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Parent-Reported Deficits in Executive Function and Sleep-Disordered Breathing in Adolescent Behavioral Weight Loss Program Participants

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ABSTRACT

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Objective: Children and adolescents with obesity and overweight are at increased risk for developing sleep disordered breathing (SDB) and SDB has been associated with cognitive deficits and executive dysfunction. The aim of this study was to examine the relationship between executive functioning and SDB among adolescents participating in a behavioral weight loss intervention. Methods: Adolescents ($n = 37$) and their caregivers completed the Behavior Rating Inventory of Executive Function (BRIEF) and caregivers completed the Pediatric Sleep Questionnaire (PSQ). Using the Sleep Related Breathing Disorder scale on the PSQ adolescents were classified as at risk or not at risk for SDB. Correlations were calculated to evaluate associations between executive function and SDB. MANOVA analyses were also conducted to determine whether significant differences in executive function exist between adolescents at risk for SDB, and those not at risk. Results: Significant correlations were found between SDB and executive functioning ($r = 0.75$; $p < .001$). Significant differences were observed between SDB risk and non-SDB risk groups on the BRIEF parent report ($F (1, 35) = 3.73$; $p < 0.01$). Differences in parent-report BRIEF scores across risk groups represent a large effect ($d = 1.73$). However, these differences were not replicated on the BRIEF self-report ($F (1, 35) = 1.24$; $p > 0.05$). Conclusions: Adolescents with overweight or obesity participating in behavioral weight loss interventions may be at increased risk for SDB and those adolescents at risk for SDB may have executive dysfunction. These deficits may have implications for treatment.

Keywords: executive function, sleep-disordered breathing, children, adolescents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Parent-Reported Deficits in Executive Function and Sleep-Disordered Breathing in Adolescent Behavioral Weight Loss Program Participants

Obesity is among the most common pediatric health conditions. Despite prevention and intervention efforts to reduce obesity prevalence, greater than 30% of US children and adolescents are either overweight or obese (Ogden, Carroll, Kit, & Flegal, 2014). Although often seen as a disease in its own right, obesity is considered to be a risk factor for the development of other health conditions including sleep disordered breathing (SDB) which can range from mild snoring to obstructive sleep apnea (OSA) (Lobstein, Baur, & Uauy, 2004; Verhulst, Van Gaal, De Backer, & Desager, 2008). SDB has been associated with unfavorable health consequences. For example, SDB has been associated with hypertension as well as increased risk for developing metabolic syndrome (Montesano et al., 2010; Redline et al., 2007). Glucose intolerance and insulin resistance have also been independently associated with SDB, thus increasing an individual's chance of developing type 2 diabetes (Punjabi et al., 2004). Past research has demonstrated that the risk for developing SDB is two to four times higher in obese children and adolescents compared to their non-obese peers (Lobstein et al., 2004). There is also evidence of an association between body mass index (BMI) and SDB severity, indicating that individuals with severe obesity are at greatest risk for developing SDB (Lobstein et al., 2004; Redline et al., 1999; Verhulst et al., 2008).

In addition to significant health consequences, SDB in children has also been associated with behavioral difficulties including impairment in cognitive and academic function (Bourke et al., 2011). Numerous studies have demonstrated that individuals with SDB display deficits in executive function. Specifically, deficits have been reported in the areas of working memory, planning, organization, inhibition of impulses, attention, and decision making (Engleman, Cheshire, Deary, & Douglas, 1993; Engleman, Martin, Deary, & Douglas, 1997; Karpinski, Scullin, & Montgomery-Downs, 2008; McNally, Shear, Tlustos, Amin, & Beebe, 2012; O'Brien et al., 2004; Thomas, Rosen, Stern, Weiss, & Kwong, 2005). These SDB-related cognitive difficulties are likely related to that fact that SDB results in arousals which disrupt the sleep stages, resulting in sleep fragmentation. Moreover, SDB-related sleep fragmentation has been shown to decrease blood oxygenation resulting in hypoxia (decreased oxygen). Both sleep fragmentation and hypoxia can lead to a disruption of neural mechanisms affected by sleep and lead to disruption in the restorative processes of sleep. Beebe and Gozal (2002) also explain how SDB, specifically sleep apnea, affects the prefrontal cortex, resulting in executive dysfunction.

Executive functioning may play an important role in children and adolescents success with weight control. A meta-analytic review established that impulsivity in children is associated with the child's weight. Greater degrees of impulsivity and less behavioral control was significantly associated with pediatric obesity (Thamotharan, Lange, Zale, Huffhines, & Fields, 2013). Impulsivity and inhibition are among the common symptoms associated with SDB and individuals with SDB exhibit greater impulsivity and are less able to inhibit their behaviors (Beebe et al., 2004). Given these associations, the effect that SDB has on executive functioning may be important to consider in the context of weight control intervention.

