Children with Sleep-Disordered Breathing and the Role of Attention in Executive Functioning Deficits

Gemma Golley

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School of Psychology
University of Adelaide
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Table of Contents

List of Figures

List of Tables

Abstract

Sleep-disordered breathing (SDB) is a common disorder found in children, with up to a third of children affected. SDB ranges from acute snoring to Obstructive Sleep Apnea (OSA), characterised by partial or complete cessation of airflow in the upper airway during sleep. Neurocognitive deficits as a result of SDB in children have been extensively examined, particularly in relation to executive functioning. However, these findings are inconsistent and it is possible that underlying attentional deficits in SDB are the cause of reported executive dysfunction, rather than these being a direct result of SDB. Using previously collected data, this study's focus is on whether attentional deficits play an underlying role in producing executive dysfunction. In the present study, children with SDB (18 males, 12 females, mean age, 8.30 ± 2.46 in years) and healthy matched control children (19 males, 21 females, mean age, 8.26 ± 2.15 in years) completed a battery of executive and attention tasks, as well as overnight monitoring of sleep. Despite deficits in planning ability and overall attention/executive performance amongst SDB children, there was no interaction between group and task (attention vs executive functioning), indicating that deficits in executive function are not likely the result of underlying attention problems. BMI z-score was a significant predictor of planning deficiency, alongside IQ to a lesser extent. This study offers a new perspective in the current conversation by expanding upon underlying mechanisms in children with SDB, and a deeper understanding on the individual characteristics that play a role in executive functioning deficits.

Keywords: SDB, executive functioning, attention, neurocognitive deficits

Declaration

This thesis contains no material which has been accepted for the award of any other degree of diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide’s digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time.

Contribution Statement

This thesis topic was generated with the help of my supervisor, along with designing a suitable methodology. My supervisor guided me through the steps needed to appropriately conduct the statistical analysis, and I completed all analyses and subsequent interpretations of the output. All aspects of this thesis were written by me. However, apart from the Statistical Analysis section, the Methods section was heavily relied upon my supervisor’s previous work.

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Thank you to the friends over the years and the deeply engaging talks that have led me to this point, to my last academic year (for now). I will never forget my time these past four years, or the people in them. Thank you for your collective kindness, I will continue to truly cherish it.

Lastly, I would like to appreciate my partner Daniel for keeping me grounded all year (and always). Thank you for believing I can achieve anything, even when I began to doubt it. But most importantly, thank you for encouraging me to engage in the things that bring me the most joy. If there is anything I have learned in all my years of study, it is that relaxing is a part of the process, too. Thank you for teaching me that.

CHAPTER 1 - Introduction

Sleep-disordered breathing (SDB) is a common disorder in children, with an estimated prevalence between 5-10% of children exhibiting mild symptoms, and 1-4% as clinically significant, with prevalence estimated as high as 34.5% across all severities (Bourke et al., 2011a). SDB exists on a continuum ranging from Primary Snoring (PS) to Obstructive Sleep Apnea (OSA). PS simply refers to frequent snoring without significant disruption to respiration, whereas OSA is characterised by repeated episodes of complete cessation of airflow (apnea) or decreases in airflow (hypopnea) during sleep (Verstraeten & Cludts, 2004a; Archbold et al., 2004). This disorder has been extensively researched throughout the community with neurocognitive deficits being commonly reported, particularly executive functioning deficits. Despite this, other studies have found no executive functioning deficits in children with SDB (Borges et al., 2013; Kohler et al., 2009; Calhoun et al, 2009; Jackman et al., 2012). To reduce these inconsistencies, theoretical models can be used to reinforce reliable methodological practices, leading to a deeper understanding on the SDB process. For instance, a classical model offered by Beebe and Gozal (2002) aids in the understanding of SDB. They state that short disruptions during sleep (sleep fragmentation) found in children with SDB, accompanied by apnea and hypopnea, impacts the brain’s cellular and biochemical function due to a lack of restorative processes that undisturbed sleep provides (Beebe & Gozal, 2002). Beebe and Gozal (2002) suggest the neurobiological disturbances influenced by SDB are predominantly located within the prefrontal cortex (PFC), labelled as ‘executive dysfunction’, or alternatively ‘executive functioning deficits’. These SDB-related events such as upper airway obstruction, and intermittent blood gas exchange abnormalities (such as hypoxia), are found to have serious consequences on physiological wellbeing, such as increased respiratory effort, which can lead to adverse health outcomes like hypertension, cardiovascular and cerebrovascular disease (Beebe & Gozal, 2002). As illustrated from Beebe and Gozal (2002), these physiological symptoms may affect the brain's ability to function optimally, and may be further exacerbated by the severity of SDB.

The apnea/hypoxemia index (AHI) is frequently used to assess SDB severity, assessing the frequency of obstructive upper airway events during sleep as a marker of both respiratory difficulties and sleep fragmentation (Archbold et al., 2004). Typically in children, experiencing one obstructive respiratory event per hour of sleep is sufficient to meet the clinical criteria for OSA (Youssef et al., 2011; American Thoracic Society, 1996). Interestingly, children with SDB more generally are not as severely impacted by the adverse health outcomes related to this condition compared to adults with the condition, (Youssef et al., 2011) possibly due to the duration of SDB symptomology.

In a study exploring SDB children's sleep architecture (Youssef et al., 2011), children with OSA had experienced greater levels in their apnea index, apnea duration, and the degree of blood oxygen desaturation levels during the Rapid Eye Movement (REM) stage of sleep in comparison to non-REM (NREM) stages. The frequency of events are typically highest in REM, followed by the lighter stages of NREM sleep, with the lowest level of apneas occurring in slow wave NREM sleep (SWS) (Goh et al, 2000). Similarly to children's sleep architecture, adults with SDB also experience a large proportion of obstructive apneas appearing most frequently in REM sleep, thus fragmenting REM sleep for both children and adult populations with SDB (Varga & Mokhlesi, 2019). The commonality of obstructive events during REM is considered to be more harmful than the apneas for non-REM sleep, as REM is associated with greater activity in the sympathetic nervous system and cardiovascular instability (Varga & Mokhlesi, 2019).

These outcomes found in REM could increase the likelihood of developing hypertension and other cardiovascular adversities (Varga & Mokhlesi, 2019), which is a common health risk for SDB.

The literature on SDB and NREM mainly report the irregularities of NREM density and its negative impact on neurobehavioural outcomes in SDB (Kheirandish-Gozal et al., 2007; Tal et al., 2003). In particular, Weichard et al. (2016) conducted a comprehensive investigation on NREM sleep in SDB children, where children with all severities of SDB displayed significant differences in the first and fourth NREM sleep periods when compared to their counterparts in the control group. A decrease in slow-wave activity at the end of the night was associated with a decrease in verbal Intelligence Quotient (IQ). It was suggested by the authors that this was due to the role slow-wave activity has in consolidating declarative memory. In addition, as children aged, slow-wave activity decreased over time (Weichard et al., 2016). Similarly in Shahveisi et al.’s (2018) study, a reduction in SWS was reported but only when paired with individual characteristics such as age and BMI. Indeed, in a study assessing these characteristics in elderly men, SWS reduction was considered a marker for adverse health outcomes, affecting neurocognition ability, metabolism and other bodily complications (Shahveisi et al., 2018).

