect of group (ADHD, Anxiety, TD) on saccade latencies. However, we found a significant interaction between the participant group (i.e., the ADHD group vs. the anxiety group), and emotional faces (angry and happy). The pairwise comparisons showed that children with ADHD had longer saccade latencies for angry compared to happy faces indicating a slower attentional disengagement from angry compared to happy faces. In contrast, there was no difference in saccade onset latencies between angry and happy faces for children with anxiety (see *Figure* 2). In line with our predictions, children with ADHD showed slower processing of (i.e., increased time to disengage from) angry compared to happy faces. However, children with anxiety did not exhibit faster processing of negative stimuli, that is to say, we obtained no evidence to support avoidance in children with anxiety.

Further exploratory analyses aimed to determine whether anxiety might exert a modulatory influence on attentional effects in ADHD. We identified a sub-group of ADHD participants with anxiety (n=10) and contrasted their performance with a subgroup with ADHD (n=11). These analyses, with the ADHD group split between ADHD with vs those without anxiety, produced no significant effect of group, nor any robust interaction between group and cue condition, suggesting that children with ADHD and anxiety initiated saccades comparably rapidly relative to children solely with ADHD in relation to the emotional stimuli (see Tables 4 and 5).

<Table 4 about here>

<Table 5 about here>

<Figure 2 about here>

Saccadic Errors

Omission Errors. Our analysis of saccadic omission errors showed a numerical group effect whereby children with ADHD made more saccadic omission errors than TD children that approached significance, however, this tendency disappeared when multiplicity correction was adjusted (b = .52, SE =.30, z = 1.77, p =.18). There was no significant interaction between group and cue condition on saccadic omission errors (see Table 3).

Exploratory analyses in children with ADHD with and without anxiety produced a group effect that approached but did not achieve statistical significance. This numerical tendency was such that children solely with ADHD made more omission errors than children with ADHD and anxiety (b = .92, SE =.52, z = 1.77, p =.07). This finding is suggestive of the possibility that children with ADHD alone exhibit somewhat increased levels of inattention (i.e., more attentional lapses regardless of the emotional content of the stimuli) compared to children with ADHD and anxiety. No significant interactions between group (ADHD with anxiety vs ADHD without anxiety) and cue condition were found (Table 5), supporting a more generalised attentional deficit for ADHD regardless of the emotional valence of the stimuli.

Commission Errors. There was no significant effect of group (ADHD, Anxiety, TD) on inhibitory control as measured via saccadic commission errors. There was, however, a significant interaction between the group and cue condition. Pairwise comparisons showed that children with anxiety made fewer saccadic commission errors for angry compared to happy faces, indicating improved inhibitory control in response to angry (vs. happy) faces. In contrast, children with ADHD showed similar levels of inhibitory control for both happy and angry faces (*Figure* 3). The pattern of this interaction here showed that although processing efficiency and disengagement between angry and happy face cues did not differ in children with anxiety, inhibition for angry faces was associated with improved task performance, compared with the ADHD group, for which emotional faces similarly impacted inhibitory control. Also, children in the ADHD group made more commission errors, indicating reduced inhibitory control for non-face stimuli compared to happy faces relative to children in the anxiety group. No other contrasts were significant (see Table 3).

Exploratory analyses in the ADHD group showed no main effect on the group (ADHD with anxiety vs. ADHD without anxiety). The interaction between group and cue condition approached but did not achieve statistical significance. Pairwise comparisons showed that children with ADHD-only made more commission errors for neutral stimuli compared to angry faces, whereas children with ADHD and anxiety showed no difference in the number of saccadic errors between neutral and angry faces (see Table 5). This pattern is consistent with the suggestion that the presence of anxiety in ADHD might modulate inhibitory control in response to emotional (angry) stimuli.

<Figure 3 about here>

Discussion

This study examined attentional processing using centrally presented facial emotional expressions (angry and happy faces) and non-face/neutral cues in children and adolescents with

ADHD, anxiety, and typically developing controls. We focused on comparing indices of sustained attention via saccade latencies and saccadic omission errors, and inhibitory control via saccadic commission errors in a Go/No-Go eye movement task. The results showed that saccadic performance was modulated by the emotional valence of the stimuli, regardless of the participant diagnostic group. That is, attentional disengagement slower (i.e., time taken to make an eye movement from a Go cue to a target) and inhibitory control errors were fewer (i.e., inhibiting eye movements from a No-Go cue to a target) in response to centrally presented emotional face compared to neutral cues, and for angry compared to happy faces. Consistently, saccadic omission errors (a failure to make an eye movement from a Go cue to a target) were higher for emotional faces compared to neutral stimuli.

The interactive effects between the participant group and cue condition showed that children with ADHD (compared with those in the anxiety group) demonstrated slower attentional disengagement as reflected by longer saccade latencies angry compared to happy face cues. In contrast, children with anxiety showed no difference in attentional disengagement between happy and angry faces. Considering inhibitory control, children with ADHD showed inhibitory control difficulties for both angry and happy faces, and those with anxiety showed better inhibitory control in response to angry compared to happy faces. Exploratory analysis examined inhibitory control in children with ADHD with and without anxiety. The results indicated that comorbid anxiety and ADHD were associated with more inhibitory control difficulties for angry faces compared to neutral stimuli. This result suggests that children with ADHD who also experience elevated anxiety can be characterised by a distinct cognitive-affective processing profile compared to those with ADHD only or anxiety only.

Saccadic performance in children and adolescents was modulated by the presence of emotional stimuli. Slower attentional disengagement and more attentional lapses (i.e., omission errors) were found in response to centrally presented emotional faces compared to neutral stimuli. Angry faces were also associated with slower disengagement compared to happy faces. Inhibitory control (i.e., participants' ability to withhold reflexive saccades) was also modulated by the emotional valence of the central cues. Better inhibitory control was found for emotional compared to neutral stimuli, as well as for angry compared to happy faces. Collectively, these findings support the differential attentional processing between biological, socially relevant stimuli (i.e., emotional faces) and neutral/non-social stimuli, as well as between positive and negative stimuli. Research has argued that processing and responding to facial emotional expressions requires more attentional resources and involves specialized brain circuits associated with amygdala activation compared to processing neutral stimuli or faces (Pourtois et al., 2013; Vuilleumier, 2005). In addition, differences in the identification and processing of positive and negative stimuli have been previously demonstrated in a variety of studies (Kauschke et al., 2019; Nummenmaa & Calvo, 2015; Xu et al., 2021), with some studies showing more efficient processing toward positive stimuli and other studies demonstrating faster attentional processing for negative (vs positive) stimuli.

