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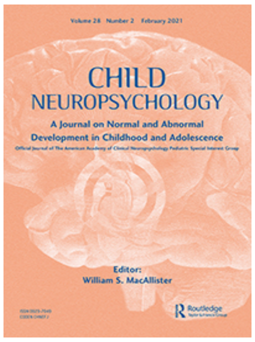

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Unique and overlapping contributions of sustained attention and working memory to parent and teacher ratings of inattentive behavior

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ABSTRACT

Sustained attention and working memory are two closely intertwined executive functions that may underlie inattentive behavior. However, little research has teased apart their precise contributions in a single study. This study examines the extent to which ratings of children's inattentive behavior are associated with these executive functions. Specifically, we investigated the unique and overlapping statistical contributions of sustained attention capacity and working memory capacity to parent and teacher ratings of inattentive behavior (operationalized as scores on both the Inattentive and Hyperactive/Impulsive scales of the Conners' Rating Scale), while controlling for IQ. Children aged 8–11 years completed measures of sustained attention capacity, working memory capacity and IQ. Parents and teachers completed Conners-3 Parent and Teacher Short Forms, as a measure of inattentive behavior. We found that the unique statistical contribution of sustained attention capacity emerged as the most important factor in both parent and teacher ratings of inattentive behavior, with effects of moderate magnitude. In contrast, working memory capacity accounted for a small amount of variance. The overlap between sustained attention and working memory explained a small but substantive amount of variance in inattentive behavior. These findings support the idea that sustained attention and working memory are distinct executive functions that may contribute to goal-directed behavior both uniquely and through their interactions.

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Sustained attention; working memory; executive function; inattentive behavior; ratings of behavior

In school, students are required to make use of different types of attentional behavior throughout the day. They must sit still, listen to the teacher, follow instructions, wait for turns and keep on task. These attentional behaviors have profound implications for students' learning and functioning in the classroom, and in the world in general. However, inattentive behavior is a relatively common problem, with as many as 24% of children exhibiting frequent inattention (Döpfner et al., 2008). The consequences of inattention are far-reaching and include academic (e.g., Lundervold et al., 2017),

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emotional (e.g., Klassen et al., 2004) and social (e.g., Bellanti & Bierman, 2000) problems. Deficits in the executive function system, particularly in sustained attention and working memory, are one possible cause of real-world inattentive behavior. This paper explores associations between these executive functions and child inattentive behavior.

Assessment of inattentive behavior

In clinical practice, children often present with inattentive and hyperactive behavior. Published guidelines (Pliszka & AACAP Work Group on Quality Issues, 2007) and prominent researchers (e.g., Barkley, 2014) argue for the use of behavior rating systems in the assessment of such behavior. There are several rating scales of inattentive behavior such as the Conners' Rating Scales (Conners, 2008), the Behavior Rating Inventory of Executive Function (Gioia et al., 2015), and the Strengths and Weaknesses of ADHD and Normal Behavior (Swanson et al., 2006). Although this is only a sample of available rating scales, these measures share the same general characteristics (Toplak et al., 2013). Typically, individuals close to the child or the child themselves rate the frequency with which inattentive behavior occurs. Rating scales provide an ecologically valid means of evaluating behavior in everyday situations and practitioners use rating scale information to inform intervention design (Toplak et al., 2013).

Potential causes of inattentive behavior

There are several theorized causes of inattentive behavior. Recent research suggests that inattentive behavior is caused by the accumulation of many genetic and environmental risk factors (Faraone et al., 2021). In one review of the causes of inattentive behavior, Goodman and Poillion (1992) identified 38 potential causes giving rise to temporary or long-term inattentive behavior. Putative categories of causes included organic (e.g., genetics, brain damage), intellectual/developmental (e.g., educational deficits, immature language development), psychological (e.g., low self-image, frustration, anxiety), environmental (e.g., physical environment, learned behavior) and birth complications (e.g., low birth weight, perinatal/prenatal problems). Deficits in the executive function system are one possible cause of inattentive behavior. Indeed, many theoretical models for the etiology of inattentive behavior posit that inattentive behavior is the result of executive function deficits (e.g., Barkley, 1997; Diamond, 2005; Pennington & Ozonoff, 1996).

The executive function system refers to a collection of inter-related processes responsible for goal-directed behavior, which are associated with the prefrontal cortex (Friedman et al., 2006; Gioia et al., 2015). Many processes have been associated with the term executive function, including working memory, attention, inhibition, planning and shifting (Anderson, 2002). While numerous executive functions have been related to inattention, sustained attention and working memory are two executive functions that likely demonstrate the most potent connection with inattentive behavior (e.g., Chacko et al., 2014). This study examines the unique and overlapping statistical contributions of sustained attention capacity and working memory capacity to parent and teacher ratings of child inattentive behavior in a sample of typically developing children, while controlling for an estimate of IQ. IQ was used as a control variable in the analyses, as previous research has shown that when the effect of IQ is removed any statistically significant relationship between objective tests of attention/executive function and ratings of inattentive behavior may be reduced to non-significance (e.g., Mangeot et al., 2002).

Sustained attention and inattentive behavior

Sustained attention is the ability to continuously maintain focus and engagement to task goals over time, especially to relatively monotonous and repetitive tasks. Specifically, Robertson et al. (1997) defined sustained attention as "the ability to self-sustain mindful, conscious processing of stimuli whose repetitive, non-arousing qualities, would otherwise lead to habituation" (p. 747). This type of attention is an elementary attentional function thought to determine the efficacy of other types of attention (e.g., selective attention, divided attention) and other cognitive domains (e.g., learning, memory; Sarter et al., 2001). In school, many everyday classroom behaviors require attention to be maintained over some period to achieve task goals (e.g., reading a book, listening in class, completing written assignments). An individual's capacity to sustain attention is determined by a dynamic interplay between cognitive factors, motivational factors (e.g., intrinsic motivation), emotional factors (e.g., stress) and arousal factors (e.g., wakefulness; McAvinue et al., 2015). Impaired sustained attention can occur from a deficit in any one or a combination of these factors, which causes the individual to disengage from the task at hand and exhibit inattentive behavior (e.g., distraction by irrelevant stimuli).