These collated findings of both child and adult sleep architecture are similar in nature, with increased obstructive events occurring in REM, and a reduction in SWS. It appears that the health outcomes are more substantial for adults than in children. This is possibly from the effect on the sympathetic nervous system and hypertension found as a result of disruption to REM sleep, to a reduction in SWS having potential to affect neurocognition, and contributing to adverse physiological outcomes. It could be speculated that the duration, or perhaps the severity, of SDB is related to the cumulative outcomes reported, given the duration is likely much longer in adult populations. Particularly, in a longitudinal study of 10,701 adults with OSA, the risk of sudden cardiac arrest increased as OSA severity increased (Gami et al., 2013), suggesting higher risk for individuals with severe SDB.

Executive Functioning

As mentioned earlier, executive functioning is linked to the PFC (Beebe and Gozal, 2002), but alongside other supporting subcortical loops, which centre around goal-orientated processes (Brocki & Bohlin, 2010). These processes include inhibition, planning, and organisation, along with strategy development and persistence. The role of executive function within the brain is a complex one, as speculated by Norman and Shallice (1986), where two specific control-to-action components are what make executive functioning so vital for our functionality. The first is 'contention scheduling', which is expressed using schemas that trigger specific memories enabling execution of routine or familiar behaviours. Once a schema is activated, it remains so until its goal is achieved, or a more powerful schema overrides it. This is also simply called inhibition (Norman & Shallice, 1986). Without contention scheduling, children with executive functioning deficits may find it difficult to improve their ability to execute familiar behaviours and actions at the rate of their peers. Best et al. (2009) illustrates how behaviours can be affected by general executive functioning deficits, particularly that children can exhibit language and reasoning impairments, which results in a lowered writing ability impacting academic success. The second control-to-action component in this proposed model is the 'supervisory attentional system' (Norman & Shallice, 1986). This system is fundamental in situations that require planning, decision-making, impulses, overcoming powerful habitual responses (inhibition), error correction or troubleshooting, and lack of perception for dangerous and difficult circumstances. This is consequential for children that display executive functioning deficits as it may increase the likelihood of engaging in risk-taking behaviours and delinquency (Best et al., 2009).

Despite the thorough insights into executive functioning, there is no consensus on the exact definition of executive functioning within the community (Wasserman & Wasserman, 2013). There are, however, core components identified via factor analysis that help define executive functioning (Wasserman & Wasserman, 2013). These components include shifting, working memory, and inhibition. Shifting simply refers to shifting effectively between multiple mental tasks (attentional shifting) (Miyake et al., 2000). Norman and Shallice (1986) agree, illustrating that the ability to shift between tasks is an important mechanism in an individual's central executive control. Continuing, working memory, particularly the process of updating, refers to more than simply storing incoming information, but actively manipulating it for the most relevant task (Miyake et al., 2000). This highlights the executive control's ability for information accessibility, ready to be utilised for relevant tasks. Inhibition is the function of deliberately inhibiting automatic or powerful responses that are deemed inappropriate in particular environments (Miyake et al., 2000). Inhibition is especially an important aspect of executive functioning due to the ability to internally control one's responses and actions (Miyake et al., 2000), a core goal-oriented process. Inhibition also works to shift attention away from potential distractors, facilitating the foundation for selective and sustained attention (Diamond, 2006). From this knowledge, it is possible that executive functioning and attentional processes (selective and sustained attention) work together in order to achieve overall successful neurocognitive functioning. In addition to the three core components of shifting, working memory and inhibition, Anderson (2002) adds planning as an important component in executive functioning. Planning refers to the ability to plan actions in advance while strategically approaching problems with efficiency (Anderson, 2002). This inclusion was legitimised from factor-analytic studies where planning was a commonality in children's executive functioning (Wasserman & Wasserman, 2013; Anderson 2002). To support Anderson's (2002) claim, planning is a fundamental process in the supervisory attention system proposed by Norman and Shallice (1986), which highlights its broadly accepted involvement within the domain of executive functioning.

Executive Functioning and Behaviour

Executive functioning deficits are typically actualised in behaviours that affect success in social and academic settings. Social problems may include prejudice, social inappropriateness, depression, and gambling as children grow older, which has been linked to general executive functioning decline (Best et al., 2009). Problems in regulating inhibition may contribute to risk-taking behaviour, and an increase in susceptibility for advertisements in children and adolescents due to succumbing to desires and impulses (Best et al., 2009). This control and resistance of powerful impulses that children with neurocognitive deficits may struggle with supports the two control-to-action components by Norman and Shallice (1986), and Miyake et al.'s (2002) core components. Academically, poor working memory includes difficulty in retaining basic instructions, difficulty performing mathematical calculations mentally, poor reasoning abilities, and even poor language skills (Best et al., 2009). On a fundamental level, planning may present difficulties in completing school assignments effectively, whereas attentional deficits may be exhibited behaviourally in the form of passive concentration and lack of understanding in class.

Examination of the Literature Surrounding Executive Functioning

While there is debate surrounding the inconsistencies on the negative neurocognitive deficits in children with SDB (Borges et al., 2013; Kohler et al., 2009; Calhoun et al., 2009;

Jackman et al., 2012), there are substantial proportions of evidence to indicate these deficits are common. For instance, a meta-analysis found 25 studies that featured children with OSA exhibiting significant executive functioning deficits compared to healthy controls (Blechner & Williamson, 2016). Diving into specific executive functioning deficits, Archbold et al. (2004) reported low performance for the planning component in SDB children after a follow-up period of testing. Owens et al. (2000) also reported planning deficits specifically, with Xanthopoulous et al. (2015) reporting planning and inhibition deficits. Gottlieb et al. (2004) reported similar deficits in planning, yet interestingly, they separated planning from executive functioning, and claimed no executive functioning deficits. Similarly, in a review conducted by Krysta et al. (2017), they reported deficits in executive functioning and working memory separately. If a theoretical application were applied to either of these studies, inconsistency in methodology may have been avoided completely. Working memory deficits were reported from Lau et al. (2015), specifically for OSA children displaying poor performance on tasks relating to the basic storage and central executive components in verbal working memory. Halbower et al. (2006) reported similar findings in children with OSA who suffered a decline in verbal working memory. These reports all appear to occur in children with severe forms of SDB (OSA), which may explain why it is more heavily investigated than milder forms of SDB. That being said, a meta-analysis appraised SDB broadly and found no relationship with any executive functioning deficits for the objective measures it assessed, yet for parental questionnaire data children with SDB differed significantly from controls on all three executive functioning domains they assessed; inhibition, shifting, and working memory (Mietchen et al., 2016a).

Many subjective reports on executive dysfunction are measured using the BRIEF (Behaviour Rating Inventory of Executive Function), which is a parentally reported scale that measures child symptomatic behaviours of executive dysfunction (Bourke et al., 2011a). It is important to note there may be biases or even missing data for a parental report measure, but subjective data such as this enables a deeper understanding on a child's symptomology that a child may not be able to recognise. In addition, real-world context is essential to capture the holistic experiences these children live with, that includes questionnaire data rather than sole objective measures (Gioia et al., 2010). In fact, studies have found that children typically perform better on executive functioning domains in a clinical setting than on tasks that actively demand the attention and skills needed in the real-world (Gioia et al., 2010). Despite that, few solely subjective reports were found besides Bourke et al.'s (2011a) study, which reported executive functioning deficits for all severities of SDB in children, particularly working memory, shifting, and planning.