In the current study, emotional faces were employed as central cues to explore participants' voluntary control toward eccentric symbolic targets. They indicated that participants exhibited slower attentional disengagement from angry faces compared to happy faces during Go trials, and concurrently they demonstrated fewer saccadic commission errors for angry (vs happy) faces in No-Go trials. This pattern suggests that angry faces held attention more strongly than happy faces. In line with the current findings, a study that employed a visual search paradigm that involved searching for angry and happy face targets in crowds of angry, happy and neutral faces (Becker et al., 2019) found that angry-face crowds took longer to search through, compared to happy and neutral face crowds. However, no significant differences in the speed or accuracy for angry and happy target detections were found (Becker et al., 2019). In a second experiment Becker et al., (2019) used an exogenous cueing paradigm in which participants had to rapidly identify a central target (numbers 1 or 0) in the presence of distracting images (happy face, angry face or abstract art image) that appeared immediately before the target's onset. The results showed that angry faces held attention longer than happy faces or images of abstract art.

Becker et al.'s (2019) results support a disengagement difficulty for angry faces when these are task-irrelevant. Slower attentional disengagement in response to centrally presented negative compared to positive stimuli has also been demonstrated in tasks that employed both saccade latencies (Belopolsky et al., 2011) and manual responses (Fox et al., 2002). Furthermore, a recent study that examined differences between happy and angry faces in motor-response stop signal paradigm in sixty young adults found that task-irrelevant angry faces embedded in stop trials were associated with shorter stop signal reaction time compared to happy faces, suggesting better inhibitory control for angry faces (Gupta & Singh, 2021). Similar findings with emotional processing measured by saccade latencies and saccadic commission errors in response to emotional faces and neutral stimuli were previously found in a study that employed the same Go/No-Go paradigm in typically developing children/adolescents and adults (Manoli et al., 2020). Further evidence from children, adolescents and adults' performance on an eye-movement Remote Distractor Paradigm that used emotional facial expressions (happy, angry) and neutral faces as distractors to eccentric target (Pavlou et al., 2024), showed that there were more saccadic errors and slower saccade latencies in the presence of angry compared with neutral and happy face distractors. In this study, no difference was found between neutral and happy face distractors.

Collectively, these findings point towards a complex interplay between emotional valence, attentional capture, and cognitive processing. Negative emotions, particularly those signalling anger or threat, are prioritized by the attentional system, affecting both the speed and accuracy of cognitive tasks.

The slower disengagement from angry faces observed in ADHD aligns with the Deficient Emotional Self-Regulation (DESR's) proposition that individuals with ADHD may struggle with regulating emotions efficiently, which could manifest as a heightened sensitivity or attentional fixation to emotionally charged stimuli, particularly those with a negative valence such as anger (Barkley, 2015; Bunford et al., 2014; Faraone et al., 2019; Shushakova et al., 2018). This proposition is further supported by the Dual-Pathway (Sonuga-Barke, 2002, 2003), which posits that both motivational-emotional and cognitive-executive challenges are core to ADHD, suggesting that the emotional impulsivity (i.e., a tendency to respond rapidly and emotionally to stimuli without adequate processing) may contribute to the observed patterns of saccadic performance. The model's emphasis on two distinct but interactive pathways - the motivational-emotional and the cognitive-executive - provides a framework for understanding the complex interplay between emotional stimuli processing and attentional control mechanisms in ADHD.

In the current paper, the differentiated saccadic response patterns, particularly the increased attentional capture by angry faces and the specific challenges in inhibitory control, may reflect an imbalance or dysregulation within these pathways, where emotional stimuli disproportionately influence attentional processes and executive functioning. Furthermore, the exploratory findings regarding ADHD and comorbid anxiety suggest a potential modulation of these pathways, where anxiety may further impact the emotional regulation and attentional control mechanisms in ADHD, potentially leading to the observed distinct cognitive-affective processing profiles. These findings underscore the importance of considering emotional regulation and impulsivity mechanisms in understanding the cognitive and attentional challenges in ADHD and anxiety, supporting the relevance of integrating DESR and Dual-Pathway Models into the conceptualization and intervention strategies for these populations. Overall, these findings suggest areas for future research and require further attention.

Our hypothesis for the interactive effects between ADHD and anxiety for attentional processing in positive and negative faces was partly supported. As predicted, children and adolescents with ADHD and anxiety showed differential processing of positive and negative emotions (Manoli et al., 2020). Specifically, children and adolescents with ADHD showed slower attentional disengagement for angry than happy faces when compared to children with anxiety, whereas those with anxiety showed no differences in attentional processing between positive and negative facial stimuli. Manoli et al., (2020) found slower threat processing was for individuals with elevated subclinical ADHD symptoms. That paper further reported, however, that trait anxiety was previously associated with an attentional bias away from the threat as reflected via the shorter saccade latencies for targets for angry face cues. Further exploration of attentional disengagement in children with ADHD with and without anxiety, we found no differences between the two groups suggesting that the presence of anxiety in ADHD did not affect saccade latencies to emotional stimuli. Previous findings suggested that the role of anxiety in ADHD may be more pronounced in complex cognitive tasks involving inhibitory control and working memory rather than continuous performance tests (Jarrett et al., 2012; Tannock, 2009).

Indeed this was evident in the current data for saccadic commission errors, where inhibition of reflective saccades was required. Children with anxiety showed a better ability to withhold reflexive saccades when an angry face was presented at fixation compared to happy faces, whereas children with ADHD showed inhibitory control difficulties across both emotional cues. We suggest that angry faces were associated with a hold of attention for angry faces in children who met the diagnostic criteria for anxiety disorders and this may be the reason to account for the differences with previous findings showing faster latencies in elevated subclinical anxiety symptoms (Manoli et al. 2020). Higher attentional demands required in response to No-Go cues may be explained by the employment of additional attentional resources and increased effort to achieve task goals (Berggren & Derakshan, 2013; Eysenck et al., 2007).

Furthermore, disrupted emotional processing in ADHD has been previously well-documented (Dan, 2020; Karalunas et al., 2020b; Raz & Dan, 2015), supporting inhibitory control challenges for both angry and happy faces for ADHD. When we explored the pattern of inhibitory control in children with ADHD with and without anxiety, we found that the presence of anxiety in ADHD was associated with higher inhibitory control difficulties for angry compared to neutral faces, supporting the distinct pattern of performance for anxiety when this co-exists with ADHD.

Previous evidence from parent reports on the Behavioural Rating on Executive Function (BRIEF; (Gioia et al., 2010) questionnaire showed a distinct impaired inhibitory control symptom pattern (i.e., more severe problems with inhibitory control) in children with comorbid ADHD/anxiety compared to those with ADHD only and anxiety only (Sørensen et al., 2011). Other studies found that comorbidity between ADHD and anxiety was associated with reduced perceptual sensitivity in detecting emotional auditory stimuli particularly anger, when compared with children with anxiety-only or ADHD-only (K Manassis et al., 2000; Katharina Manassis et al., 2007). This finding supports previous evidence showing reduced low-level perceptual analysis and recognition of angry faces in adults with ADHD that were characterised by high self-rated levels of depression and anxiety compared to healthy controls (Williams et al., 2008). The authors suggested that these findings may contribute to negative mood and problems with emotion regulation in individuals with ADHD and anxiety. These findings together with the results of the current study suggest that young people with co-occurring ADHD/anxiety may be characterised by a unique pattern of reduced cognitive control in response to threat-related stimuli, which is different from either ADHD or anxiety alone.