Much of the evidence for the role of sustained attention in inattentive behavior comes from studies of individuals diagnosed with ADHD. Research has shown moderate-to-large sustained attention deficits in children with ADHD compared to typically developing children (Huang-Pollock et al., 2012; Willcutt et al., 2005). Despite the presence of sustained attention impairments in ADHD, studies that examine the relationship between sustained attention tasks and ratings of inattentive behavior have yielded inconsistent results, with some studies showing non-significant or weak correlations between the two measures (e.g., Alloway et al., 2009; Brocki & Bohlin, 2006; Naglieri et al., 2005; Tamm et al., 2018). These mixed results are likely due in part to the measurement of sustained attention. The majority of studies that examine the relationship between sustained attention tasks and rating scale measures of inattentive behavior in the child literature operationalize sustained attention using Continuous Performance Tests (CPT) such as the Conners' CPT. Variations of these tests exist, but many require participants to detect infrequent target stimuli among long sequences of non-target stimuli over 10–30 minutes. As these tests often demonstrate very weak correlations with rating scale measures of inattention, they may have limited utility/sensitivity in detecting real-world inattentive behavior (i.e., they have limited ecological validity).

However, other sustained attention tasks may demonstrate a more powerful association with real-world attentional behavior in children. One such task is the Sustained Attention to Response Task (SART). The SART requires participants to respond to every stimulus (numbers 1–9) but to withhold their response on the appearance of the number 3 (no-go target; Robertson et al., 1997). In the Fixed version of the task, the numbers 1 to 9 are presented in sequential ascending order, whereas in the Random SART the numbers 1 to 9 are presented in random order. An important claim of the SART is that it is significantly related to everyday lapses of attention such as those experienced by individuals with ADHD (Smilek et al., 2010). A recent study by Johnson et al. (2020) found some support for this assertion. The authors examined the association between the Fixed and Random versions of the SART and ratings of inattentive behavior in a sample of 44 primary school children with high and low symptoms of ADHD. They found that commission errors on both tasks were moderately to strongly correlated with parent and teacher ratings of inattention and hyperactivity, with Spearman's correlations ranging from .365 to .505 (except the correlation between commission errors on the Fixed task and parent inattention, $r = .288$, did not reach statistical significance). To our knowledge, this is the first study that examined the relationship between SART measures and ratings of child inattentive behavior. The findings suggest that the SART may be particularly sensitive in detecting everyday inattentive behavior in children. However, given the small sample size of this study, these findings warrant further exploration. The current study builds on this work by examining a larger sample of primary school children and delineating the unique and overlapping statistical contributions of sustained attention to children's inattentive behavior.

Working memory and inattentive behavior

In the literature, the term working memory has several definitions (Cowan, 2017). These include, among others, multicomponent working memory (Baddeley, 2000), attention-control working memory (Engle, 2002), and storage-and-processing working memory (Daneman & Carpenter, 1980). In this study, working memory is defined as a "multicomponent system that holds information temporarily and mediates its use in ongoing mental activities" (Cowan, 2017, p. 1160). Baddeley's seminal tripartite model underlies this definition. This model has received considerable empirical support and has been used extensively in ADHD research. In this model, working memory includes three distinct components that operate together: (a) the central executive, which is a control system of attentional capacity that oversees the manipulation of information in short-term memory; (b) the phonological loop (or phonological short-term memory), which is responsible for the time-limited storage of verbal information; and (c) the visuospatial sketchpad (or visuospatial short-term memory), which is responsible for the time-limited storage of visual and spatial information. Later, Baddeley (2000) revised the model and added a fourth component, the episodic buffer, which is responsible for the integration of information from the storage systems and long-term memory.

The various components of the working memory system can be assessed either together or separately (Baddeley & Hitch, 1974). Typically, the capacity of the storage components is assessed using simple span tasks which require the passive storage of information, while the capacity of the central executive is assessed using complex span tasks that require the simultaneous storage and processing of information. According to the multicomponent model, short-term storage is simply one part of a larger, multicomponent system (Baddeley & Hitch, 1974). This is in contrast with attention-control working memory (e.g., Engle, 2002), which equates working memory with attention-control processes and does not include passive storage (Cowan, 2017). Thus, a passive storage task is not considered a measure of working memory according to the attention-control definition but is according to the multicomponent definition (Cowan, 2017).

Weaknesses in the working memory system may give rise to inattentive behavior because of failure to maintain and update (a) task goals in working memory and (b) the intermediate products of ongoing mental activities necessary to achieve task goals in working memory, which may cause attention to shift away from task goals to other events (Holmes et al., 2014). Previous research has demonstrated links between working memory capacity and inattentive behavior. For example, children with poor working memory are described by teachers as being inattentive with short attention spans (Gathercole et al., 2006). In another study, Lui and Tannock (2007) found that working memory (a combined score of various verbal/visuospatial simple span and complex span tasks) predicted parent ratings of inattentive behavior (over and above age and gender) in a community sample of children 7–12 years. However, not all studies have consistently found support for these associations (e.g., Tamm et al., 2018). Further evidence for the role of working memory capacity in inattentive behavior comes from studies showing the presence of working memory deficits in children with attentional difficulties. Holmes et al. (2014) found that children with ADHD (combined presentation) had deficits in the central executive component and storage components of working memory compared to typically developing children matched for age. These findings are supported by meta-analytic evidence which suggests that children with ADHD show moderate-to-large impairments in the central executive, phonological storage, and visuospatial storage components of working memory (Martinussen et al., 2005).

Statistical contributions of sustained attention and working memory to inattentive behavior: Unique or common effects?

An important empirical question is whether sustained attention and working memory provide unique or overlapping contributions to the prediction of inattentive behavior. This is because sustained attention and working memory are closely intertwined executive functions. Both functions rely on similar neural substrates, with both functions related to increased activation in the prefrontal and parietal cortices (Eriksson et al., 2015; Robertson & Garavan, 2004). Previous research has shown strong to moderate positive correlations between working memory and sustained attention at both the task and latent level (e.g., McVay & Kane, 2012; Unsworth et al., 2014). Moreover, the ability to sustain attention to task goals and prevent lapses in sustained attention is an important contributor to scores on measures of working memory capacity. Mrazek et al. (2012) reported that self-reports of mind wandering were negatively related to performance on working memory complex span tasks (reading and operation span). In another study, Unsworth and Robison (2016) found that when participants reported more mind wandering their working memory performance (assessed using a change detection task) was worse compared to when they reported being on-task. In addition, individuals with poor working memory reported more mind wandering and lapses of attention than individuals with high working memory, and mind wandering was shown to make an independent contribution to working memory capacity. There is also evidence that sustained attention and working memory co-vary on a moment-to-moment basis. DeBettencourt et al. (2019) simultaneously monitored fluctuations in attention and working memory using a hybrid task that interleaved a sustained attention task and a whole report working memory task.

Attention fluctuations were measured using a CPT task and working memory assessed using a change detection task was probed based on of participants' attentional state (operationalized as the speed of response in the CPT task). The study found that fluctuations in sustained attention coincided with fluctuations in working memory performance. The authors concluded that sustained attention and working memory draw on a common cognitive resource that waxes and wanes. Taken together, the available evidence provides support for the close integration of these two cognitive abilities.