Attentional Deficits

A critical limitation of previous studies has been the lack of consideration for the interaction of executive functioning with attention in children with SDB. Attention underpins much of higher neurocognitive performance, and without it, it may be almost impossible to successfully function in a world with constant stimuli (Simon, 1986). Because of this, it seems sensible to assume that attention is related with higher neurocognitive functioning. In fact, a majority of the studies mentioned above found attentional deficits in addition to executive functioning deficits in SDB children (Blechner & Williamson, 2016; Lau et al., 2015; Xanthopoulous et al., 2015; Krysta et al., 2017; Gottlieb et al., 2004; Bourke et al., 2011a). However, there are a select few studies in the SDB literature that have only reported attentional deficits, with no executive functioning deficits found. For instance, Kennedy et al. (2004), and Blunden et al. (2000) both reported deficits in selective and sustained attention in children who snore (presumably PS). Additionally, a review supports these findings showing that selective and sustained attention were the most consistently reported attentional deficit found in children with OSA (Owens, 2009). Gottlieb et al.'s (2004) study, which was mentioned above, found more attentional deficits than executive functioning deficits, with visual attention and auditory attention being significantly impaired in children with SDB. Hunter et al. (2015) reported that even children with PS experienced attentional deficits compared to control children. Barnes et al. (2012) reported similar findings, where visual attention was impaired in children with PS as part of a working memory task, which according to the authors could indicate a basic attention processing deficit underlying executive task difficulties. Overall, attentional deficits appear at all severities of child SDB, whereas deficits in aspects of executive function are predominantly evident in the more severe cases. Out of the literature examined, only two studies (Xanthopoulous et al., 2015; Lau et al., 2015) reported using different tests to measure both executive functioning and attention separately, which found deficits in both domains. However, the relative influence of attention deficits impacting the nature of executive ability remains to be explored in a context regarding children with SDB.

Underlying Attentional Deficits in Executive Functioning

The literature examined may unintentionally disregard attention as a functional component in executive functioning despite it being commonly reported alongside executive functioning. This may be due to a lack of theoretical frameworks to follow, which have now been provided by Beebe and Gozal (2002), Miyake et al. (2000), Anderson (2002), and the inclusion of another study in adults by Verstraeten & Cluydts (2004b). Verstraeten & Cluydts (2004b) have found underlying attention deficits to be a primary cause of executive functioning problems in adults. They provide a theoretical framework regarding how to separate both attention and executive functioning, and in doing so highlight the relative deficit in each after accounting for the other (Verstraeten & Cluydts, 2004a). This unique perspective in the field appropriately recognises the role attention plays in executive functioning deficits in SDB. By way of illustration, inhibition appears to shift attention away from distractors, signifying the possibility of inhibition and attention working together. Similarly, shifting incorporates attentional components by mentally switching attention to another task, hence this skill often being referred to as 'attentional shifting'. This allows for the possibility that executive functioning is not working alone, but relies on attentional processes to provide us with healthy functioning. Relating that to the SDB literature, it may be that attention deficits are the reason executive functioning is suffering under SDB symptomology. It may also explain the inconsistent findings of executive functioning in the child SDB literature, due to attention not being independently assessed and accounted for. To follow up on their framework, Verstraeten and Cluydts' (2004b) study focused on the measurement of executive functioning and attention in thirty-six adults with moderate to severe OSA. The adults with OSA exhibited poorer recall for digits and symbols for executive functioning tasks, alongside omissions in vigilance assessment tasks. Attention was controlled for in all executive functioning tasks including the specific attention task utilised in the study. Despite controlling for this, there were no executive functioning differences between the OSA adults and the thirty-two controls, displaying that both groups reported similar accuracy in completing all tasks. The OSA adults were also compared to severe patients of OSA, and no executive functioning deficits were reported. Despite this, there were reports of general slow information-processing exhibited via reaction time, along with diminished working memory. This was found in a reaction time subtest, which was not a particularly challenging or engaging task. The authors speculated that these particular findings are a result of lapse in attention, as it was one of the last trials to complete in the neurocognitive assessments. Thus, they claim that there may not necessarily be a deficit in executive functioning, but rather in the participants' ability to sustain attention.

Aims of the Current Study

The idea of attention's potential underlying contribution to the workings of executive functioning will be this study's focus. This will be done using the theoretical advice of Verstraeten & Cluydts (2004a) to separate attention and executive functioning so they can be assessed independent of each other, while accounting for the relative influence of each on SDB outcomes. This study aims to investigate whether similar processes are evidenced in children with SDB, and in doing so help clarify the precise neurocognitive dysfunction experienced directly as a consequence of SDB symptoms.

CHAPTER 2 – Methods

Participants

SDB

Children in the SDB group were recruited from the Ears, Nose and Throat (ENT) Department of the Women's and Children's Hospital (WCH), North Adelaide, South Australia. Specifically, these children were awaiting adenotonsillectomy (AT) surgery for suspected SDB. AT refers to the surgical removal of the adenoid and tonsil tissues which can cause snoring and obstruction to the upper airway structure. This surgery is suitable for children with SDB as it is reported to completely or partially reduce upper airway obstruction in these children (Tal et al., 2003; Kohler et al., 2009). Children were excluded from the study if they spoke English as a second language, had previous ENT or craniofacial surgery, were taking medications that could alter their sleep, respiratory patterns, or neurocognition (such as stimulants or psychiatric medication), and medical conditions/illness that could result in hypoxaemia, sleep fragmentation, neurocognitive deficits or behavioural problems, such as attention-deficits/hyperactivity disorder (ADHD). For the current study, a total of 29 children (18 males and 11 females) aged 5 to 12 were included in the final analysis. This age range was intentional to avoid developmental changes arising from puberty that could affect brain development, and characteristics of SDB such as upper airway structure.

Control

Control children were recruited from posters displayed in assorted health clinics and institutions, local newspaper advertisements, local schools, or through parents already enlisted in the study. The exclusion criteria were identical to the SDB children, with the exception of SDB symptomology being a requirement. Control children in the current study were between 5-12 years of age, reported to snore less than 2 nights per week, and not undergone or awaiting ENT surgery. Control children were excluded from the analysis if their polysomnography (PSG) at baseline displayed significant SDB (i.e. an AHI > 1), which is the standard for diagnosis in children with SDB (ATS, 1996). In total the current study included 38 control children (17 males and 21 females).

Measurements of height and weight were recorded for both groups before polysomnography was undertaken, and collated into body mass index (BMI) percentiles. This was determined using standardised growth charts (Kuczmarski et al., 2000). In addition, both groups were screened for SDB using the Sleep Disturbance Scale for Children (SDSC), which has impressive generalisability, and substantially robust validity and reliability (Huang et al., 2014; Romeo et al., 2013; Lecuelle et al., 2020; Bruni et al., 1996). The study that collected this data was approved by the Human Research Ethics Committees, the University of Adelaide, Adelaide, South Australia, along with approval for the study's location (WCH).

Materials and Apparatus

NEuroPSYchology (NEPSY)

The NEPSY is a battery assessing neuropsychological development in children ranging from 3 years to 12 years of age (Korkman et al., 1998). It was designed to identify and distinguish a range of developmental disabilities such as dyslexia, attention deficits, learning difficulties, etc. (Korkman et al., 1998). The domains assess a range of neurocognitive abilities, such as Attention and Executive Functioning, Language, Memory and Learning, Sensorimotor, and Visuospatial Processing. For the variables of interest, Auditory Attention (selective attention) and Response set (inhibition), Visual Attention, and Tower (planning) were used. Auditory Attention and Response set are measured using one test, with different rules applied to accurately measure the desired functions. Using this set, the procedure as recommended by Verstraeten & Cluydts (2004a) can be applied.