Finally, numerical (but not statistically robust) effects were consistent with the suggestion that participants with ADHD had increased challenges with sustained attention, as reflected by numerically increased saccadic omission errors across all cue conditions when compared to TD children. Previous studies that have also employed an emotional Go/No-Go task showed similar evidence with higher omission errors regardless of the emotional valence of facial expressions in children with ADHD compared to healthy controls (Kochel et al., 2013). These findings may reflect excessive mind wandering that frequently characterises individuals with ADHD, during which unrelated thoughts interfere with task performance and promote distractibility (Seli et al., 2015). Increased distractibility in ADHD has been suggested to underlie difficulties with sufficient suppression of activity in the default attention network (DMN) during cognitive tasks (Fassbender et al., 2009; Sonuga-Barke & Castellanos, 2007).

Our exploratory analyses between children with ADHD with and without anxiety show that the presence of anxiety in ADHD was associated with numerically fewer saccadic omission errors compared to those with ADHD-only, consistent with previous evidence showing that anxiety has a moderating role in ADHD attention difficulties (Maric et al., 2018; Ruf et al., 2017).

Some potential limitations must be taken into consideration. First, our ADHD group comprised both children with ADHD only and children with ADHD and anxiety. The small sample size in ADHD with and without anxiety did not allow for a direct comparison across the four diagnostic groups. Even though our analyses were able to handle uneven group sample sizes well (Pinheiro, J. C., & Bates, 2000), larger sample sizes in these groups would have provided a more representative distribution of the population for further generalisability of the results. Replication of our exploratory analyses with a larger sample size would allow a direct comparison with children with anxiety only and TD controls would provide more robust effects of the pattern of results for individuals with comorbid ADHD and anxiety. Second, the study's ecological validity may have been compromised since the current findings were obtained in a lab-based experimental context (Holleman et al., 2020), and attentional processes in social situations may vary in 'real-world', naturalistic contexts (i.e., at school or home). Even though we have used images from real faces using eye-movement indices of attention that serve better ecological validity of facial processing than motor or other behavioural responses to these stimuli, other studies may benefit from using facial expressions that are dynamically manipulated and vary in intensity (Martin-Key et al., 2018). Also, beyond facial emotional expressions, stimuli that vary in intensity (highly or less aversive) should provide further information about attentional biases and interactions with cognitive control related to psychopathology.

Conclusions

Overall, the findings from the current study support the distinct pattern of attentional processes toward emotional stimuli between ADHD and anxiety, and their comorbid profile. The current study draws on the importance of considering emotional valence and socially relevant stimuli when examining cognitive control. Attentional bias towards negative stimuli (angry faces) was manifested in both ADHD and anxiety groups but with a different pattern. The presence of anxiety in ADHD was associated with a unique pattern of executive control in response to negative stimuli compared to that observed in children with ADHD only. Regardless of the emotional valence of stimuli, the presence of anxiety in ADHD may have a protective role in the general inattention deficits. Our findings emphasise the importance of considering and screening for co-occurring symptoms and behaviours related to executive functions and emotional processing in the assessment procedures used for ADHD and anxiety to ensure effective interventions. Further studies may consider exploring the cognitive control mechanisms in the ADHD/anxiety comorbidity in conjunction with emotion processing and regulation patterns related to ADHD and anxiety. Emotion dysregulation including difficulties regulating negative emotions, frustration discomfort and irritability are common features of ADHD and are associated with greater impairment levels both in young people and adults (Faraone et al., 2019).

Funding

This research project was funded by the University of Southampton's Vice-Chancellor Scholarship and the Solent NHS Trust.

Disclosure Statement

ESB has received speaker fees from Medici and Takeda and research funding from QBTech. No potential conflict of interest was reported by the other authors.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, [AM], upon reasonable request.

Acknowledgements: The study was undertaken at the Centre for Innovation in Mental Health-Developmental Laboratory and the Centre for Vision and Cognition, at the University of Southampton. The authors would like to thank all the participants and their families who kindly volunteered in this research.

References

Ahmed, S. P., Bittencourt-Hewitt, A., & Sebastian, C. L. (2015). Neurocognitive bases of emotion regulation development in adolescence. *Developmental Cognitive Neuroscience*, *15*, 11–25. https://doi.org/10.1016/J.DCN.2015.07.006

American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5). *Diagnostic and Statistical Manual of Mental Disorders 4th Edition TR.* https://doi.org/10.1176/appi.books.9780890425596.744053

Ansari Nasab, S., Panahi, S., Ghassemi, F., Jafari, S., Rajagopal, K., Ghosh, D., & Perc, M. (2022). Functional neuronal networks reveal emotional processing differences in children with ADHD. *Cognitive Neurodynamics*, *16*(1), 91–100. https://doi.org/10.1007/S11571-021-09699-6/TABLES/3

Armstrong, T., & Olatunji, B. O. (2012). Eye tracking of attention in the affective disorders: a meta-analytic review and synthesis. *Clinical Psychology Review*, *32*(8), 704–723. https://doi.org/10.1016/j.cpr.2012.09.004

Arnsten, A. F. T. (2009). The Emerging Neurobiology of Attention Deficit Hyperactivity Disorder: The Key Role of the Prefrontal Association Cortex. *The Journal of Pediatrics*, *154*(5), I. https://doi.org/10.1016/J.JPEDS.2009.01.018

Barkley, R. A. (2015). Emotional dysregulation is a core component of ADHD. In *Attention-deficit hyperactivity disorder: A handbook for diagnosis and treatment, 4th ed.* (pp. 81–115). The Guilford Press.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3). https://doi.org/10.1016/j.jml.2012.11.001

Barry, T. J., Vervliet, B., & Hermans, D. (2015). An integrative review of attention biases and their contribution to treatment for anxiety disorders. *Frontiers in Psychology*, *6*, 968. https://doi.org/10.3389/fpsyg.2015.00968

Becker, S. P., Langberg, J. M., Evans, S. W., Girio-Herrera, E., & Vaughn, A. J. (2015). Differentiating Anxiety and Depression in Relation to the Social Functioning of Young Adolescents With ADHD. *Journal of Clinical Child and Adolescent Psychology*, *44*(6), 1015–1029. https://doi.org/10.1080/15374416.2014.930689

Belopolsky, A. V., Devue, C., & Theeuwes, J. (2011). Angry faces hold the eyes. *Visual Cognition*, *19*(1), 27–36. https://doi.org/10.1080/13506285.2010.536186

Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety: why you see them and why you don't. *Biological Psychology*, *92*(3), 440–446. https://doi.org/10.1016/j.biopsycho.2012.03.007

Bowen, R., Chavira, D. A., Bailey, K., Stein, M. T., & Stein, M. B. (2008). Nature of anxiety comorbid with attention deficit hyperactivity disorder in children from a pediatric primary care setting. *Psychiatry Research*, *157*(1–3), 201–209. https://doi.org/10.1016/j.psychres.2004.12.015

Bunford, N., Evans, S. W., & Langberg, J. M. (2014). Emotion Dysregulation Is Associated With Social Impairment Among Young Adolescents With ADHD. *Https://Doi.Org/10.1177/1087054714527793*, *22*(1), 66–82. https://doi.org/10.1177/1087054714527793

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*(2), 203–216. https://doi.org/10.1016/j.cpr.2009.11.003

Clauss, K., Gorday, J. Y., & Bardeen, J. R. (2022). Eye tracking evidence of threat-related attentional bias in anxiety- and fear-related disorders: A systematic review and meta-analysis. *Clinical Psychology Review*, *93*, 102142. https://doi.org/10.1016/J.CPR.2022.102142

Conners, C. (2008). Conners 3rd edition: Manual. *Toronto, Ontario, Canada: Multi-Health Systems*.