The current study

The present study aimed to investigate the precise statistical contributions of sustained attention capacity and working memory capacity to ratings of children's inattentive behavior using commonality analysis. Commonality analysis is useful for understanding complex associations and informing theory (Nimon, 2010), as it breaks down the variance accounted for by all the predictors in multiple regression into unique effects (i.e., variance unique to each predictor) and common effects (i.e., variance shared by each combination of predictors; Nimon & Oswald, 2013). This is important as to ascertain the relative importance of predictors for the outcome variable, it is necessary to, 1) establish a relationship between the predictors and the outcome and, 2) determine the degree to which the predictors, uniquely or in combination, share variance in the outcome (Seibold & McPhee, 1979). Several other statistical methods widely employed in the literature are unable to identify common variance among correlated predictors and, as a result, fail to detail the contribution related predictors make to the outcome. In this study, commonality analysis allowed us to delineate the relative statistical contribution of sustained attention and working memory to child inattentive behavior and thus offer a better understanding of whether these abilities provide unique or overlapping statistical contributions to inattentive and hyperactive behavior. Specifically, we examined the unique and overlapping statistical contributions of sustained attention capacity and working memory capacity to teacher and parent ratings of child inattentive behavior (operationalized as scores on the Inattention scale and Hyperactive/Impulsive scale of the Conners'), while controlling for an estimate of IQ. It is important to note that this study explores the statistical contributions sustained attention and working memory make to inattentive behavior in line with the theoretical view that weaknesses in these executive functions are a possible cause of inattentive behavior. However, the design of this study is correlational, thus it can only reveal associative and not causal relationships.

Method

Participants

One hundred and four third- and fourth-class students (53 females and 51 males), aged 8–11 years ($M = 9.60$, $SD = .64$) took part in the study. Students attended a public primary school in a suburb of an Irish city. Table 1 describes parent and teacher ratings of inattentive and hyperactive behavior in comparison to a normed referenced sample.

Table 1. Ratings of inattentive and hyperactive behavior.

T-score	Guideline	C 3-P(S) IN	C 3-P(S) HY/IM	C 3-T(S) IN	C 3-T(S) HY/IM
≥ 70	Very Elevated Score	15 (15%)	23 (23.2%)	12 (11.9%)	12 (11.9%)
65–69	Elevated Score	9 (9%)	6 (6.1%)	3 (3%)	5 (5%)
60–64	High Average Score	9 (9%)	7 (7.1%)	6 (5.9%)	4 (4%)
40–59	Average Score	67 (67%)	63 (63.6%)	80 (79.2%)	80 (79.2%)
< 40	Low Score				

The number of participants in each *T*-score classification is presented. *T*-score classifications are approximations and do not reflect absolute rules. C 3-P(S) = Conners 3-Parent Short Form, C 3-T(S) = Conners 3-Teacher Short Form, IN = inattention, HY/IM = hyperactivity/impulsivity.

Four students in the sample had been diagnosed with a neurodevelopmental disorder, as reported by parents (ADHD, $n = 1$; autism spectrum disorder, $n = 2$; dyslexia, $n = 1$). One child was receiving medication for ADHD (18 mg Concerta).

Procedure

The data reported in this study forms part of a larger dataset on the cognitive predictors of academic achievement. The study was granted ethical approval by the relevant university research ethics committee and was discussed in detail with school personnel before recruitment. Informed parental consent and participant assent were obtained from all participants before beginning testing. Three weeks before data collection, teachers distributed project information packs to students, which included informed consent/assent forms for parents and children, respectively. Students who returned signed consent forms to the teacher were eligible to take part. Students completed cognitive assessments individually in a single session with the first author. Testing took place in a quiet room in the school. After testing, students selected a small token for taking part (e.g., pencil, notebook). Parents and teachers completed the Conners-3 Parent and Teacher Short Forms, respectively.

Materials

Cognitive measures

Verbal IQ. The Similarities subtest of the WISC-V (Wechsler, 2014) measures verbal abstract reasoning and was used as a proxy for IQ. Abstract reasoning is regarded as a central part of intelligence which predicts various types of thinking, including visual-spatial reasoning (Hunt, (2011).. The Similarities subtest has a high g loading (Canivez et al., 2016) and has previously been used as a proxy for IQ in children (e.g., McAvinue et al., 2015). Participants were presented with pairs of words that represented common objects or concepts and were asked to describe how they were similar. Scores on each item varied from 0 to 2 depending on the degree of abstraction evident in the participant's response. Pertinent general categorization was awarded full credit. Raw scores were used for data analysis.

Working memory. Working memory was measured using the Digit Span subtest of the WISC-V (Wechsler, 2014). Participants listened to and subsequently repeated a string of numbers read out loud by the researcher in the same order (Forward Span task), reverse order (Backward Span task) and ascending order (Sequencing Span task). Raw scores (total number of correct trials) on all three tasks were summed to create a total score. The Forward task measures the storage component of verbal working memory, as the participant is required to immediately recall digit sequences. By contrast, the Backward Span task and Sequencing Span task measure the central executive of working memory, as the participant is required to recall the digits in reverse or ascending order (Alloway et al., 2004). This additional requirement places significant processing demands on the child (Alloway & Alloway, 2010). Some researchers posit that Digit Span Backward tasks assess short-term storage (e.g., Rosen & Engle, 1997); however, the more widespread view in the child literature is that Backward Span and Sequencing Span tasks rely on the central executive of working memory (Alloway et al., 2006).

Sustained attention. The Fixed SART (Manly et al., 2003; Robertson et al., 1997) assesses an individual's ability to self-sustain attention to a monotonous, repetitive task (Robertson et al., 1997). The numbers 1 to 9 were individually presented on screen in sequential ascending order (see, Figure 1 for task parameters). Participants were required to press the spacebar for every number (go-trial) but not to press for the number 3 (no-go trial). There were 225 trials in total, including 25 no-go trials (number 3) and 200 go-trials (all other numbers). The task took 5.4 minutes to complete. All participants completed 36 practice trials (32 go-trials and 4 no-go trials). The SART provides several measures of sustained attention. In this study, we combined errors of commission (i.e., the number of times a participant pressed for 3), errors of omission (i.e., the number of times a participant did not press for a go-trial number), and reaction time standard deviation to form a composite sustained attention score (i.e., measures were converted to z-scores and averaged). Sustained attention composite scores were reversed so that

