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Dimensional associations between executive function processes and symptoms of ADHD, ASD, oppositional defiance and anxiety in young school-referred children

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ABSTRACT

Executive function (EF) difficulties are implicated in Neurodevelopmental Disorders (NDDs), such as Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD). Because NDDs are highly comorbid and frequently co-occur with additional clinical problems, it is unclear how specific EF problems are associated with symptoms of ASD and ADHD, whilst accounting for co-occurring anxiety or oppositional defiance disorder (ODD) symptoms. The current study utilised a large sample of young children ($n = 438$, aged 4–8) referred to Cardiff University's Neurodevelopment Assessment Unit (NDAU) by teachers for cognitive and/or socio-emotional problems. As part of the referral process, the teachers completed the Strengths and Difficulties Questionnaire (SDQ), which revealed that most children displayed moderate to high hyperactivity (86%) and prosocial (73%) problems, as well as high levels of symptoms in other clinical domains (41% emotional, 61% conduct and 68% peer problems). Children completed tasks to assess episodic memory, cognitive inhibition, cognitive flexibility and visuomotor control, whilst parents completed questionnaires to measure symptoms of ASD, ADHD, anxiety and ODD. Dimensional analyses showed that poorer cognitive inhibition and visuospatial episodic memory were significantly associated with ADHD symptoms, whereas cognitive flexibility was negatively associated with ODD symptoms. Having more ASD symptoms was associated with fewer cognitive inhibition problems, whereas anxiety was associated with better cognitive flexibility. Our approach to assessment and analysis shows that specific cognitive processes are associated with distinct neurodevelopmental and clinical symptoms, which is ultimately relevant to early identification of and intervention for young children at risk of cognitive and/or socio-emotional problems.

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1. Introduction

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

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

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

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

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

Research has also found that comorbid anxiety may mitigate some EF problems by increasing cortical arousal and alertness (Arnsten, 2009), but can worsen performance on more complex EF tasks (e.g., Castagna et al., 2019; Lawson et al., 2015). Attentional Control Theory (ACT; Eysenck et al., 2007) tries to explain these mixed findings by proposing that the effects of anxiety are moderated by the working memory demands of the task, arguing that worry affects task performance by pre-empting some processing and storage capacity of the working memory system. As a result, anxiety is detrimental under conditions of high working memory demand. Previous studies have shown that children with ADHD + ASD are at increased risk of both comorbid anxiety and ODD, which may coincide with more severe EF problems in a cumulative way (i.e., children with more comorbidities will have poorer EF abilities; Cooper et al., 2014; Haywood et al., 2021).

Because of the potential for cumulative and counteracting EF mechanisms in children with varying comorbid diagnoses, commonly used case–control studies are unable to detect specific associations between EF and individual symptoms of NDDs, ODD and anxiety. Further, the presence of co-occurring symptomatology may also alter cognitive processes at a subthreshold level (e.g., Carter Leno et al., 2018; de la Osa et al., 2019). The high co-occurrence between NDDs and additional clinical symptoms, as well as increasing evidence that NDD symptoms and co-occurring cognitive problems are dimensional traits which show no sudden change at the diagnostic boundary (Arildskov et al., 2022; Kim et al., 2019; Salum et al., 2014), has encouraged the adoption of a transdiagnostic and dimensional approach in studying NDDs and EF in young children (e.g., Astle & Fletcher-Watson, 2020; Griffith et al., 2019; Landis et al., 2021; Neely et al., 2016). A shift in focus from disorder categories to dimensional measures of important domains of functioning aligns with the Research Domain Criteria (RDoC) initiative, launched by the National Institute of Mental Health (NIMH), to help identify the underlying neuropsychological and biological mechanisms that are associated with clinical outcomes (Insel et al., 2010). In the study of EF, using an

RDoC approach to assessment and analysis will enable us to dimensionally account for co-occurring subthreshold symptoms and disentangle specific associations between EF processes and symptoms of NDDs, anxiety and ODD.