Craske, M. G., Stein, M. B., Eley, T. C., Milad, M. R., Holmes, A., Rapee, R. M., & Wittchen, H. U. (2017). Anxiety disorders. *Nature Reviews Disease Primers 2017 3:1*, *3*(1), 1–19. https://doi.org/10.1038/nrdp.2017.24

Dan, O. (2020). Recognition of emotional facial expressions in adolescents with attention deficit/hyperactivity disorder. *Journal of Adolescence*, *82*(1), 1–10. https://doi.org/10.1016/J.ADOLESCENCE.2020.04.010

Dudeney, J., Sharpe, L., & Hunt, C. (2015). Attentional bias towards threatening stimuli in children with anxiety: A meta-analysis. *Clinical Psychology Review*, *40*, 66–75. https://doi.org/10.1016/j.cpr.2015.05.007

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Faraone, S. V., Bellgrove, M. A., Brikell, I., Cortese, S., Hartman, C. A., Hollis, C., Newcorn, J. H., Philipsen, A., Polanczyk, G. V., Rubia, K., Sibley, M. H., & Buitelaar, J. K. (2024). Attention-deficit/hyperactivity disorder. *Nature Reviews Disease Primers 2024 10:1*, *10*(1), 1–21. https://doi.org/10.1038/s41572-024-00495-0

Faraone, S. V, & Radonjic, N. V. (2023). Neurobiology of Attention Deficit Hyperactivity Disorder. *Tasman's Psychiatry*, 1–28. https://doi.org/10.1007/978-3-030-42825-9_33-1

Faraone, S. V., Rostain, A. L., Blader, J., Busch, B., Childress, A. C., Connor, D. F., & Newcorn, J. H. (2019). Practitioner Review: Emotional dysregulation in attention-deficit/hyperactivity disorder – implications for clinical recognition and intervention. *Journal of Child Psychology and Psychiatry*, *60*(2), 133–150. https://doi.org/10.1111/jcpp.12899

Fassbender, C., Zhang, H., Buzy, W. M., Cortes, C. R., Mizuiri, D., Beckett, L., & Schweitzer, J. B. (2009). A lack of default network suppression is linked to increased distractibility in ADHD. *Brain Research*, *1273*, 114–128. https://doi.org/10.1016/j.brainres.2009.02.070

Gin, K., Stewart, C., & Jolley, S. (2021). A systematic literature review of childhood externalizing psychopathology and later psychotic symptoms. *Clinical Psychology & Psychotherapy*, *28*(1), 56–78. https://doi.org/10.1002/CPP.2493

Gioia, G. A., Isquith, P. K., Guy, S. C., Kenworthy, L., & Baron, I. S. (2010). TEST REVIEW Behavior Rating Inventory of Executive Function. *Http://Dx.Doi.Org/10.1076/Chin.6.3.235.3152*, *6*(3), 235–238. https://doi.org/10.1076/CHIN.6.3.235.3152

Gupta, R., & Singh, J. P. (2021). Only irrelevant angry, but not happy, expressions facilitate the response inhibition. *Attention, Perception, and Psychophysics*, *83*(1), 114–121. https://doi.org/10.3758/S13414-020-02186-W/FIGURES/2

Holleman, G. A., Hooge, I. T. C., Kemner, C., & Hessels, R. S. (2020). The 'Real-World Approach' and Its Problems: A Critique of the Term Ecological Validity. *Frontiers in Psychology*, *11*, 721. https://doi.org/10.3389/fpsyg.2020.00721

Jakobi, B., Arias-Vasquez, A., Hermans, E., Vlaming, P., Buitelaar, J., Franke, B., Hoogman, M., & van Rooij, D. (2022). Neural Correlates of Reactive Aggression in Adult Attention-Deficit/Hyperactivity Disorder. *Frontiers in Psychiatry*, *13*. https://doi.org/10.3389/FPSYT.2022.840095/FULL

Jarrett, M. A., Wolff, J. C., Davis, T. E., Cowart, M. J., & Ollendick, T. H. (2012). Characteristics of Children With ADHD and Comorbid Anxiety. *Journal of Attention Disorders*, *20*(7), 1087054712452914-. https://doi.org/10.1177/1087054712452914

Karalunas, S. L., Weigard, A., & Alperin, B. (2020a). Emotion-cognition interactions in ADHD: Increased early attention capture and weakened attentional control in emotional contexts. *Biological Psychiatry. Cognitive Neuroscience and Neuroimaging*, *5*(5), 520. https://doi.org/10.1016/J.BPSC.2019.12.021

Karalunas, S. L., Weigard, A., & Alperin, B. (2020b). Emotion–Cognition Interactions in Attention-Deficit/Hyperactivity Disorder: Increased Early Attention Capture and Weakened Attentional Control in Emotional Contexts. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *5*(5), 520–529. https://doi.org/10.1016/j.bpsc.2019.12.021

Katzman, M. A., Bilkey, T. S., Chokka, P. R., Fallu, A., & Klassen, L. J. (2017). Adult ADHD and comorbid disorders: clinical implications of a dimensional approach. *BMC Psychiatry*, *17*(1), 302. https://doi.org/10.1186/s12888-017-1463-3

Kauschke, C., Bahn, D., Vesker, M., & Schwarzer, G. (2019). The Role of Emotional Valence for the Processing of Facial and Verbal Stimuli-Positivity or Negativity Bias? *Frontiers in Psychology*, *10*(JULY). https://doi.org/10.3389/FPSYG.2019.01654

Kochel, A., Leutgeb, V., & Schienle, A. (2013). Disrupted Response Inhibition Toward Facial Anger Cues in Children With Attention-Deficit Hyperactivity Disorder (ADHD): An Event-Related Potential Study. *Journal of Child Neurology*, *29*(4), 459–468. https://doi.org/10.1177/0883073813476139

Lenth, R. V. (2021). *emmeans: Estimated Marginal Means, aka Least-Squares Means*. https://cran.r-project.org/package=emmeans

Manassis, K., Tannock, R., & Barbosa, J. (2000). Dichotic listening and response inhibition in children with comorbid anxiety disorders and ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*(9), 1152–1159. https://doi.org/10.1097/00004583-200009000-00015