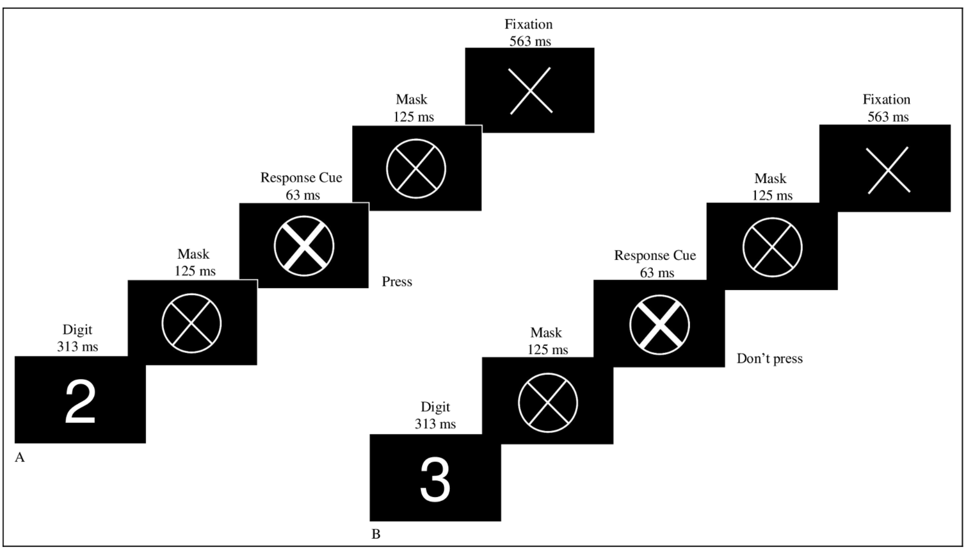

Figure 1. Graphic representation of a single Go/No-Go trial of the fixed SART.
(a) Go trial (1, 2, 4, 5, 6, 7, 8, 9). (b) No-go trial (3). Numbers appeared in white on a black background.

a higher score indicated better sustained attention. The task has previously been used to assess sustained attention in typically developing children (e.g., Lewis et al., 2017) and children with ADHD (e.g., McAvinue et al., 2015).

Behavioral measures

Inattentive behavior was measured using the Inattention subscale and Hyperactivity/Impulsivity subscale of the Conners-3 Parent and Teacher Short Forms. To supplement our analysis, the Learning Problems and Executive Functioning subscales were also included.

Inattentive behavior. The Conners-3 Parent/Teacher Short Form (Conners, 2008) is a questionnaire designed to assess ADHD symptoms and related issues. The questionnaires feature multiple scales. The scales we used to assess inattentive behavior included the inattentive scale and the hyperactive/impulsive scale. The learning problems (parent form only), executive functioning (parent form only) and learning problems/executive functioning (teacher form only) scales were also included. Parents/teachers rated items as not true at all (0), just a little true (1), pretty much true (2) and very much true (3). Raw scores on each scale were converted to T-scores (M = 50, SD = 10) standardized for age and gender.

Data analysis

We first investigated the relationship between the variables using bivariate correlational analyses. We then ran multiple regression analysis for each outcome variable (parent/teacher-rated inattention, parent/teacher-rated hyperactivity, parent-rated learning problems, parent-rated executive functioning, and teacher-rated learning problems/executive functioning) with IQ, working memory and sustained attention as the predictors. Visual and statistical methods were employed to investigate the assumptions of normality of residuals (Shapiro-Wilk test), influential cases (visual inspection of box plots, Cook's distance), linearity (Residual vs Fitted plot), independence of errors (Durbin-Watson test) and homoscedasticity (Goldfeld-Quandt test) prior to the main analysis.

Commonality analyses were used to assess the contribution of each predictor to the outcome variables. As previously outlined, commonality analysis partitions the R^2 explained by the predictors into unique and common effects (Nimon & Oswald, 2013). Figure 2 demonstrates the unique and common partitions for the current study. Commonality coefficients can be evaluated in terms of their magnitude (i.e., < 1% negligible, > 1% small, > 9% moderate, and > 25% large; Marchetti et al., 2018). Bootstrapped 95% confidence intervals (CIs) were calculated using percentile bootstrapping procedures (1000 bootstrap samples). Because unique partitions, unlike common partitions, are always positive and thus CIs containing zero are not possible this was done to quantify the precision of each partition rather than to test for statistical significance (Marchetti et al., 2018). Commonality analyses were conducted using the *R* package *yhat* 2.0–2 (Nimon et al., 2020).

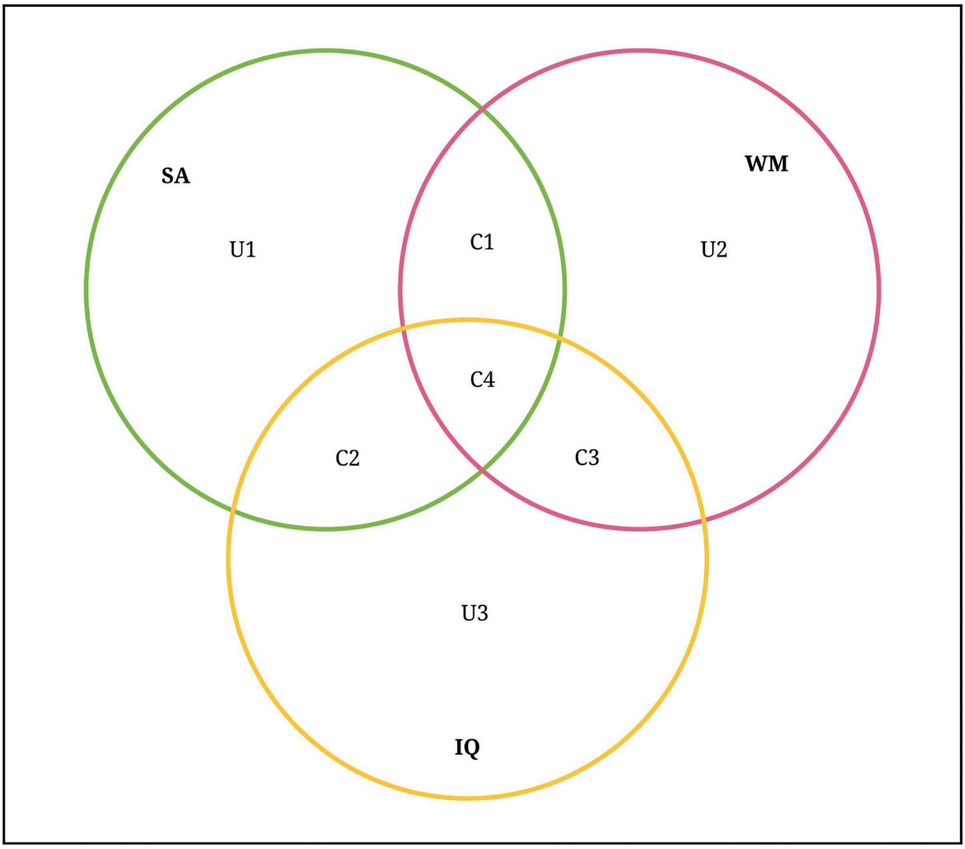

Figure 2. Commonality analysis in the current study.
SA = sustained attention, WM = working memory. Unique and common partitions comprise: unique variance in the outcome associated with sustained attention (U1), unique variance in the outcome associated with working memory (U2), unique variance in the outcome associated with IQ (U3), common variance in the outcome associated with sustained attention and working memory (C1), common variance in the outcome associated with sustained attention and IQ (C2), common variance in the outcome associated with working memory and IQ (C3), and common variance in the outcome associated with sustained attention, working memory and IQ (C4).