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

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

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

1.1. *Current study*

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

2. Materials and methods

2.1. *Transparency statement and preregistration*

Below, we report how we determined our sample size, inclusion/exclusion criteria, all data exclusions, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study. No part of the analyses reported in this study or the study procedures were preregistered before being conducted and no analysis code was used. The conditions of our ethics approval do not permit public archiving of anonymised study data. Readers seeking access to the data should contact the lead investigator (SvG) or the local ethics committee at the School of Psychology, Cardiff University. Access will be granted to named individuals in accordance with ethical procedures governing the reuse of sensitive data. Specifically, requestors must complete a formal data sharing agreement with the lead investigator. Legal copyright restrictions prevent public archiving of the measures and tasks used (SDQ, NIH Toolbox, ANT, Lucid Ability Test, CBCL, AQ, Hungry Donkey and BELT), which can be obtained from the copyright holders in the cited references.

2.2. *Participants*

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

2.3. Background information

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

2.4. Measures

2.4.1. Emotional and behavioural problems

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

2.5. Symptoms of ADHD, oppositional defiance disorder (ODD) and anxiety

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

2.6. Autism Spectrum Disorder (ASD) symptoms

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

2.7. Executive function

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

2.7.1. Cognitive flexibility

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

2.7.2. Cognitive inhibition

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

2.7.3. Visuomotor control

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

2.8. Other cognitive processes influencing executive function

2.8.1. Episodic memory

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

2.8.2. Verbal IQ

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

2.9. Procedure

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

2.10. Data analysis

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

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

To examine type and extent of EF problems in our sample we used age-standardised scores from the NIH Toolbox and

Table 1 – Prevalence of teacher reported SDQ problems in children with a moderate to high SDQ score ($n = 405$).

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

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

ANT-Pursuit to look at the proportion of children who scored 1 SD below the average.

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

3. Results

3.1. *Missing values*

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

3.2. *Preliminary analysis*

We examined associations between potential covariates (age, sex, verbal IQ) and symptom scores and EF variables (see Supplementary Tables 1 and 2). Verbal IQ was positively associated with performance on the DCCS and the Flanker. Girls performed better on the DCCS t (337) = −2.344, $p = .020$. Age was positively correlated with performance on all EF tasks as well as with severity of ADHD and anxiety symptoms. Girls were rated as having fewer ASD symptoms, t (353) = 2.516, $p = .012$. Because age was associated with ADHD and EF performance, age was controlled for when examining correlational associations between ADHD, anxiety, and EF. Sex was controlled for when examining correlational associations between autism symptom severity and cognitive flexibility. Age, sex and verbal IQ were controlled in all regression analyses.

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

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

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

We confirmed that the difficulties identified by teachers corresponded to symptoms of NDDs and additional clinical symptoms using correlational analyses (see Supplementary Table 3). Children who were identified by teachers as being at moderate to high risk of emotional and/or behavioural difficulties ($n = 405$) had more NDD symptoms, with over half

Table 2 – Prevalence of moderate to high risk (teacher SDQ) children who performed in the below average range on each EF assessment.

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

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

Table 3 – Bivariate Pearson correlations between symptom severity scores, executive function (EF) and memory assessments.

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

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

(n = 211, 52%) exceeding clinical cut-off scores on the questionnaires; ADHD (n = 56, 14%), ASD (n = 62, 15%) and ADHD + ASD (n = 93, 24%). ODD and Anxiety most frequently co-occurred with ADHD (ODD; n = 26, 6%) and ASD (Anxiety; n = 27, 7%), and rarely occurred independent of NDDs (2% and 4%, respectively).

3.5. *EF problems in the sample*

3.5.1. *EF difficulties in children with moderate to high risk of mental health problems*

Table 2 shows how children in the moderate to high risk group performed on our range of EF measures. We examined the proportion of children in each group who showed below average EF and memory performance relative to age-standardised norms. Our sample demonstrated difficulties across cognitive domains, with the greatest prevalence of below average performance found for visuomotor control (55%). To examine which dimensions of symptom severity were specifically associated with these EF and memory difficulties, further analyses were conducted using a dimensional approach.

3.6. *Dimensional associations between EF performance and disorder symptom severity scores*

Table 3 shows the correlations between EF performance and symptom severity scores for the full sample of children (n = 438). ADHD symptoms were significantly negatively associated with episodic memory and cognitive inhibition; anxiety was significantly positively associated with cognitive flexibility and visuomotor control.