Neuroimaging studies also attest to the importance of executive functioning in weight control interventions. One such study examined individuals' ability to resist cravings when presented with food stimuli in an fMRI task following gastric bypass surgery. When individuals were asked to resist the craving, there appeared to be increased activation in the Dorsolateral Prefrontal Cortex (DLPFC). Those participants who were more successful in losing weight showed significantly more activation in the DLPFC when instructed to resist cravings than those participants considered to be less successful (Goldman et al., 2013). The DLPFC is an area that is considered important for executive functioning and as discussed earlier, Beebe and Gozal (2002) proposed that the prefrontal cortex is affected by SDB (Berman et al., 1995).

Executive functioning has also been associated with lifestyle characteristics that are associated with pediatric obesity. Children who reported high levels of sedentary behavior and who reported eating food with high fat and sugar content also reported increased levels of executive dysfunction when compared to their peers who reported higher levels of physical activity and healthier eating (Riggs, Huh, Chou, Spruijt-Metz, & Pentz, 2012). With past research suggesting that SDB may lead to executive dysfunction, it is possible that SDB plays an important role in the relationship between executive dysfunction and pediatric obesity; a role that has largely gone uninvestigated in past research.

The aim of the current study was to evaluate whether overweight/obese adolescents participating in a behavioral weight loss program exhibit symptoms of SDB and whether these symptoms might be associated with executive functioning. We hypothesized that participants at risk for SDB would demonstrate deficits in executive functioning compared to obese adolescents not at risk for SDB.

Methods

Participants

Thirty seven adolescents enrolled in a behavioral weight loss intervention program participated in the study. Initially there were 42 potential participants but we excluded participants who did not complete the study assessment at either measurement occasion (n=2) or whose executive function profiles were of questionable validity per the manual for the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, 2000; n=3). Participant ages ranged from 12 to 17 (M=14.32, SD=1.56) and there were 14 male and 23 female participants. All participants had a Body Mass Index (BMI) percentile categorized as overweight (i.e., ≥ 85th percentile) or obese (i.e., ≥ 95th percentile; M=97.71, SD=1.66). Only English speakers were recruited to participate. The primary caregiver who prepared meals for the adolescent completed parent-report questionnaires. Adolescents with severe mental illness (including but not limited to bipolar disorder, recent traumatic brain injury, and psychotic disorders) were excluded from the study. The Institutional Review Board of the authors' institution approved all study procedures. Written informed consent was obtained from parents/guardians and adolescent participants completed written assent.

Measures

Anthropometric data. Height (in inches) and weight (in pounds) were measured at each assessment occasion by a trained research assistant using a calibrated electronic scale (Seca 217, SECA Corp., Hanover, MD) and a portable stadiometer (Seca 813, SECA Corp., Hanover, MD). Height and weight were measured without shoes in light clothing. Height, weight, age, and sex data were used to calculate Body Mass Index z-score (BMIz), a value standardized for age and sex which is robust to restriction of range. BMIz transformations were completed using a SAS application provided by the Centers for Disease Control and Prevention (CDC, 2007).

Sleep-disordered breathing. The adolescents' caregiver completed the Pediatric Sleep Questionnaire (PSQ) in its entirety (Chervin, Hedger, Dillon, & Pituch, 2000). Adolescents were assessed for risk of SDB using the Sleep-Related Breathing Disorder scale of the PSQ. The Sleep-Related Breathing Disorder subscale on the PSQ consists of 22 items that measure symptoms of SDB including symptoms such as snoring, cessation of breathing during sleep, and excessive daytime sleepiness. This measure has good internal consistency ($\alpha = 0.89$) and good test-retest reliability ($\rho = 0.75$). Sensitivity and specificity of this subscale has been reported as 0.85 and 0.87, respectively. Scores above 0.33 are considered to be indicative of SDB, as established by Receiver Operating Characteristic (ROC) analyses in past research (Chervin et al., 2000). We also collected information regarding previous diagnoses including ADHD and OSA from the PSQ, and also asked if the subjects were currently being treated for these conditions.