Results

Preliminary analyses

Preliminary analyses were undertaken to assess the distribution of study variables, identify outliers and assess the assumptions of multiple regression. Because commonality analysis decomposes the R^2 from multiple regression, violation of regression assumptions may impact the bias and precision of commonality coefficients (Ray-Mukherjee et al., 2014). A complete summary of preliminary analyses can be found in Appendix A.

Distribution and outliers

One cognitive variable, sustained attention, and all teacher- and parent-rated variables were not normally distributed (all *ps* < .05). We identified some outliers with regards to sustained attention, working memory and all teacher- and parent-rated variables except parent-rated hyperactivity. As such, robust tests are used where appropriate.

Assumptions of multiple regression

The assumption of homoscedasticity was violated for all teacher-rated models (all *ps* < .001). To adjust for heteroscedasticity in these regression models (teacher-rated inattention, teacher-rated hyperactivity, teacher-rated learning problems/executive functioning), we applied heteroscedasticity-consistent estimations of the covariance matrix of the coefficient estimates (using the Sandwich package; Zeileis, 2004; Zeileis et al., 2020). This correction computes robust standard errors for ordinary least squares estimators. The assumption of normality of residuals was violated for all models (all *ps* < .05) except for teacher-rated learning problems/executive functioning ($p = .167$). However, this was not viewed as problematic, as in larger samples (e.g., where the number of cases is > 10 per variable) violation of this assumption does not significantly impact regression results (Schmidt & Finan, 2018). All other multiple regression assumptions were met.

Descriptive statistics

Descriptive statistics and correlations for the predictor and outcome variables are presented in Tables 2 and 3, respectively.

Correlations between study variables

As several variables were not normally distributed and several outliers were identified, the more robust Spearman's correlations are reported (see, Table 3). IQ showed a weak-to-moderate negative association with parent-rated learning problems, teacher-rated inattention, and teacher-rated learning problems/executive functioning. Working memory showed a weak-to-moderate negative association with parent-rated inattention, parent-rated learning problems and all teacher-rated outcomes. Finally, sustained

Table 2. Descriptive statistics for cognitive and behavioral measures.

Variables	*n*	*M*	*SD*	*Min*	*Max*	*Mdn*
IQ	103	24.14	4.16	13	35	24
WM	104	24.65	5.08	12	44	24
Sustained attention	104	0.00	0.84	−2.6	1.05	.25
C 3-P(S) Inattention	100	56.27	13.71	40	90	53.5
C 3-P(S) Hyperactivity/Impulsivity	99	57.64	15.19	40	90	52
C 3-P(S) Learning Problems	100	51.06	10.35	41	90	48
C 3-P(S) EF	100	52.03	11.93	40	89	50
C 3-T(S) Inattention	101	52.82	11.95	41	90	49
C 3-T(S) Hyperactivity/Impulsivity	101	52.15	11.77	41	90	48
C 3-T(S) Learning Problems/EF	101	50.61	10.89	40	84	47

C 3-P(S) = Conners 3-Parent Short Form, C 3-T(S) = Conners 3-Teacher Short Form, EF = executive functioning.

Table 3. Spearman correlations between cognitive and behavioral measures.

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. IQ	-	.26**	.16	−.13	−.07	−.29**	.08	−.24*	−.15	−.36***
2. WM		-	.26**	−.23*	−.05	−.35***	−.12	−.36***	−.28**	−.47***
3. Sustained attention			-	−.36***	−.34**	−.35***	−.30**	−.37***	−.24*	−.41***
4. C 3-P(S) Inattention				-	.72***	.61***	.64***	.60***	.42***	.57***
5. C 3-P(S) Hyperactivity/ Impulsivity					-	.44***	.59***	.51***	.36***	.41***
6. C 3-P(S) Learning Problems						-	.42***	.50***	.29**	.62***
7. C 3-P(S) EF							-	.39***	.24*	.38***
8. C 3-T(S) Inattention								-	.73***	.85***
9. C 3-T(S) Hyperactivity/ Impulsivity									-	.52***
10. C 3-T(S) Learning Problems/ EF										-

C 3-P(S) = Conners 3-Parent Short Form, C 3-T(S) = Conners 3-Teacher Short Form, EF = executive functioning *p < .05, **p < .01, ***p < .001.

attention showed a weak-to-moderate negative association with all parent- and teacher-rated variables. Notably, all behavioral measures were positively correlated with each other with moderate-to-strong effect sizes.

Commonality results[1]

Regression and commonality results for parent- and teacher-rated outcome variables are presented in Tables 4 and 5, respectively. Figures 3 and 4 graphically represent the results of each commonality analysis .

Parent-rated inattention

Overall, the model explained 22.32% variance in parent ratings of inattention. Interestingly, the unique effect of sustained attention emerged as the most important predictor as its contribution was the largest (13.99% [2.7%, 29.2%]) with a moderate effect size. In contrast, the unique effect of working memory explained a very limited amount of variance in ratings (2.59% [0%, 12.5%]). The overlap between sustained attention and working memory accounted for a small amount of variance in ratings (3.93% [.1%, 10%]). None of the other unique or common effects explained any meaningful variance (all effects < 1%).

Parent-rated hyperactivity

IQ, sustained attention and working memory explained 18.9% of the variance in parent ratings of hyperactivity. Surprisingly, the unique effect of sustained attention was the only effect to meaningfully explain parent-rated hyperactivity (17.98% [4.1%, 33.8%]), with a moderate effect size. No other unique effects or common effects explained any substantial variance (all effects < 1%).

[1]To ensure that the models were not conflated by age we examined the correlations between age and our predictor variables. Neither sustained attention nor working memory demonstrated significant relations with age (both *ps* > .05); however, there was a significant relationship between IQ and age (r = .205, p = .037). All analyses were re-run with IQ scaled scores and the results were very similar (see Appendix B).