Manassis, K., Tannock, R., Young, A., & Francis-John, S. (2007). Cognition in anxious children with attention deficit hyperactivity disorder: a comparison with clinical and normal children. *Behavioral and Brain Functions : BBF*, *3*(1), 4. https://doi.org/10.1186/1744-9081-3-4

Manoli, A., Liversedge, S. P., Sonuga-Barke, E. J., & Hadwin, J. A. (2020). The Differential Effect of Anxiety and ADHD Symptoms on Inhibitory Control and Sustained Attention for Threat Stimuli: A Go/No-Go Eye-Movement Study. *Journal of Attention Disorders*, 108705472093080. https://doi.org/10.1177/1087054720930809

Maric, M., Bexkens, A., & Bögels, S. M. (2018). Is Clinical Anxiety a Risk or a Protective Factor for Executive Functioning in Youth with ADHD? A Meta-regression Analysis. *Clinical Child and Family Psychology Review*, *21*(3), 340–353. https://doi.org/10.1007/s10567-018-0255-8

Martin-Key, N. A., Graf, E. W., Adams, W. J., & Fairchild, G. (2018). Facial emotion recognition and eye movement behaviour in conduct disorder. *Journal of Child Psychology and Psychiatry*, *59*(3), 247–257. https://doi.org/10.1111/jcpp.12795

Merikangas, K. R., Nakamura, E. F., & Kessler, R. C. (2022). Epidemiology of mental disorders in children and adolescents. *Https://Doi.Org/10.31887/DCNS.2009.11.1/Krmerikangas*, *11*(1), 7–20. https://doi.org/10.31887/DCNS.2009.11.1/KRMERIKANGAS

Nummenmaa, L., & Calvo, M. G. (2015). Dissociation between recognition and detection advantage for facial expressions: a meta-analysis. *Emotion (Washington, D.C.)*, *15*(2), 243–256. https://doi.org/10.1037/EMO0000042

Pavlou, K., Benson, V., & Hadwin, J. A. (2016). Exploring Links between Neuroticism and Psychoticism Personality Traits, Attentional Biases to Threat and Friendship Quality in 9–11-year-olds. *Journal of Experimental Psychopathology*, *7*(3), jep.055316. https://doi.org/10.5127/jep.055316

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews Neuroscience*, *9*(2), 148–158. https://doi.org/10.1038/nrn2317

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166. https://doi.org/10.1016/j.tics.2009.01.006

Pinheiro, J. C., & Bates, D. M. (2000). Mixed-Effects Models in S and S-PLUS. In *Mixed-Effects Models in S and S-PLUS*. Springer-Verlag. https://doi.org/10.1007/b98882

Polanczyk, G. V., Salum, G. A., Sugaya, L. S., Caye, A., & Rohde, L. A. (2015). Annual research review: A meta-analysis of the worldwide prevalence of mental disorders in children and adolescents. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *56*(3), 345–365. https://doi.org/10.1111/JCPP.12381

Pourtois, G., Schettino, A., & Vuilleumier, P. (2013). Brain mechanisms for emotional influences on perception and attention: What is magic and what is not. *Biological Psychology*, *92*(3), 492–512. https://doi.org/10.1016/J.BIOPSYCHO.2012.02.007

Racine, N., McArthur, B. A., Cooke, J. E., Eirich, R., Zhu, J., & Madigan, S. (2021). Global Prevalence of Depressive and Anxiety Symptoms in Children and Adolescents During COVID-19: A Meta-analysis. *JAMA Pediatrics*, *175*(11), 1142–1150. https://doi.org/10.1001/JAMAPEDIATRICS.2021.2482

Raz, S., & Dan, O. (2015). Altered event-related potentials in adults with ADHD during emotional faces processing. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, *126*(3), 514–523. https://doi.org/10.1016/j.clinph.2014.06.023

Richards, H. J., Benson, V., Donnelly, N., & Hadwin, J. A. (2014). Exploring the function of selective attention and hypervigilance for threat in anxiety. *Clinical Psychology Review*, *34*(1), 1–13. https://doi.org/10.1016/j.cpr.2013.10.006

Richards, H. J., Benson, V., & Hadwin, J. A. (2012). The attentional processes underlying impaired inhibition of threat in anxiety: The remote distractor effect. *Cognition and Emotion*, *26*(5), 934–942. https://doi.org/10.1080/02699931.2011.630990

Rueda, M. R., Checa, P., & Rothbart, M. K. (2010). Contributions of Attentional Control to Socioemotional and Academic Development. *Https://Doi.Org/10.1080/10409289.2010.510055*, *21*(5), 744–764. https://doi.org/10.1080/10409289.2010.510055

Ruf, B. M., Bessette, K. L., Pearlson, G. D., & Stevens, M. C. (2017). Effect of trait anxiety on cognitive test performance in adolescents with and without attention-deficit/hyperactivity disorder. *Journal of Clinical and Experimental Neuropsychology*, *39*(5), 434–448. https://doi.org/10.1080/13803395.2016.1232373

Sacco, R., Camilleri, N., Eberhardt, J., Umla-Runge, K., & Newbury-Birch, D. (2022). A systematic review and meta-analysis on the prevalence of mental disorders among children and adolescents in Europe. *European Child and Adolescent Psychiatry*, *1*, 1–18. https://doi.org/10.1007/S00787-022-02131-2/METRICS

Salari, N., Ghasemi, H., Abdoli, N., Rahmani, A., Shiri, M. H., Hashemian, A. H., Akbari, H., & Mohammadi, M. (2023). The global prevalence of ADHD in children and adolescents: a systematic review and meta-analysis. *Italian Journal of Pediatrics 2023 49:1*, *49*(1), 1–12. https://doi.org/10.1186/S13052-023-01456-1

Sciberras, E., Lycett, K., Efron, D., Mensah, FK. F., Gerner, B., Hiscock, H., Gillberg, C., Gillberg, IC., Rasmussen, P., Jensen, PS., Martin, D., Cantwell, DP., Jarrett, MA., Ollendick, TH., Newcorn, JH., Halperin, JM., Jensen, PS., Pliszka, SR., Bowen, R., … Bixler, EO. (2014). Anxiety in children with attention-deficit/hyperactivity disorder. *Pediatrics*, *133*(5), 801–808. https://doi.org/10.1542/peds.2013-3686

Seli, P., Smallwood, J., Cheyne, J. A., & Smilek, D. (2015). On the relation of mind wandering and ADHD symptomatology. In *Psychonomic Bulletin and Review* (Vol. 22, Issue 3, pp. 629–636). Springer New York LLC. https://doi.org/10.3758/s13423-014-0793-0

Shin, L. M., & Liberzon, I. (2010). The Neurocircuitry of Fear, Stress, and Anxiety Disorders. *Neuropsychopharmacology*, *35*(1), 169. https://doi.org/10.1038/NPP.2009.83