Executive function. The Behavior Rating Inventory of Executive Function (BRIEF) was used to measure executive function. This measure consists of 86 items that are intended to measure various facets of executive function including inhibition, shift, emotional control, initiation, working memory, planning and organizing, material organization, and monitoring (Gioia, 2000). The Behavioral Regulation Index consists of three subscales, inhibit, shift, and emotional control. The Behavioral Regulation Index is considered a measure of a child's capacity to engage in socially acceptable behavior via inhibitory control, cognitive shifting, and emotional regulation. The Metacognition Index includes the initiate, working memory, planning and organizing, organization of materials, and monitor subscales. The Metacognition Index is intended to measure a child's initiation and successful completion of problem solving tasks. Finally, the Global Executive Composite incorporates all eight clinical scales. This summary score represents the child's overall executive functioning abilities. The Global Executive Composite has demonstrated high internal consistency ($\alpha = 0.97$) and appears to be a good measure of executive function (Gioia, 2000). Subscales and Indices on the BRIEF are standardized T-scores (M = 50, SD = 10) with higher scores reflecting greater impairment while scores above 65 are considered to be in the clinical range.

The Behavior Rating Inventory of Executive Function – Self-Report (BRIEF-SR) is a self-report measure of executive function appropriate for adolescents ages 11-18. The BRIEF-SR consists of 80 questions and similar clinical scales and overall indices as mentioned above. The Global Executive Composite on the BRIEF-SR has also demonstrated high internal consistency ($\alpha = 0.96$; Walker, 2006).

Procedures

Participating caregivers and adolescents completed the study measures prior to beginning the behavioral weight loss intervention. The PSQ and the BRIEF were completed by each participant's caregiver. The BRIEF-SR was completed by the adolescents. The adolescents' height and weight were also recorded prior to intervention and this data was used to calculate the participants BMIz as described above. The Sleep-Related Breathing Disorder scale on the PSQ was used to assess the adolescents' risk of SDB. The 0.33 cutoff criterion as suggested by an ROC analysis in past research was used to determine the adolescents' risk of SDB (Chervin et al., 2000).

Statistical Analyses

SPSS 21 (IBM Corp., Armonk, New York) was used for all statistical analyses. Comparisons of categorical data were carried out using chi-square analyses and comparisons of continuous data were made using MANOVA. A Pearson Correlation between the Global Executive Composite on the BRIEF and the PSQ was also computed to evaluate the relationship between executive functioning and SDB. A MANOVA was performed using the BRIEF-SR clinical scale T-scores as the dependent variables and SDB risk, as determined by the PSQ, as the fixed factor. A second MANOVA was carried out using the BRIEF (parent report) clinical scale T-scores as the dependent variables and SDB risk as the fixed factor. Finally, we calculated an effect size (Cohen's *d*) comparing Global Executive Composite scores between SDB risk and non-SDB risk groups.

Results

Chi-square analyses revealed that there was not a significant difference in the proportion of males and females between the groups, χ^2 (1) = 0.95; $p > 0.05$, proportion of participants reporting past diagnosis of ADHD, χ^2 (1) = 1.8; $p > 0.05$, or proportion of participants with past diagnosis of a sleep disorder, χ^2 (1) = 0.95; $p > 0.05$. Average age for the group at risk for SDB (n = 20) was 14.2, (SD = 1.3), and the average age for the group at minimal risk (n = 17) was 14.4 (SD = 1.7); there was no between group difference in age, $t(35) = .401$, $p > 0.05$. A t-test confirmed there was no between group differences in BMIz $t(35) = .102$, $p > 0.05$. A Pearson Correlation analysis demonstrated a strong association between the BRIEF Global Executive Composite and Sleep-Related Breathing Disorder scale on the PSQ, $r = 0.75$; $p < .001$. The overall MANOVA analysis examining associations between the BRIEF-SR and SDB risk did not demonstrate significant group differences in self-reported executive function between adolescents at risk for SDB and those at minimal risk, F (1, 35) = 1.24; $p > 0.05$. In contrast, the MANOVA comparing parent ratings of executive function between adolescents at risk for SDB and those at low or minimal risk was statistically significant, F (1, 35) = 3.73; $p < 0.01$. All eight clinical scales were significantly different between groups and all three indices (i.e., Behavioral Regulation, Metacognition; Global Executive Composite) were significantly different between groups. The effect size of the difference between BRIEF Global Executive Composite scores between SDB risk groups demonstrated a large effect, $d = 1.73$. Means, standard deviations, F-statistics, and p-values for the clinical scales and indices for the BRIEF-SR and BRIEF by group (risk for SDB; low or high) are presented in Table 2 and Figure 1.