The following information is provided by Korkman et al. (1998). Auditory Attention measures vigilance and the maintenance of selective auditory attention. Multiple squares ranging from yellow, blue, red, and black are presented to the child on a table, and when the child hears a word prompt such as 'yellow', they pick up the yellow square and place it in a box, as instructed. If a mistake is made, it is not be corrected but the next prompt is given. Poor performance on this task may reflect poor attention and vigilance on simple and repetitive tasks.

Auditory Response measures regulation of responses, and the ability to maintain complex mental tasks. The test is similar to the former, but this test focuses on inhibiting previous learned responses when given a word prompt. For this task, new rules are established, such as when the child hears the prompt 'red', they put a yellow square in the box, whereas when they hear 'yellow', they place the red square in the box. Low scores on this task are reflected in two forms, omissions and commission errors, where the former implies inattentiveness and the latter displaying responsiveness but to the wrong target.

Visual attention involves the ability for a child to scan and identify the target picture in an array quickly and accurately. The target pictures must be identified as quickly as possible. If a child performs slowly and inaccurately in this task, it can be perceived as a general neurocognitive impairment.

As for Tower, it measures planning and problem-solving ability. The child must move three coloured balls placed on three pegs to a target position. The target position is illustrated via pictures shown to the child. The child only has a limited number of moves to reflect the target position, and if the balls do not reflect the target position after all moves are taken, this is considered to be a failed attempt. The difficulty increases as one completes the task. Low scores on Tower may reflect impairments in generating new solutions to problems and planning performance. All of the subtests for the Attention/Executive Functioning have a mean of 10, with a standard deviation of 3.

Validity and Reliability

The Core Domains of the NEPSY present high reliability coefficients with a slight decrease in subsets, but are at an acceptable standard (Korkman et al., 1998; Ahmad & Warriner, 2010). Specifically, reliability coefficients are held at a high standard between the ages of 5-12, which reflects the current sample. Validity testing is not focused specifically on the tests used for this study but there is still support for the general area of Attention/Executive Functioning subtests as a whole. Particularly, for convergent validity, the NEPSY subtests were compared with the subtests of the Benton Neuropsychological Tests (Korkman et al., 1998; Ahmad & Warriner, 2010). Moderate correlations for the Attention/Executive Functioning domain were found (Korkman et al., 1998; Ahmad & Warriner, 2010), exhibiting that the NEPSY subtests used in the current study are sufficient to measure the target functions. In addition, this tool is appropriate for the current sample as it can identify various degrees of neurocognitive dysfunction in clinical groups such as ADHD, learning disabilities, autism spectrum disorder, etc. (Korkman et al., 1998).

Both Tower and Auditory Attention and Response set exhibit strong reliability, with 0.82 and 0.81 respectively (Korkman et al., 1998). These tests exhibit high internal consistency, meaning that they measure what is expected. Visual Attention exhibited notable reliability also, with 0.71 (Korkman et al., 1998). The NEPSY presents relatively acceptable levels of stability coefficients over multiple testing times, essential for follow-up testing (Korkman et al., 1998).

Tower and Visual Attention presented mild stability, with 0.47, and 0.43 respectively (Korkman et al., 1998) Auditory Attention and Response set, however, is highly stabilised throughout different periods of testing, with 0.80 (Korkman et al., 1998). As this set is complex and demanding, it may not be as affected by practice effects as the other two simplified tests are.

Stanford Binet Intelligence Scales 5th edition

The Stanford Binet Intelligence Scales 5th edition (SB-5), full scale intelligence quotient (IQ) was used as a measure of 'general intelligence' in all children, and control for any performance differences that may be the effect of general intelligence than SDB per se (Janzen et al., 2004). A significant improvement in this edition of the SB-5 is the expanded age range from 2-years to 85-years of age (Janzen et al., 2004), making it suitable for the current study.

The following details are provided by Roid (2016). Working Memory (WM) was included in analyses of executive function. WM includes the composite score of Verbal and Non-Verbal WM. The standard scores for both FSIQ, and WM composite scores includes a mean of 100, with a standard deviation of 15.

The primary verbal WM abilities being assessed include impulse control, freedom from distractibility, patience with complex tasks, auditory attention span, and retention span. The non-verbal WM abilities include many listed within the verbal ability, in addition to speed of movement, precision of movement, and tracking of visual sequences.

Validity and Reliability

There is substantially less literature on the 5th edition of the Stanford than other editions, but support for the SB-5 specifically was found in Afrooz et al.'s (2014) study. The Wechsler Intelligence Scale for Children 3rd edition (WISC-3) was compared and a correlation coefficient of 0.81 was reported, demonstrating that the SB-5 displays similarity to WISC-3, in that it measures the appropriate constructs relating to general intelligence. Strengthening this claim, only one standard deviation of difference was reported for the total IQ's score between the two tests (Afrooz et al., 2014). Regarding the assessment of general intelligence, high reliability was reported in specific indices that measure intelligence more broadly, with a Pearson's *r* of 0.87-0.94 (Gygi et al., 2017). Construct and concurrent validity are exhibited in the WM domain. The SB-5 verbal WM component reported higher correlations than other measures of verbal WM, the correlations ranging from 0.16-0.53 (Pomplun & Custer, 2005) Similarly, the SB-5 non-verbal WM also reported higher correlations than other general non-verbal WM measures, the correlations ranging from 0.13-0.52 (Pomplun & Custer, 2005). Particularly, both subtests of the SB-5 WM scores reflected high correlations with the WJ-3 Auditory Memory scores (Pomplun & Custer, 2005), illustrating similarity in assessing the working memory domain of executive functioning. Evidence toward generalisability is expressed via children with ADHD, who reflected lower performance in the WM domain of the SB-5 compared to controls (Marusiak & Janzen, 2005). As children with ADHD are reported to exhibit impaired working memory, these results also reflect that of criterion-related validity.

Polysomnography

Although polysomnography (PSG) is a highly labour intensive, time consuming, and expensive procedure to run (Pang & Terris, 2006), it captures multiple physiological responses related to sleep and is commonly used to identify sleep disorders, such as SDB. It works to identify the severity rate of SDB, detects sleep stages, ventilation and blood gas exchanges whilst remaining non-invasive during sleep.

The Compumedics S-Series Sleep System (Melbourne, Australia) was used to collect various data, including electroencephalographic left and right electrooculographic (EOG), submental and diaphragmatic electromyphgraphic (EMG) data. Piezoelectric motion detection was used to assess leg movements, electrocardiogram (ECG) for heart rate, a thermistor and nasal pressure for oro-nasal airflow, uncalibrated respiratory inductive plethysmography for chest and abdominal movements, and pulse oximetry for arterial oxygen saturation (SaO2). Throughout this process, a sleep technician unaware of the status the child held (SDB vs control) monitored the children using an infrared camera and recorded observations of sleep behaviour, confirming snoring and non-snoring events, etc.