Shushakova, A., Ohrmann, P., & Pedersen, A. (2018). Exploring deficient emotion regulation in adult ADHD: electrophysiological evidence. *European Archives of Psychiatry and Clinical Neuroscience*, *268*(4), 359–371. https://doi.org/10.1007/S00406-017-0826-6/METRICS

Sonuga-Barke, E. J. S. (2002). Psychological heterogeneity in AD/HD—a dual pathway model of behaviour and cognition. *Behavioural Brain Research*, *130*(1–2), 29–36. https://doi.org/10.1016/S0166-4328(01)00432-6

Sonuga-Barke, E. J. S. (2003). The dual pathway model of AD/HD: an elaboration of neuro-developmental characteristics. *Neuroscience & Biobehavioral Reviews*, *27*(7), 593–604. https://doi.org/10.1016/J.NEUBIOREV.2003.08.005

Sonuga-Barke, E. J. S., & Castellanos, F. X. (2007). Spontaneous attentional fluctuations in impaired states and pathological conditions: A neurobiological hypothesis. In *Neuroscience and Biobehavioral Reviews* (Vol. 31, Issue 7, pp. 977–986). Neurosci Biobehav Rev. https://doi.org/10.1016/j.neubiorev.2007.02.005

Sørensen, L., Plessen, K. J., Nicholas, J., & Lundervold, A. J. (2011). Is behavioral regulation in children with ADHD aggravated by comorbid anxiety disorder? *Journal of Attention Disorders*, *15*(1), 56–66. https://doi.org/10.1177/1087054709356931

Stirling, L. J., Eley, T. C., & Clark, D. M. (2006). Preliminary evidence for an association between social anxiety symptoms and avoidance of negative faces in school-age children. *Journal of Clinical Child and Adolescent Psychology*, *35*(3), 431–439. https://doi.org/10.1207/s15374424jccp3503_9

Tannock, R. (2009). ADHD with anxiety disorders. In T. E. Brown (Ed.), *ADHD Comorbidities: Handbook for ADHD Complications in Children and Adults* (p. 456). American Psychiatric Pub.

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B. J., & Nelson, C. (2009). The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Van Cauwenberge, V., Sonuga-Barke, E. J. S., Hoppenbrouwers, K., Van Leeuwen, K., & Wiersema, J. R. (2015). "Turning down the heat": Is poor performance of children with ADHD on tasks tapping "hot" emotional regulation caused by deficits in "cool" executive functions? *Research in Developmental Disabilities*, *47*, 199–207. https://doi.org/10.1016/J.RIDD.2015.09.012

Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–594. https://doi.org/10.1016/J.TICS.2005.10.011

Wechsler, D. (2003). Wechsler intelligence scale for children–Fourth Edition (WISC-IV). *San Antonio*.

Weissman, A. S., Chu, B. C., Reddy, L. A., & Mohlman, J. (2012). Attention Mechanisms in Children with Anxiety Disorders and in Children with Attention Deficit Hyperactivity

Disorder: Implications for Research and Practice. *Journal of Clinical Child and Adolescent Psychology*, *41*(2), 117–126. https://doi.org/10.1080/15374416.2012.651993

Westfall, J. (2016). *Running head : PANGEA PANGEA : Power ANalysis for GEneral Anova designs*.

Williams, L. M., Hermens, D. F., Palmer, D., Kohn, M., Clarke, S., Keage, H., Clark, C. R., & Gordon, E. (2008). Misinterpreting emotional expressions in attention-deficit/hyperactivity disorder: evidence for a neural marker and stimulant effects. *Biological Psychiatry*, *63*(10), 917–926. https://doi.org/10.1016/j.biopsych.2007.11.022

Xu, Q., Ye, C., Gu, S., Hu, Z., Lei, Y., Li, X., Huang, L., & Liu, Q. (2021). Negative and Positive Bias for Emotional Faces: Evidence from the Attention and Working Memory Paradigms. *Neural Plasticity*, *2021*. https://doi.org/10.1155/2021/8851066

Yarmolovsky, J., Szwarc, T., Schwartz, M., Tirosh, E., & Geva, R. (2017). Hot executive control and response to a stimulant in a double-blind randomized trial in children with ADHD. *European Archives of Psychiatry and Clinical Neuroscience*, *267*(1), 73–82. https://doi.org/10.1007/s00406-016-0683-8

Table 1

Sample Demographics and ANOVA test for Group Differences in Age and Estimated IQ.

		ADHD (*n*=21) *Mean (SD)*	**ANXIETY** (*n*=21) *Mean (SD)*	**TD** (*n*=29) *Mean (SD)*	***Kruskal Wallis*** χ^2	***p-value***
Age (years)		11.00 (2.12)	11.09 (1.64)	11.83 (2.19)	2.52	.28
Estimated IQ		103.81 (12.50)	105.00 (11.40)	109.00 (13.86)	1.40	.50
		n (%)	n (%)	n (%)	**Pearson's** χ^2	***p-value***
Gender	Males	15(.71)	9(.43)	14(.48)	4.99	.17
	Females	6(.28)	12(.57)	15(.52)		

Table 2

Means for Saccade Latency (ms) and Proportion of Omission and Commission Errors across Groups (ADHD, Anxiety, Controls).

	ADHD (n=21) *Mean (SD)*	**ANXIETY (n=21)** *Mean (SD)*	**TD (n=29)** *Mean (SD)*
Saccade latency			
Non-face	374.85 (157.58)	375.28 (149.17)	360.61 (141.27)
Angry face	486.88 (161.61)	476.70 (147.82)	481.93 (163.83)
Happy face	458.35 (160.38)	476.03 (151.52)	458.81 (155.93)
Omission errors			
Non-face	.08 (.28)	.06 (24)	.04 (.20)
Angry face	.18 (.38)	.13 (.34)	.10 (.30)
Happy face	.15 (.36)	.10 (.31)	.09 (.29)
Commission errors			
Non-face	.66 (.47)	.62 (.48)	.61 (.49)
Angry face	.50 (.50)	.41 (.49)	.44 (.50)
Happy face	.48 (.50)	.49 (.50)	.50 (.50)

Note. Standard deviations (SD) are shown in parentheses.

Table 3

LMEs and GLMEs for Participant Group, Cue Condition and Interactions on Saccade Latency and Accuracy.