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

Finally, multiple regression analyses examined to what extent different cognitive processes can predict severity of discrete clinical symptom dimensions (ADHD, ODD, ASD,

Table 4 – Summary of final step multiple regression analyses examining EF and memory assessments as predictors of disorder symptom severity, controlling for the presence of other symptoms, age, sex and verbal IQ.

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

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

Anxiety; see Table 4), whilst controlling for potential covariates (age, sex, verbal IQ), and the presence of other symptoms. Difficulties with episodic memory (ΔF (1,298) = 6.271, p = .013) and cognitive inhibition (ΔF (1,280) = 3.900, p = .049) were significant predictors of ADHD symptoms. Severity of anxiety symptoms was predicted by better cognitive flexibility (ΔF (1,289) = 7.992, p = .005), better cognitive inhibition predicted ASD severity (ΔF (1,280) = 4.402, p = .037), and poorer cognitive flexibility predicted ODD severity (ΔF (1,289) = 7.006, p = . 009).

4. Discussion

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

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

4.1. *EF, memory and ADHD*

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

4.2. *EF and ODD*

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

4.3. *EF and ASD*

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

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

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

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

4.4. *EF and anxiety*

While some studies found that anxiety is associated with poorer cognitive flexibility (e.g., Godoy et al., 2021), we found a positive association between anxiety and performance on the cognitive flexibility task. This finding is broadly in line with research demonstrating that comorbid anxiety may reduce some EF difficulties in young children with ADHD symptoms by enhancing stimulus-focused attention, which compensates for under-arousal associated with ADHD symptoms (Anning et al., 2023; Arnsten, 2009). We found no associations between anxiety and other EF processes. These discrepancies may reflect the age of our sample: in contrast to NDDs, anxiety disorders typically emerge later in development (Beesdo et al., 2009), and are most likely to be expressed as fears about separation, as opposed to generalised or social anxiety disorder (e.g., Anning et al., 2023). Our non-specific assessment of anxiety may therefore reflect milder symptoms, which could be somewhat beneficial at this level of EF performance. Few of our children (6%) were referred by their teachers for 'pure' emotional problems and most who exhibited anxiety symptoms had difficulties in other areas (including ASD, ADHD), so our study may well have been underpowered to detect associations between 'pure' anxiety and EF. Finally, any effect of anxiety on cognitive functioning may become more prominent when a task involves multiple EF processes working simultaneously, placing greater demands on working memory systems (Eysenck et al., 2007).

4.5. *Implications*

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

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

4.6. *Strengths and limitations*

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

Turning to limitations, the current study did not examine how some clinical dimensions might moderate associations between NDD symptoms and EF. Previous research has indicated that comorbid additional clinical symptoms are associated with more severe cognitive problems, as is the case when attention problems are combined with emotional dysregulation and aggression symptoms (Blok et al., 2022). Because we found that ODD symptoms were independently associated with cognitive flexibility problems, our results suggests that ODD might strengthen the ADHD - EF association. However, while ODD may exacerbate EF difficulties in NDDs, the opposite may be true for anxiety, which was associated with less difficulty. Therefore, although some comorbidities might have enhancing moderating effects because they are associated with greater executive dysfunction, anxiety symptoms may diminish specific EF difficulties in NDDs (e.g., Anning et al., 2023; Castagna et al., 2019); however, examining these complex interactive and potential counteracting EF mechanisms was beyond the scope of our study.

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

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

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

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

5. Conclusions

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

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

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Author contributions statement

Kate Anning: Investigation Conceptualisation, Formal Analysis, Data Curation, Writing – Original Draft. Kate Langley: Investigation. Writing-Reviewing and Editing. Chris Hobson: Investigation. Writing – Reviewing and Editing. Stephanie Van Goozen: Investigation. Conceptualisation. Supervision. Writing – Reviewing and Editing. Project administration. Funding acquisition.

Data availability statement

The conditions of our ethics approval do not permit public archiving of anonymised study data. Readers seeking access to the data should contact the lead investigator (SvG) or the local ethics committee at the School of Psychology, Cardiff University. Access will be granted to named individuals in accordance with ethical procedures governing the reuse of sensitive data. Specifically, requestors must complete a formal data sharing agreement with the lead investigator.

Declaration of competing interest

The authors report no conflict of interest.

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Supplementary data

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