The criteria for all SDB-related events were defined using the respiratory protection guidelines for paediatric studies (ATS, 1996). Obstructive apneas were labelled as the lack of airflow in the continued movements from the chest and abdominal wall, whereas obstructive hypopneas were defined as the 50-80% reduction in airflow with erratic chest and abdominal wall movements. Central apneas were described as the decline in airflow between 20-50%, with respiratory effort of <50%. Events in which respiratory events reflected both that of central and obstructive activity were categorised as mixed apneas. The Obstructive Apnea Hypopnea Index (OAHI) was presented as the total number of obstructive apneas, mixed apneas, and obstructive hypopneas divided by total sleep time, then expressed as the total numbers of events per hour of sleep. A score of OAHI > 1 per hour was indicative for OSAS criteria in children. Similarly, the Central Apnea Hypopnea Index (CAHI) were presented as the total number of central apneas, and central hypopneas divided by total sleep time, which then was expressed as the number of events per hour during sleep. The Apnea and Hypopnea Index (AHI) was presented in the same format, with the total number of respiratory events divided by total sleep time and actualised as the number of events per hour during sleep. In regard to spontaneous and respiratory arousals, the spontaneous arousal index (SAI) were reported as the total number of spontaneous arousals per hour during total sleep time, and respiratory arousal index (RAI) illustrated as the total number of respiratory arousals per hour during total sleep time.

Procedure

Participants were involved in extensive neurocognitive assessments, the Stanford Binet Intelligence Scale 5th Edition (SB-5) and the NEuroPSYchology (NEPSY), alongside one night of PSG recording. Neurocognitive assessment was conducted in a quiet room within the Women's and Children's Hospital by a trained examiner who was blind to the status each child held. Neurocognitive testing occurred within a three-week period from the child's overnight PSG session. Testing lasted approximately 2-3 hours with a 10-15-minute drink and snack break. The first test given was the SB-5, followed by the break and was completed after the administration of the NEPSY. Parents remained in the room during assessment, directly behind the child, and were engaged in a quiet activity. After assessment, a summary of the child's performance was sent to parents once collated.

Statistical Analysis

Using R studio (RStudio Team, 2020), Wilcoxon rank-sum tests were run to determine group differences for demographic characteristics and sleep data, with chi-squared tests used for categorical data, such as age and ethnicity. an ANCOVA (Analysis of Covariance) was used for neurocognitive data due to significant group differences presented in the demographic data. ANCOVAs were used once outliers were removed, and after visual inspection of Q-Q plots, histograms, skew, and kurtosis values, parametric testing could be followed. The primary analysis involved a two-way repeated measures ANCOVA, once again accounting for the significant demographic differences found. Factors will include group (SDB vs control) and test (Auditory attention vs Auditory Response), taken from the NEPSY. Finally, linear regression was used to compare the sleep parameters that were found to vary between groups with executive functioning performance to investigate sleep-based markers for SDB-related executive dysfunction.

CHAPTER 3 – Results

Eight outliers were removed from the data that impacted the normality of three neurocognitive measures (Verbal WM, Auditory Attention, and Visual Attention). After removing these outliers', scores for both Verbal WM and Auditory Attention were considered to approximate a normal distribution on visual inspection of histograms and Q-Q plots (all data points falling within the 95% CI range). Visual Attention required further logarithmic transformation to meet assumptions of normality.

Wilcoxon rank-sum tests were run for the demographic and sleep variables as a majority did not meet normality according to parametric testing assumptions. Gender and ethnicity differences were measured using a chi-squared test. Assessment of age, gender, SES, and ethnicity resulted in no significant differences between the two groups, however IQ and BMI z-score were both found to differ. Referring to Table 1, the SDB group exhibited lower intelligence scores IQ (M = 98.00, SD = 42.00) compared to the controls (M = 110.00, SD = 49.00), indicating that the control group exhibited higher general intellectual performance (W = 875.5, $p < 0.001$). Since this has high potential to skew performance on the neurocognitive assessments (Diaz-Asper et al., 2004; Foley et al., 2009; Dean et al., 2008), IQ was included as a covariate in subsequent analyses. The two groups statistically differed on BMI z-score (W = 383.5, $p= 0.03$), with the SDB group maintaining higher BMI (M = 1.02, SD = 4.93) than the controls (M = 0.34, SD = 3.40). As the negative impact BMI has on neurocognitive performance (Miller et al., 2015; Reinert et al., 2013), it was also included as a covariate alongside IQ in subsequent analyses.

As shown in Table 1, groups did not differ for any of the sleep stages, with the exception of REM latency, which exhibited a trend (W = 700.5, $p = 0.05$) with the SDB group entering REM almost 15 minutes earlier (M = 74.00, SD = 144.50) compared to the controls (M = 88.00, SD = 93.00). Total sleep time did vary between groups (W = 7.68.5, $p = 0.006$) with controls reporting significantly more minutes of sleep during PSG (M = 446.32, SD = 32.71) than the SDB group (M = 414.14, SD = 59.58). Expectedly, the SDB group exhibited greater RAI (M = 1.04, SD =14.48) compared to controls (M = 0.28, SD =2.45), indicating a higher frequency of respiratory arousals (W = 289, $p < 0.001$). In addition, the SDB group also displayed higher OAHI scores (M = 3.34, SD = 4.57) compared to controls (M = 0.14, SD = 0.18), exhibiting higher obstructive apneas per hour of total sleep time (W = 216, $p < 0.001$). Finally, a significantly higher overall AHI was expectedly found (W = 299, p < 0.001) in the SDB group (M = 1.99, SD =19.26) rather than in controls (M = 0.53, SD = 4.22).

Table 1

Group Differences: Demographic and Sleep Variables

Variable	SDB	Control
SES	955.46 (388.31) [959.01, 90.86]	1007.72 (331.15) [994.80, 90.44]
Age	7.94 (7.75) [8.22, 2.46]	8.23 (7.60) [8.47, 2.20]
IQ	98.00 (42.00) [96.90, 9.12]	110.00 (49.00) [108.47, 11.18]***
BMI z-score	1.02 (4.93) [0.71, 1.29]	0.34 (3.40) [0.34, 0.77]**
Sleep Efficiency	79.60 (44.90) [78.50, 9.17]	82.10 (31.30) [81.66, 6.80]
Total Sleep Time (TST) mins	420.00 (300.50) [414.14, 59.58]	445.00 (147.50) [446.32, 32.71]***
REM latency	74.00 (144.50) [78.98, 31.91]	88.75 (93.00) [90.34, 21.89][1]

Variable	SDB	Control
WASO	47.00 (157.50) [56.19, 43.71]	33.75 (116.50) [39.14, 27.33]
SaO2nardirTST	92.00 (17.00) [91.59, 3.58]	93.00 (8.00) [93.00, 1.93]
Move Time%TST	1.68 (3.17) [1.92, 0.89]	1.52 (2.89) [1.72, 0.80]
Movements p/h TST	7.38 (18.37) [8.48, 4.12]	6.15 (10.36) [6.79, 2.76]
Awakenings p/t TST	0.71 (3.28) [0.98, 0.79]	0.72 (2.75) [0.82, 0.56]
S1%	3.07 (9.48) [3.65, 2.51]	3.10 (7.83) [3.32, 1.84]
S2%	43.35 (26.10) [43.36, 6.48]	44.49 (25.65) [45.15, 6.17]
SWS%	34.07 (30.11) [34.43, 7.45]	30.74 (24.04) [31.37, 5.69]
REM%	18.44 (28.24) [18.56, 6.09]	19.91 (18.98) [20.16, 4.32]
PLMI	1.13 (27.16) [5.47, 8.07]	1.18 (19.55) [3.13, 4.74]
SAI	8.26 (7.37) [8.13, 1.73]	9.28 (9.38) [9.35, 2.60]^1
RAI	1.04 (14.48) [2.63, 3.51]	0.28 (2.45) [0.43, 0.46]***
AI total	12.12 (19.11) [13.37, 4.88]	11.31 (13.49) [11.39, 3.04]
OAHI	0.99 (16.33) [3.35, 4.57]	0.07 (0.60) [0.14, 0.18]***
CAHI	0.59 (5.07) [1.02, 1.30]	0.40 (3.95) [0.63, 0.74]
AHI	1.99 (19.26) [4.37, 5.42]	0.53 (4.22) [0.77, 0.78]***

Note: Median (Range) [Mean, Standard Deviation]; statistically significant group differences presented as such, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{1} = $p = 0.05$.