		Saccade Latency				**Saccade Accuracy**							
		Hits				OE				CE			
		β	*SE*	*t*	*p*	*β*	*SE*	*z*	*p*	*β*	*SE*	*z*	*p*
Intercept		6.01	.02	345.23	**<.001**	-2.45	.15	-15.83	**<.001**	.06	.09	.70	.48
Gender													
Females vs Males		.03	.03	.88	.38	-.77	.23	-3.32	**<.001**	-.18	.18	-1.00	.32
Age						-.19	.06	-3.32	**<.001**				
Cue Condition													
Angry vs Happy		.04	.01	3.09	**<.01**	.10	.12	.88	.38	-.31	.13	-2.36	**<.05**
Happy vs non-face		.24	.01	17.41	**<.001**	.66	.09	7.01	**<.001**	-.67	.11	-5.96	**<.001**
Non-face vs Angry		-.29	.01	-20.34	**<.001**	-.76	.11	-7.10	**<.001**	.98	.12	8.34	**<.001**
Group													
ADHD vs TD		.02	.04	.40	.69	.32	.28	1.13	.26	.17	.22	.74	.46
ADHD vs ANX		-002	.04	.05	.96	.10	.29	.34	.74	.14	.25	.57	.57
ANX vs TD		.02	.04	.46	.65	-22	.27	-.80	.42	-.02	.22	-.07	.94
Cue Condition * Group													
Angry/ Happy	ADHD/TD	-.03	.03	-1.14	.26	-.11	.25	-.45	.65	-.32	.28	-1.12	.26
	ADHD/ANX	.07	.03	2.06	**<.05**	.09	.27	.35	.73	.64	.31	2.11	**<.05**
	ANX/TD	-.03	.03	-1.06	.29	.02	.25	.08	.94	-.33	.29	-1.15	.25
Happy/ non-face	ADHD/TD	.03	.03	1.01	.31	.24	.21	1.14	.26	.37	.23	1.58	.11
	ADHD/ANX	-04	.03	-1.22	.23	.12	.22	.53	.59	-.49	.25	-1.92	**.05**
	ANX/TD	.01	.03	.30	.77	-.36	.21	-1.47	.08	.12	.24	.51	.61
Non-face/Angry	ADHD/TD	.002	.03	.06	.95	-.13	.23	-.54	.59	-.05	.25	-.21	.83
	ADHD/ANX	-.02	.03	-.70	.48	-.21	.25	-.84	.40	-.15	.27	-.56	.57
	ANX/TD	.02	.03	.70	.49	.34	.24	1.42	.16	.21	.26	.82	.41

Note. Hits= correct saccades on Go trials; CE = commission errors; OE = omission errors; (β) = *beta*-coefficients; SE = standard errors of estimates

Table 4

Means for Saccade Latency (ms) and Proportion of Omission and Commission Errors for ADHD Group (with vs without Anxiety).

	ADHD-without anxiety (n=11) *Mean (SD)*	**ADHD with anxiety (n=10)** *Mean (SD)*
Saccade latency		
Non-face	388.45 (165.80)	361.57 (147.94)
Angry face	501.69 (167.33)	472.46 (155.05)
Happy face	470.10 (170.66)	447.05 (148.99)
Omission errors		
Non-face	.11 (.31)	.06 (.32)
Angry face	.24 (.43)	.11(.32)
Happy face	.21(.41)	.09 (.29)
Commission errors		
Non-face	.67 (.47)	.65 (.50)
Angry face	.45 (.50)	.55 (.50)
Happy face	.48 (.50)	.48 (.50)

Table 5

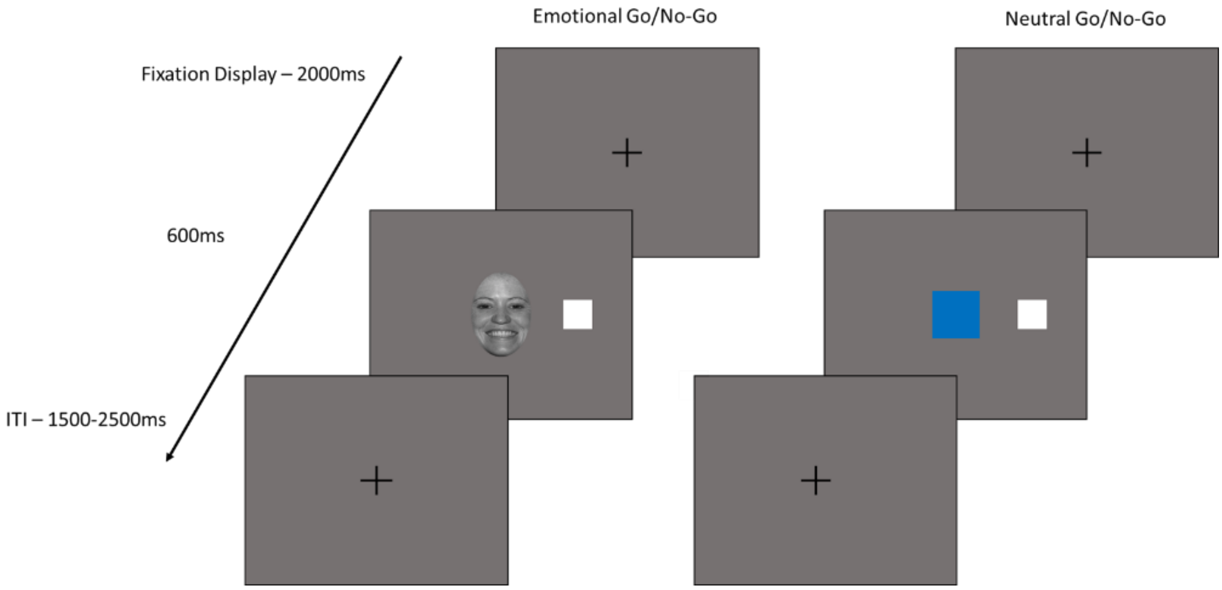
LMEs and GLMEs for ADHD Group (with vs without Anxiety), Cue Condition and Interactions on Saccade Latency and Accuracy.

	Saccade Latency				**Saccade Accuracy**							
	Hits				OE				CE			
	β	*SE*	*t*	*p*	*β*	*SE*	*z*	*p*	*β*	*SE*	*z*	*p*
Intercept	6.03	.04	146.62	**<.001**	-2.62	.33	-7.97	**<.001**	.29	.18	1.59	.11
Gender												
Females vs Males	-.002	.07	-.03	**.97**	.01	.69	.01	.99	.46	.32	1.43	.15
Cue Condition												
Angry vs Happy	.08	.03	2.54	**<.05**	.19	.20	.99	.32	.04	.28	.16	.87
Happy vs non-face	.22	.02	8.91	**<.001**	.59	.21	2.86	**<.01**	-1.10	.31	3.54	**<.001**
Non-face vs Angry	-.30	.03	-10.14	**<.001**	-.79	.21	-3.78	**<.001**	1.06	.30	3.49	**<.001**
Group												
ADHD-only vs ADHD/Anxiety	.05	.06	.75	.46	.92	.54	1.70	.09	-.01	.34	.02	.98
Group *Cue Condition												
Angry/Happy	.02	.06	.35	.73	-.13	.35	-.36	.72	-.76	.49	-1.54	.12
Happy/non-face	-.03	.05	-.59	.56	.24	.38	.62	.53	-.19	.56	-.35	.73
Non-face/Angry	.01	.06	.13	.90	-.11	.39	-.29	.77	.95	.56	1.68	.09

Note. Hits= correct saccades on Go trials; CE = commission errors; OE = omission errors; (β*)* = *beta*-coefficients; SE = standard errors of estimates