Table 4. Regression results for IQ, working memory and sustained attention as predictors of parent-rated outcome variables.

Predictor variables	R^2	R^2_{adj}	*b*	*SE b*	*β*	95% CI of *β*	Unique	Common	Total
Model 1: Parent IN	0.2232	0.1987							
Constant			71.893***	8.690					
IQ			−0.123	0.321	−0.037	−0.218, 0.150	.001	.017	.018
Working memory			−0.487	0.274	−0.175	−0.367, 0.035	.026	.056	.081
Sustained attention			−7.070***	1.709	−0.387	−0.568, −0.193	.140	.050	.189
Model 2: Parent HY/IM	0.189	0.1631							
Constant			58.070***	9.851					
Verbal IQ			−0.073	0.369	−0.019	−0.208, 0.157	.000	.003	.003
Working memory			0.083	0.312	0.027	−0.156, 0.221	.001	.008	.009
Sustained attention			−8.844***	1.938	−0.439	−0.625, −0.222	.180	.009	.188
Model 3: Parent LP	.3285	.3073							
Constant			75.499***	6.088					
Verbal IQ			−0.593**	0.225	−0.235	−0.407, −0.033	.049	.064	.113
Working memory			−0.385*	0.192	−0.184	−0.414, 0.010	.029	.101	.130
Sustained attention			−5.425***	1.197	−0.394	−0.534, −0.222	.145	.072	.217
Model 4: Parent EF	.1243	.0966							
Constant			47.886***	8.027					
Verbal IQ			0.441	0.296	0.151	−0.056, 0.356	.020	−.013	.007
Working memory			−0.250	0.253	−0.103	−0.311, 0.085	.009	.009	.018
Sustained attention			−4.893**	1.579	−0.308	−0.510, −0.087	.089	.013	.101

IN = inattention, HY/IM = hyperactivity/impulsivity, LP = learning problems, EF = executive functioning. *$p < .05$, **$p < .01$, *** $p < .001$.

Table 5. Regression results for IQ, working memory and sustained attention as predictors of teacher-rated outcome variables.

Predictor variables	R^2	R^2_{adj}	*b*	*SE b*	*β*	95% CI of *β*	Unique	Common	Total
Model 1: Teacher IN	0.3128	0.2913							
Constant			73.841**	7.541					
IQ			−0.386	0.264	−0.130	−0.286, 0.045	.015	.061	.076
Working memory			−0.475*	0.224	−0.197	−0.375, −0.022	.031	.117	.149
Sustained attention			−5.677**	1.628	−0.401	−0.574, −0.180	.138	.112	.250
Model 2: Teacher HY/IM	0.1875	0.1621							
Constant			62.045**	6.948					
Verbal IQ			0.144	0.294	0.049	−0.136, 0.238	.002	.005	.008
Working memory			−0.545*	0.270	−0.230	−0.429, −0.018	.042	.064	.106
Sustained attention			−4.283*	1.766	−0.307	−0.522, −0.079	.081	.064	.145
Model 3: Teacher LP/EF	.4511	.4339							
Constant			80.422**	7.206					
Verbal IQ			−0.666**	0.250	−0.247	−0.396, −0.071	.054	.116	.170
Working memory			−0.555*	0.213	−0.254	−0.441, −0.086	.052	.181	.233
Sustained attention			−5.282**	1.283	−0.410	−0.560, −0.231	.145	.161	.306

IN = inattention, HY/IM = hyperactivity/impulsivity, LP/EF = learning problems/executive functioning. *$p < .05$, **$p < .01$.

Teacher-rated inattention

IQ, sustained attention and working memory explained 31.28% of the variance in teacher ratings of inattention. Similar to parent ratings of inattention, the unique effect of sustained attention emerged as the strongest predictor since its contribution was the largest (13.83% [2.2%, 27.7%]), while the unique contribution of working memory was also relatively small (3.13% [.1%, 11%]). In this model, the common effect of sustained attention and working memory emerged as the second largest component (6.7% [1.3%, 14%]) and the common effect of all three predictors emerged as the third largest component though its contribution was limited (3.4% [.2%, 8.4%]).

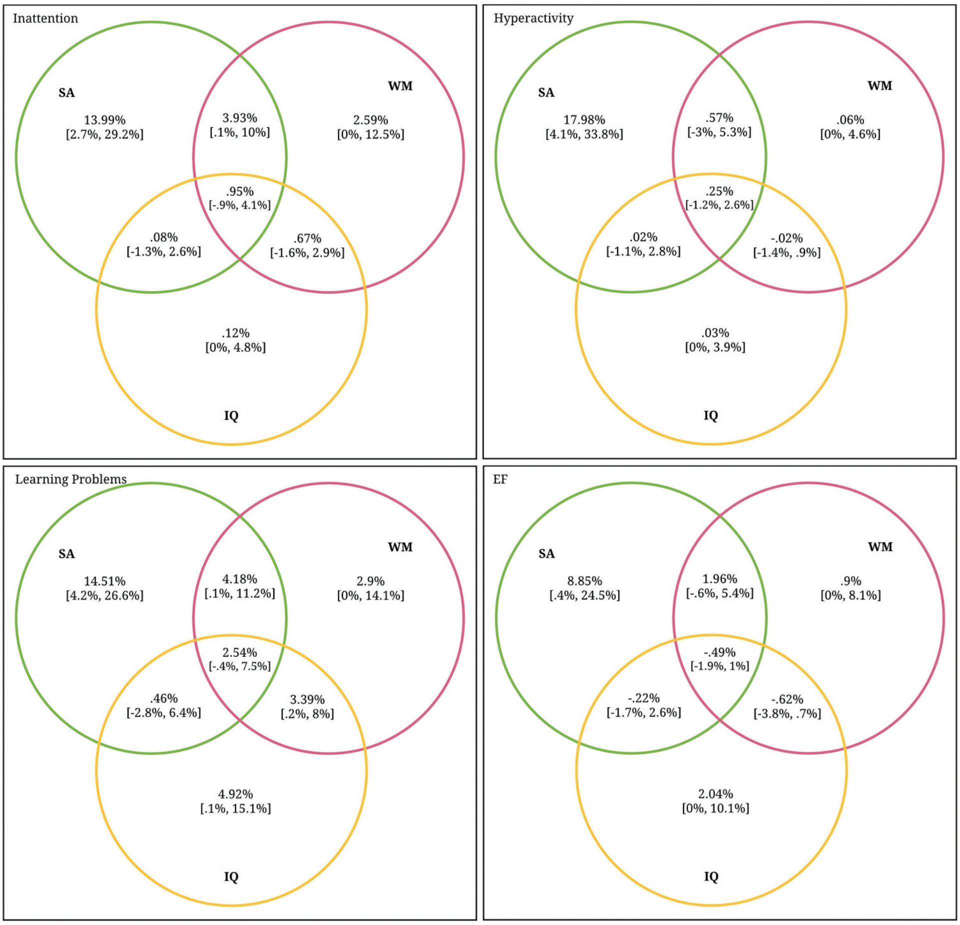

Figure 3. Commonality analyses with parent-rated behaviors as the outcome variables. SA = sustained attention, WM = working memory, EF = executive functioning.