An ANCOVA was conducted for the neurocognitive measures, with IQ and BMI z-score included as covariates. This output can be found in Table 2. The two groups did not differ in any neurocognitive tests besides Tower ($F(1, 63) = 7.62$, $p = 0.008$, $\eta^2 = 0.108$). Specifically, the controls performed better (M = 13.37, SD = 2.06) than the SDB (M = 10.76, SD = 3.32). The overall Attention Executive domain was also significantly different between groups ($F(1, 63) = 4.14$, $p = 0.04$, $\eta^2 = 0.062$), again with controls performing higher (M = 133.50, SD = 11.46) than the SDB children (M = 102.14, SD = 15.82).

A two-way repeated measures ANCOVA was conducted for the major analysis, with IQ and BMI included as covariates. The results indicate that IQ affects the performance of both the attention and executive functioning tasks, despite controlling for any differences between the two groups ($F(1,128) = 18.04$, $p < 0.001$, $\eta^2 = 0.12$). Significant effect of task type was found, with children performing higher in Auditory Attention (attention) (M = 10.12, SD = 2.61) than in Auditory Response (executive functioning) (M = 9.30, SD = 2.12), ($F(1,128) = 4.56$, $p < 0.001$, $\eta^2 = 0.03$). No significant differences were found between the two groups on test performance overall ($F(1,128) = 0.15$, $p > 0.05$, $\eta^2 = 0.00$), along with no interaction between group and task type was found. ($F1, 128) = 0.06$, $p > 0.05$, $\eta^2 = 0.00$), which can be seen in Figure 1.

Table 2.

Group Differences: Neurocognitive Variables

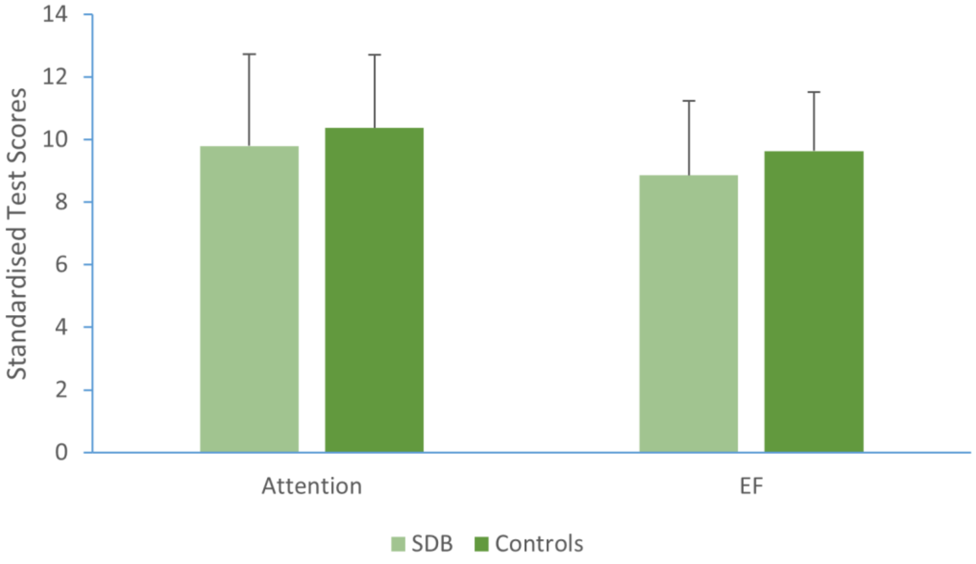
Variable	SDB	Control
Attention Executive Domain	102.14 (15.82)	113.50 (11.46)*
Tower	10.76 (3.32)	(13.37, 2.06)**
Auditory Attention	9.79 (2.93)	10.37 (2.34)
Auditory Response	8.86 (2.37)	9.63 (1.88)
Visual Attention	10.97 (2.43)	11.92 (2.60)
Working Memory (WM)	102.1 (10.55)	111.21 (13.33)

Non-Verbal WM	10.31 (2.71)	11.82 (3.0.7)
Verbal WM	10.34 (2.11)	12.03 (2.58)

Note: Layout is presented as such: Mean (Standard Deviation); statistically significant group differences presented as such, * = $p < 0.05$, ** = $p < 0.01$.

Figure 1

Group Differences Between Tasks



Note: This figure shows no interaction effect present in the current sample, with both groups performing higher in attention rather than in executive functioning overall.

Subsequently, a series of multiple linear regression models were run to determine whether differences in sleep variables may be predictive of the reduced planning function (Tower) shown in SDB children. Both IQ and BMI z-score were found to predict the performance of Tower scores in children with SDB, however, SAI, RAI, OAHI, AHI, and REM latency were not significantly predictive of Tower scores.

Results of the first multiple linear regression indicated that there was an overall trend of BMI, IQ, and SAI in predicting Tower scores ($F(3, 25) = 2.912$, $p = 0.05$, $R^2 = 0.17$). The individual predictors were examined further and indicated that BMI z-score were significant predictors of the model ($t = 2.357$, $p = 0.02$, $\beta = 0.41$), with IQ just outside the significance threshold ($t = 1.908$, $p = 0.06$, $\beta = 0.33$). However, SAI was not a significant predictor ($t = -0.512$, $p = 0.6$, $\beta = -0.09$).

The second multiple linear regression model also reported an overall trend of BMI, IQ, and RAI in predicting Tower scores ($F(3, 25) = 2.814$, $p = 0.05$, $R^2 = 0.16$). BMI reported as a significant predictor of Tower scores ($t = 2.235$, $p = 0.03$, $\beta = 0.39$). However, IQ was not a significant predictor of Tower scores ($t = 1.834$, $p = 0.07$, $\beta = 0.31$), alongside RAI ($t = 0.204$, $p = 0.8$, $\beta = 0.03$).

The third multiple linear regression model reported an overall significant effect of BMI, IQ, and OAHI in predicting Tower scores ($F(3, 25) = 3.025$, $p = 0.04$, $R^2 = 0.17$). BMI was reported as a significant predictor ($t = 2.189$, $p = 0.03$, $\beta = 0.37$), however IQ was not ($t = 1.888$, $p = 0.07$, $\beta = 0.32$). Similarly, OAHI was not a significant predictor of Tower scores ($t = 0.718$, $p = 0.4$, $\beta = 0.12$).

The fourth linear regression model including AHI, with BMI and IQ as predictors. The model exhibited an overall trend ($F(3,25) = 2.885$, $p = 0.05$, $R^2 = 0.16$). BMI was found to be a significant predictor ($t = 2.17$, $p = 0.03$, $\beta = 0.38$), whereas both IQ ($t = 1.86$, $p = 0.07$, $\beta = 0.32$) and AHI ($t = 0.45$, $p = 0.6$, $\beta = 0.07$) were not significant predictors.