Figure 1

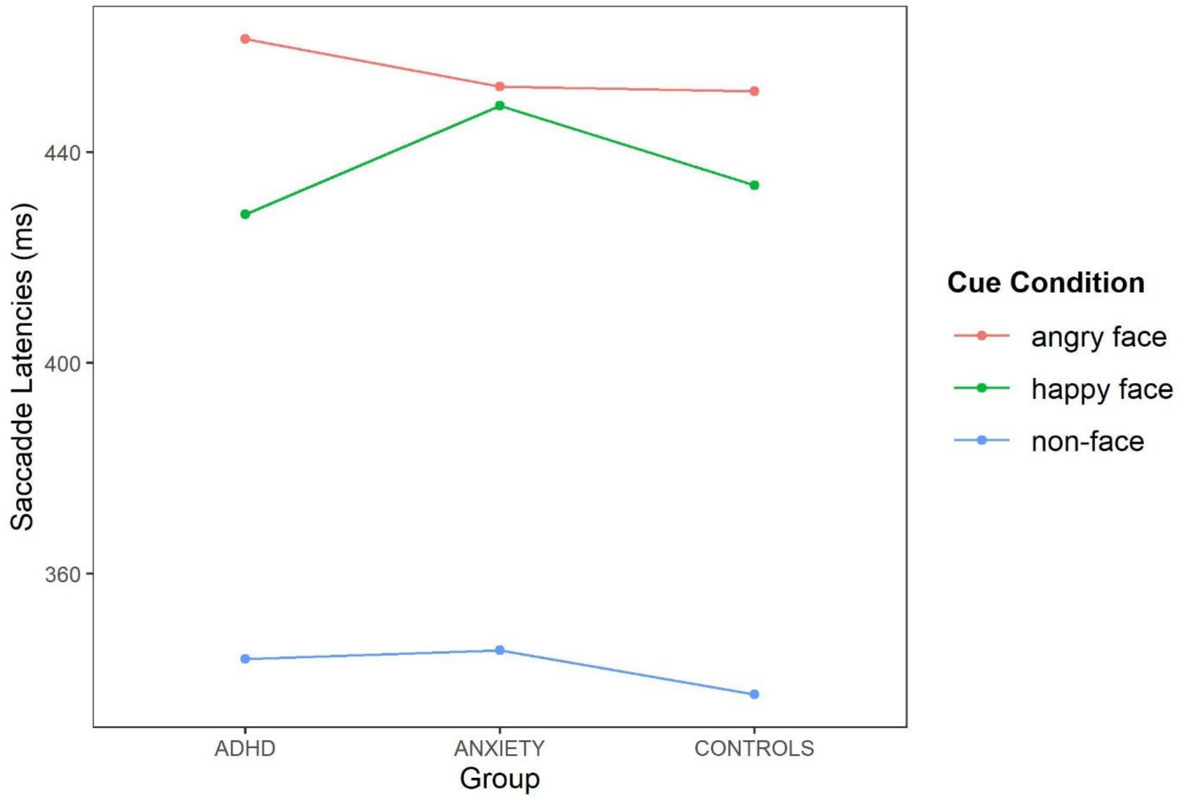
A trial sequence of the Go/No-Go task for face and non-face stimuli.



Note. The trial sequence here is represented by a happy face.

Figure 2

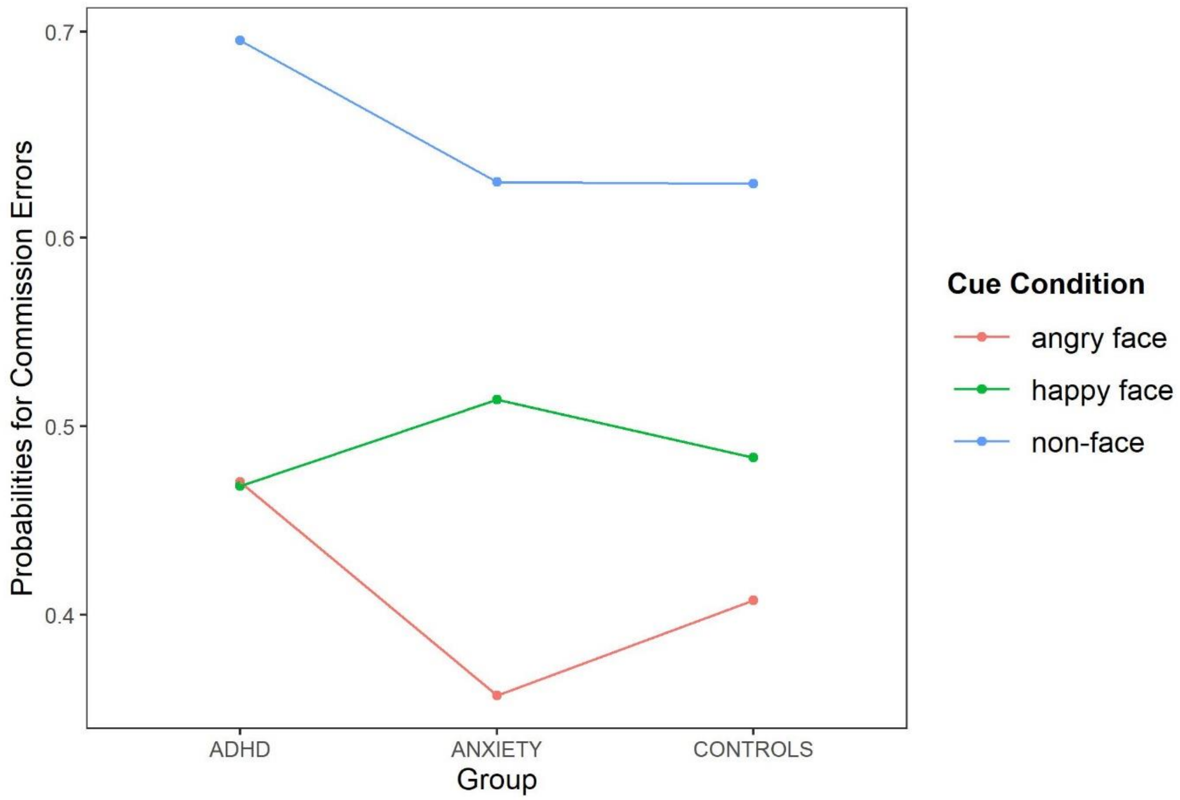
Interactive effects between Participant Group and Cue Condition on Saccade Latencies



Note. Significant interaction between ADHD and Anxiety groups with angry and happy face cues. The ADHD group showed longer saccade latencies for angry compared to happy faces, whereas the anxiety group showed similar saccade latencies for angry and happy face cues.

Figure 3

Interactive effects between Participant Group and Cue Condition on Probabilities for Saccadic Commission Error



Note. Significant interaction between ADHD and Anxiety groups with angry and happy face cues. The ADHD group similar number of saccadic commission errors for angry and happy faces, whereas the anxiety group showed fewer saccadic commission errors for angry compared to happy face cues.