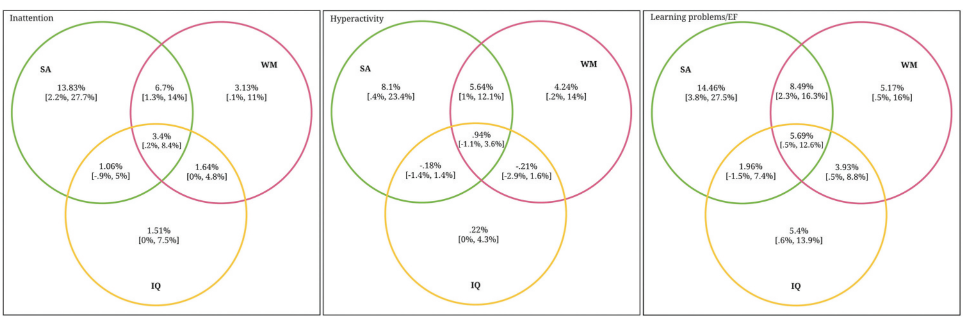

Figure 4. Commonality analyses with teacher-rated behaviors as the outcome variables. SA = sustained attention, WM = working memory, EF = executive functioning.

Teacher-rated hyperactivity/impulsivity

The model explained 18.75% of the variance in teacher ratings of hyperactivity. The unique effect of sustained attention (8.1% [.4%, 23.4%]), the unique effect of working memory (4.24% [.2%, 14%]) and the overlap between sustained attention and working memory (5.64% [1%, 12.1%]) all explained a small amount of variance in the outcome variable. None of the other effects explained meaningful variance (all commonality coefficients < 1%; see, Figure 4).

Supplementary analysis: Parent- and teacher-rated learning problems/executive functioning

The predictors accounted for 32.85% of the variance in parent-rated learning problems though explained considerably less variance in parent-rated executive functioning (12.43%). The unique effect of sustained attention explained the most variance in both models (14.51% [4.5%, 26.6%] and 8.85% [.4%, 24.5%], respectively). All other unique and common partitions explained a small or negligible proportion of the variance (see, Figures 3 and 4). With teacher-rated learning problems/executive functioning, the predictors accounted for a large amount of variance 45.11%. As was the case with all other outcome variables, the unique effect of sustained attention contributed the largest proportion of variance (14.46% [3.8%, 27.5%]), with a moderate effect size. Notably, the overlap between sustained attention and working memory also explained a moderate proportion of variance (8.49% [2.3%, 16.3%]).

Discussion

Working memory capacity and sustained attention capacity are two closely intertwined executive functions often thought to underlie inattentive behavior. This study examines the extent to which ratings of children's inattentive behavior are associated with these functions. Specifically, we examined the unique and overlapping statistical contributions of working memory capacity and sustained attention capacity to parent and teacher ratings of children's inattentive behavior, while controlling for IQ, using a novel analytical method, commonality analysis. Commonality analysis revealed a dominant role of sustained attention in uniquely accounting for inattentive and hyperactive behavior. This was true for both parent-rated and teacher-rated models of inattention and hyperactivity/impulsivity. Specifically, the unique contribution of sustained attention was the largest component explaining a moderate amount of variance in parent-rated inattention (13.99%), parent-rated hyperactivity (17.98%), teacher-rated inattention (13.83%) and teacher-rated hyperactivity (8.1%). By contrast, the unique contribution of working memory was lesser, accounting for a limited amount of variance in parent-rated inattention (2.59%), teacher-rated inattention (3.13%) and teacher-rated hyperactivity (4.24%), and no meaningful variance in parent-rated hyperactivity (0.6%). Interestingly, working memory mostly accounted for variance in inattentive behavior via common partitions (i.e., shared variance) with sustained attention (C1) and with all three predictors (C4). The overlapping contribution of sustained attention capacity and working memory capacity explained a small amount of variance in parent-rated inattention (3.93%), teacher-rated inattention (6.7%) and teacher-rated hyperactivity (5.64%). IQ did not contribute any meaningful unique or shared variance to ratings except for a small amount of variance in teacher-rated inattention (total common variance 6.1%). Notably, there was a lot of unexplained variance across all models.

Sustained attention and inattentive/hyperactive behavior

The findings of this study contrast with other studies, which report no substantive relationship between objective tests of sustained attention and ratings of inattentive behavior in children. For example, Alloway et al. (2009) found no significant association between sustained attention, assessed using the Conners' Kiddie CPT, and teacher ratings of inattentive and hyperactive/impulsive behavior on the Conners' Rating Scale in either children with ADHD or children with poor working memory. Another study on the relationship between intelligence, CPT, and behavior ratings, Naglieri et al. (2005) found no significant correlations between Conners' CPT scores and teacher/parent ratings on the Conners' Rating Scale in children referred for neuropsychological evaluation. A key difference between these studies and the present study is the operationalization of sustained attention. In this study, we used the Fixed SART to assess children's sustained attention abilities. The Fixed SART measures an individual's ability to self-sustain attention during a monotonous task while placing minimal demands on other cognitive processes such as working memory, inhibition, and planning (Robertson et al., 1997). Indeed, it is widely regarded as a pure measure of sustained attention (Manly et al., 2003). This is because it is an extremely simple and monotonous task due to the predictable occurrence of go and no-go targets, which lures the respondent into a pattern of automatic responding and so yields slips of sustained attention. The use of the Fixed SART likely contributed to our ability to detect an association between sustained attention and ratings of inattentive behavior. The results of the present study underscore the ecological validity of the SART in detecting real-world attentional behavior. Given these findings, we would like to echo the call of Johnson et al. (2020) for researchers to develop a normative sample of the SART for school-aged children. With norms, the SART, a short 5-minute test of sustained attention, would aid practitioners in the comprehensive assessment of child inattentive behavior alongside behavioral report, clinical interview, and direct observation.