The final multiple linear regression run was focusing on REM latency with BMI and IQ as predictors. There was no significant effect reported for the overall model ($F(3, 25) = 2.805$, $p = 0.06$, $R^2 = 0.16$), however upon further inspection, BMI was a significant predictor of Tower scores ($t = 2.150$, $p = 0.04$, $\beta = 0.38$), yet IQ ($t = 1.836$, $p = 0.07$, $\beta = 0.31$) and REM latency were not significant predictors of Tower scores ($t = -0.151$, $p = 0.8$, $\beta = -0.02$).

CHAPTER 4 – Discussion

The research aim for this study was to investigate if similar underlying attentional processes found in Verstraeten & Cluydts’ (2004b) study influenced executive dysfunction in SDB children. The current study found no clear interaction between underlying attentional deficits affecting executive functioning deficits in children with SDB. Despite the limited literature available on this topic, these findings do not reflect that of Verstraeten & Cluydts (2004b), which found an interaction effect of attentional deficits influencing executive functioning in adults with SDB. BMI z-score and IQ were found to significantly differ between the two groups, and were thus included as covariates. Significant differences found between the two groups’ test performance were in Tower, with the SDB children exhibiting a planning deficiency compared to their controls. The Attention/Executive Domain also exhibited significant differences, however, since this a combination of both the attention and executive functioning tests, this domain was likely driven solely by the Tower scores. There were no significant differences found between both groups and sleep stages, which contradict the findings reported by Goh et al. (2000) and Weichard et al. (2016). These findings state that there are increased obstructive events in REM, with a reduction in SWS, yet the current study found no support for these findings. The significant differences in sleep parameters (SAI, RAI, OAHI, AHI, and REM latency) were evaluated to determine if these components were significant predictors of Tower scores, particularly if they contributed to planning deficiency. No sleep parameters were reported to significantly affect Tower scores. However, BMI z-score was a significant predictor of planning deficiency, with IQ exhibiting a trend.

A possible explanation for the current study’s results may be due to the current SDB sample displaying mild SDB symptomology which may have not been sufficient to develop further deficits other than executive functioning, only the planning component. Verstraeten & Cluydts's (2004b) study which found an interaction of attentional deficits and executive functioning included moderate to severe patients of SDB, whereas Hunter et al. (2015) reported that children with higher AHI were significantly impaired compared to other lower AHI groups. This emphasises the possibility that SDB severity may impact the trajectory and range of potential neurocognitive deficits from developing. This relates to the current findings where only planning deficiency was found in a sample of children with predominantly mild SDB.

Another unexpected finding was the lack of impact both the sleep stages and respiratory events had on executive functioning deficits. This finding was inconsistent with a number of studies that claim sleep fragmentation as a consequence of SDB contributed to neurocognitive deficits, particularly those of executive functioning. However, a number of studies report similar findings to the current study (Vitelli et al., 2015; Bourke et al., 2011b). Interestingly, studies reporting no effects of SDB on executive function include more mild severity of SDB (Kohler et al., 2009; Calhoun et al., 2009; Jackman et al., 2012). It may be plausible to speculate that neurocognitive functioning in children with mild SDB are not as severely impacted as children with moderate to severe SDB, or that a certain threshold of SDB severity is required before such deficits become evident. The latter explanation would also help explain the lack of correlation between the planning deficiency and sleep parameters shown in the current study. Despite this, there are other factors that increase the impact of executive functioning deficits.

In the regression models, BMI z-score consistently remained a significant predictor of Tower (planning) scores. IQ was also consistently on the threshold of significance but cannot be confidently called an individual predictor based on these results. These findings were not the focus of this investigation, however, they do reflect broader findings in the literature (Mamrot &

Hanć, 2019; Xanthopoulous et al., 2015). An intriguing finding from the literature is the commonality of inhibition control deficits for overweight and/or obese children. Particularly, obesity in non-SDB children was associated with inhibitory control deficits even after obesity was controlled for (Owens, 2009). In addition, a review found similar findings in 27 studies with inhibitory control deficits in non-SDB overweight and obese children (Mamrot & Hanć, 2019), while a systematic review found that BMI predicted lower inhibition performance in non-SDB children and adolescents (Reinert et al., 2013). Similar inhibitory deficits also appear for SDB children. Beebe et al. (2004) found that children with OSA had a substantial rate of impairment, particularly for cancellation tasks that measure inhibition compared to controls. Karpinski et al. (2008) reported general deficits in executive functioning, with the strongest effect being inhibition for pre-schoolers at risk for SDB. The SDB studies mentioned did not include any measurement for weight, so the effect of obesity on inhibition deficiency cannot be determined here. However, Mietchen et al. (2016b) reported inhibitory control deficits in children with SDB who were also overweight/obese.

Behaviours that reflect this deficiency may include eating greater portions of food, with high fat and/or high sugar content, with low intake of vegetables (Mamrot & Hanć, 2019), thus increasing body mass. A focus on short-term pleasure rather than planning for the long-term may cause children to be more vulnerable toward eating unhealthily to achieve short-term gratification (Mamrot & Hanć, 2019). Relating this idea to the planning deficiency found in the current study, if overweight/obese children are not able to strategically plan for the future, they may remain complacent and engage in comfort behaviours, such as unhealthy eating. This in turn may affect obesity levels in children, which will further the executive functioning deficits reported in the literature.

This effect of obesity is partially consistent with the current study’s results, where BMI impacted executive functioning. Auditory Response (inhibition) used for the primary analysis in this study did not report any inhibition deficits despite the BMI z-score being a significant predictor of executive functioning deficits compared to any other variable. A possible explanation is similar to the last, in which the extent of executive functioning deficits present is influenced by SDB severity, but also may be exacerbated with higher BMI.

Although IQ did not reach statistical significance amongst all linear regressions, it is worth considering given the borderline effect shown in a relatively small sample of predominantly mild SDB severity. It is possible the effect may have reached statistical significance with a large, more representative sample of SDB. It is common for lower IQ to be reported alongside executive functioning deficits in children with SDB (Owens, 2009; Vitelli et al., 2015; Gottlieb et al., 2004; Bourke et al., 2011b; Blunden et al., 2000). Speculation as to why these two factors are reported alongside each other may be that lower IQ influences the deficits found in executive function, just as obesity influences executive functioning deficits. Relating to Beebe and Gozal’s (2002) theoretical application of SDB altering cellular structure, it could be worth exploring if SDB leads to a decrease in IQ. If this is the case, lower IQ may lead to comorbidities such as learning disabilities, thus hindering executive functioning to a greater extent than even the severest form of SDB could produce (Rohrer-Baumgartner et al., 2014). Interestingly, an improvement in OAHI was found to be predictive of performance IQ (Biggs et al., 2014). Performance IQ is related with Fluid Intelligence (Gf) which relies on the ability to adapt to new situations (Biggs et al., 2014). This is similar to working memory’s updating function as it updates constantly and retrieves the most relevant information for the situation at hand. Indeed, executive functioning has been strongly correlated with Gf, particularly with working memory as the strongest predictor (van Aken et al., 2016). It is sensible to assume that SDBs effects (such as OAHI) influence the functioning of general IQ, which may be related to lower executive functioning. As this is beyond the scope of the current study, this would be an interesting exploration for future studies to embark upon.