Another potential reason for the weak or non-significant associations between tests of sustained attention and ratings of inattentive behavior often reported in the literature may be due to the sample of participants selected. That is, the majority of studies that examine the relationship between tests of sustained attention and rating scale measures of inattentive behavior select participants based on behavioral and/or attentional/EF deficits or disorders and are therefore likely to have a restricted range of measurement on both the attentional capacity and behavioral measures (Hunter et al., 2006). This restricted range may result in weak or non-significant correlations between tests of sustained attention and inattentive behavior. Participants in this study were a community-based sample and not preselected based on any neurological or behavioral condition; the sample was, therefore, less likely to have a restricted range on the independent and dependent variables. However, it is unclear whether the results of the current study would generalize to children diagnosed with ADHD or inattentive behavior. An interesting avenue for future research would be to examine if the same pattern of results is evident in such clinical samples.

Working memory and inattentive behavior

The finding that working memory capacity uniquely accounted for little substantive variance in child inattentive behavior is not surprising in light of some empirical research on the relationship between objective tests of working memory capacity and behavioral reports of attention (e.g., Tamm et al., 2018). However, these findings are surprising given the emphasis the literature places on the role of working memory in inattention. For example, some influential researchers in the field posit that the ADHD Inattentive subtype is due to a primary deficit in the central executive of working memory (e.g., the working memory theory of inattention; Diamond, 2005). The findings of the present study do not lend support to this contention. Importantly, through the use of commonality analysis in this study, we see that when the unique variance explained by working memory is pitted against the unique variance explained by sustained attention, sustained attention emerges as the more important component. This result emphasizes the importance of embedding sustained attention into current theoretical understandings of inattentive behavior.

In this study, we used a composite score from the Digit Span subtest of the WISC-V to operationalize the multi-component definition of working memory. This subtest includes a short-term storage component (Forward Span task). Some may suggest that this measure conflates working memory with short-term memory; however, according to the multi-component model any measure of short-term storage is considered a measure of working memory. To examine whether the results differed when the Forward Span task was removed from the working memory capacity composite score, we re-ran the analyses using a combined score from the Backward Span task and Sequencing Span task in all models (reported in Appendix C). Importantly, the same pattern of results found in our primary analyses was evident, which suggests that the limited unique role of working memory was not due to the inclusion of the Forward Span task in our working memory capacity measure.

Overlap between sustained attention and working memory

The primary aim of the study was to examine whether the contributions of sustained attention and working memory were unique or overlapping. Although they have been conceptualized as distinct entities, these functions have proven difficult to differentiate at a theoretical (e.g., Baddeley, 1992), empirical (Unsworth et al., 2004), and neural level (Eriksson et al., 2015; Robertson & Garavan, 2004). Commonality analysis indicated that the overlap between sustained attention and working memory explained a small but substantive amount of variance in parent ratings of inattention (3.93%) and teacher ratings of inattention (6.7%) and hyperactivity (5.64%). Though these values are of small magnitude, they accounted for a larger component contribution than that accounted for by the unique effect of working memory. The findings support the notion that sustained attention and working memory are distinct functions that may contribute to goal-directed behavior both uniquely and through their interactions. Future research examining the role of either cognitive function in child inattentive behavior should consider the common variance shared between these two constructs to ensure a better understanding of when they overlap and, equally important, when they do not.

Sustained attention, working memory and learning problems/executive function

To supplement our primary study aim, we also examined the contribution of sustained attention and working memory to parent and teacher ratings of learning problems and executive functioning. The unique component of sustained attention explained a moderate amount of variance (8.85–14.51%), the unique component of working memory explained a small amount of variance (0.9–5.17%) and the overlap between working memory and sustained attention explained a small-to-moderate amount of variance (1.96–8.49%) in parent and teacher ratings. These findings replicate the main results found in the commonality analyses of ratings of inattention and hyperactivity though IQ contributed somewhat more unique variance to ratings of learning problems and executive functioning (2.04–5.4%).

Limitations

These findings must be interpreted in the context of the study's potential limitations. First, this study explores the statistical contributions sustained attention and working memory make to inattentive behavior in line with the theoretical view that weaknesses in these executive functions are a possible cause of inattentive behavior. However, the design of this study is correlational, thus it can only reveal associative and not causal relationships. It should be noted when interpreting the results that empirical research is yet to determine the nature of the association between executive function and inattentive behavior. That is, whether executive function deficits (a) precede and are a possible causal risk factor for inattentive behavior, (b) follow and are a consequence of inattentive behavior, (c) are a correlate of inattentive behavior without paying a causal role in its development (Snyder et al., 2015). Second, because the data was collected in a school setting only one test of sustained attention, working memory and IQ was administered due to concerns about children missing class time. Multiple measures of each construct would have been preferable. For example, multiple measures of IQ that assess both verbal and non-verbal reasoning. Future research should use multiple measures of each construct. Third, we used a verbal working memory task to assess working memory capacity, which may have resulted in smaller associations between working memory and ratings of inattentive behavior. This is because children with attentional difficulties tend to have the largest deficits in visuospatial working memory with slightly smaller verbal working memory deficits compared to controls (Martinussen et al., 2005). However, the Digit Span subtest of the WISC is one of the most widely used measures of working memory in clinical settings (Kasper et al., 2012), thus ensuring the results of the present study are directly relevant for practitioners. Nonetheless, future research should endeavor to use tasks that assess both verbal and visuospatial working memory. Fourth, while parents were asked to provide details on children's special educational needs and diagnoses, we did not explicitly probe the presence of mental health conditions such as anxiety and depression. This would be important information for future studies to collect as inattentive behavior can sometimes occur, not due to deficits in cognitive systems per se, but due to emotional difficulties like anxiety or depression. Another avenue for future research related to this would be to examine the contributions of auditory sustained attention to ratings of inattentive behavior and any potential differences with visual sustained attention.

Conclusion

The current study investigated the extent to which ratings of inattentive behavior are associated with underlying executive functions, namely sustained attention and working memory. Specifically, we examined the unique and overlapping statistical contributions of sustained attention capacity and working memory capacity to ratings of child inattentive behavior, while controlling for IQ. Given the close relationship between these cognitive functions, commonality analysis was used to determine their precise statistical contributions to inattentive behavior. Commonality analysis offers insights into complex relationships between predictors with respect to an outcome. The unique contribution of sustained attention capacity emerged as the most important factor in ratings of inattentive behavior, with effects of moderate magnitude. In contrast, working memory capacity accounted for a small amount of variance. The overlap between sustained attention and working memory explained a small but substantive amount of variance in inattentive behavior. These findings are in keeping with the idea that sustained attention and working memory are distinct cognitive functions that may contribute to goal-directed behavior both independently and through their interactions.

Disclosure statement

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