In this relatively mild SDB child population, there is no evidence of broad executive functioning deficits. This first investigation of the interaction between attention and executive functioning in children with SDB does not suggest attentional deficits underlying any reduction in executive functioning performance. Instead, this study provides insight into the individual factors affecting executive functioning, those being BMI and potentially IQ. The current study adds clarification to the debate of executive functioning deficits existence, but not in the way this study originally intended. It was expected that respiratory events would affect executive functioning deficits, following from Beebe and Gozal's (2002) work. However, it appears that sleep factors, at least those quantified using PSG, are not strong predictors of executive functioning deficits for cases of children with mild SDB. Instead individual factors such as (body mass and IQ) appear to be more influential, and so future research could endeavor to find more sensitive measures of sleep disruption in mild SDB cases that better predict function outcomes.

Suggestions

In regards to reducing these executive functioning deficits, it is heavily reported in the SDB literature that adenotonsillectomy has been the most effective treatment for the majority of children, even for overweight/obese children (Kohler & van den Heuvel, 2008). Adenotonsillectomy involves the removal of adenoids and/or tonsils that commonly cause obstruction to the upper airway (Kohler et al., 2009). Access for oxygen to flow through the upper airway organically reduces respiratory-related events, and because of this, executive functioning performance improves (Al-Zaabi et al., 2018; Friedman et al., 2003; Wei et al., 2007). In particular, a meta-analysis found pre-school children exhibited improvements in neurocognitive performance, and even IQ post-adenotonsillectomy (Song et al., 2016). It may be possible for a young child's IQ to also improve when neurocognitive performance increases. The same was not found in older children, possibly due to surpassing critical developmental periods. From the large success rate, adenotonsillectomy should be the first treatment option for children who are obese and/or exhibit SDB symptomology, particularly at a young age to avoid irreversible executive functioning deficits and decreases in IQ. As for optimising the improvement of executive functioning for SDB children, neurocognitive training, such as implementing computer training and planning strategies could be an effective approach used in the classroom (Mamrot & Hanć, 2019).

Another suggestion, in regards to cognitive recording, lies within the utilisation of Event-Related Potential (ERP) recordings (Barnes et al., 2012). ERPs are non-invasive and because of this, can be used on infants right through to elders (Barnes et al., 2012). ERP record millisecond-by-millisecond neural data on information processing, such as inhibition and working memory updating (Sus & Sinha, 2009). Collating the standardised cognitive testing results can be time-consuming for the research, who can instead rely upon ERP due to its sensitivity and accuracy in measuring subtle neurocognitive changes (Barnes et al., 2012). Such an approach may be particularly applicable in mild SDB cases, such as the current study, where neurocognitive effects are seemingly more subtle and difficult to capture with traditional face-to-face assessment interviews.

Uncertainties

Despite some readily available suggestions, there remains uncertainties surrounding the sample and results specifically. The duration of SDB may be an important factor that is not considered in this research. A suggestion for future research may include assessing a birth cohort, including overweight infants, to determine the onset of SDB. Even a measurement that determines the first appearance of SDB may be useful for understanding the condition. As for the results, impairment in executive functioning was found in a visual task (Tower) rather than an auditory task which was chosen for the major analysis (Auditory Response), yet the limited literature available on this specific area is inconsistent with the current study. Both auditory and visual tasks exhibit poor performance for children with SDB compared to controls, specifically in children with mild SDB and children with OSA respectively (Key et al., 2009; Kheirandish-Gozal et al., 2010). A speculation as to why this is inconsistent with the current study may simply be the inclusion of assessment used, as there are varying opinions on what each test measures in the community (Karpinski et al., 2008). Key et al. (2009) included similar methodology as the current study, with the NEPSY assessment and PSG, but with ERP used also, whereas Kheirandish-Gozal et al. (2010) only included PSG and a memory recall test. This highlights the need for consistent methodology in order to rely on findings that can be generalisable to SDB children, thus providing reliable psychoeducation to medical professionals, and to the community. Uncertainty also surrounds to what extent the current sample was motivated to complete the neurocognitive assessments due to long testing periods. It may be useful to have data that quantifies the level of invested mental effort, to determine its predictive influence. Future studies may wish to include motivation assessment to rule out any alternative explanations for deficits detected, an example being difficulty grasping the instructions.

Limitations

This study does not conclude without addressing its limitations. The most prominent limitation is the small sample size in the current study, particularly when focusing on the SDB children. In the linear regression models, there was a medium effect found when comparing OAHI to Tower scores, yet no significant effect was presented. Similarly, a large effect was found when assessing the impact of both SAI and AHI on Tower scores, but again no significant effect was found. If the current sample was larger, these factors may have been shown to be better predictors of executive dysfunction. This small sample size may have been a large contributor to the lack of statistical findings, but it appears it was sufficient to detect an effect for a planning deficiency in SDB children. It is reasonable to assume that future studies that implement a larger sample size may have a higher chance of finding more executive functioning deficits, possibly even attentional deficits. The mild SDB severity in the current sample can also be classified as a limitation. This study sample did not represent the SDB continuum as a whole, and as a consequence, may have failed to illustrate potential deficits in all executive functioning components. Another limitation is the large variability in SES within both the control and SDB groups, distorting the reliability of the mean. Although groups were not found to differ in SES, and largely represented the broader community in terms of level of SES, it is difficult to conclusively rule out any bias in the results as a consequence of the large variability in SES scores. Two reviews reported that children with lower SES also report lower executive functioning compared to higher SES children (Ursache & Noble, 2015; Hackman & Farah, 2009), particularly in working memory, inhibitory control, and attentional shifting (Hackman & Farah, 2009). A further limitation is the polysomnographic data being recorded from a single night, which can lead to what is referred to as ‘first night effects’ (Kahn et al., 1996). In particular, the total amount of sleep significantly differed between the two groups but were not considered in the sleep parameter analyses due to the artificial nature of the sleeping environments. It may be that these children experienced restlessness, predominantly from the laboratory setting, which potentially limits the validity of the sleep results being an accurate representation of a particular child's sleep and SDB severity. If the current study recorded more than one night's sleep, it may have avoided this limitation, but also more accurately portray the typical respiratory-related events during sleep, as according to Borges et al. (2013), AHI and SaO2 levels tend to fluctuate night to night. It may be worth exploring home recordings of sleep to capture multiple nights of sleep to accurately reflect average sleep behaviour.

Conclusion

The aim of this study was to continue the investigation of executive functioning deficits in children with SDB. Particularly, attempting to replicate the findings of Verstraeten & Cluydts (2004b) where an interaction between attentional deficits and executive functioning deficits were present in adults with SDB. The was the first study to actively assess this potential interaction in children, but did not find any underlying attentional deficits that affect executive dysfunction. Despite this, some evidence of executive functioning deficits in a relatively mild SDB group were evidence, particularly so for measures of planning ability. Upon further investigation, it appeared that BMI, and to a lesser extent IQ, are significant contributors to executive functioning in children, suggesting that further investigation of the interaction of these factors with SDB on executive functioning in children is warranted. The major limitation to the generalisability of these findings is the relatively mild SDB severity. Future work should aim to ensure broader coverage and comparison across the full range of severities, as well as methodological approaches that provide a more representative assessment of sleep, such as multiple PSG recordings as well as possible home recordings. This is recommended as respiratory and physiological processes fluctuate from night to night, as well as the laboratory environment potentially biasing the sleep experience. Overall, this study suggests that individual characteristics such as BMI and IQ have the potential to affect executive functioning to a greater extent than mild SDB, and supports the need for a deeper investigation into the predictors.

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