Discussion

Overweight and obese adolescents are at risk for sleep disordered breathing which may have detrimental effects on executive functioning. Findings from our study suggest that overweight/obese adolescents enrolled in a behavioral weight loss program who were at risk for SDB demonstrated significantly poorer executive functioning compared to adolescents at minimal risk for SDB. Differences in the Global Executive Composite, which represents overall executive function by combining all eight clinical scales from the BRIEF, between risk groups demonstrated a very large effect size. This finding suggests that parents of adolescents with SDB notice executive dysfunction in the adolescents' daily functioning. This finding may also suggest that the utilization of the PSQ in conjunction with the BRIEF may be highly effective screening tools in determining executive dysfunction in the presence of SDB. These effects are larger than have been observed in previous studies using self-report or objective measure (O'Brien et al., 2004; Tan, Healey, Schaughency, Dawes, & Galland, 2014). In contrast to group differences based on parent-report, there were no group differences in self-reported executive function between adolescents at risk for SDB compared to those at minimal risk. The reason underlying differences between parent and self-report in regards to executive function in this sample is unclear. However, similar findings have been reported in adolescents following traumatic brain injury. One study noted that parents reported significantly greater executive dysfunction than their child, using the BRIEF. The authors attributed this finding to a lack of deficit awareness (Wilson, Donders, & Nguyen, 2011). Thus, our findings suggest that adolescents at risk for SDB may also have limited insight into deficits related to executive function.

We would point out that many of the subscales and indices from the BRIEF parent report form that were elevated in the SDB at risk group would be considered to be in the clinically significant range. More specifically, adolescents at risk for SDB appear to have deficits in working memory, as well as their abilities to plan and organize. Other reported deficits include abilities related to transitioning efficiently from one activity to another, and making careless mistakes or failing to check their work. Broadly speaking, their abilities to control their emotions and behavior appropriate to the environment, and to use appropriate problem solving abilities appear to be impaired. It is important to note that there were no significant group differences in past diagnoses of ADHD between adolescents at risk for SDB and those not at risk. Demonstrating that the executive deficits noted are not due to ADHD is important because past research has shown that children with SDB are at increased risk for ADHD (Chervin et al., 2002). However, the pattern of our results are similar to those reported by Toplak, Bucciarelli, Jain, and Tannock (2009) in adolescents with ADHD who had elevated scores on the inhibit, shift, working memory, and plan/organize subscales of the BRIEF. Similarly, adolescents with ADHD have demonstrated deficits in their abilities to plan and organize, control their emotions and behavior, and utilize optimal problem solving strategies. This similarity is striking and likely reflects an overlap in behavioral presentation between SDB and ADHD. For example, increased inattention and hyperactivity have been associated with increased SDB severity in children and adolescents (Chervin et al., 2002). In addition, SDB symptoms, specifically snoring, is a predictor of hyperactivity (Chervin, Ruzicka, Archbold, & Dillon, 2005). Furthermore, treatment for SDB has been associated with remission of symptoms of inattention and hyperactivity lending evidence to the notion that SDB may be playing an important role in generating symptoms of inattention, hyperactivity, and executive dysfunction (Ali, Pitson, & Stradling, 1996).

Our findings may have important clinical implications for obese adolescents participating in a behavioral weight loss programs. Clinical impairment in executive function may make it more difficult for these adolescents to reach weight loss goals. K. McNally, Rohan, Pendley, Delamater, and Drotar (2010) demonstrated that children with deficits in executive function displayed poorer adherence to treatment of diabetes. In their study strict treatment adherence predicted more favorable outcomes and level of executive functioning was related to treatment adherence. It has also been demonstrated that individuals with ADHD and executive functioning deficits struggle to be successful in weight loss interventions (Cortese, Comencini, Vincenzi, Speranza, & Angriman, 2013). Relatedly, executive dysfunction has been associated with increased body mass (Gunstad et al., 2007), suggesting that executive functioning is important in the maintenance of a healthy weight. Finally, the importance of the association between executive functioning and weight loss has been demonstrated in a prior study. Children in a weight loss program that received training (in the form of a game) to improve executive functioning not only showed marked improvement on tasks of working memory as well as measures of working memory and meta-cognition as measured by the BRIEF, but were also more successful at maintaining their weight loss eight weeks post-intervention (Verbeken, Braet, Goossens, & van der Oord, 2013). Taken together with our current findings, we hypothesize that adolescents with SDB and executive dysfunction would have more difficulty adhering to treatment recommendations and thus achieving identified weight loss goals. Therefore, screening for SDB and gauging a child's executive functioning may be important in weight loss treatment planning. Future research may be conducted to determine if SDB affects an adolescent's success in weight loss intervention programs.

In terms of treatment, there are several recommendations to help reduce SDB symptoms depending on the severity, which can range from mild to severe. Behavioral techniques such as changing sleep position may be effective because apneas are much more likely to occur in the supine position. Another common recommendation is encouraging weight loss which has been shown to reduce symptoms of SDB (Verhulst, Franckx, Van Gaal, De Backer, & Desager, 2009). Snoring can also be decreased by treating nasopharynx inflammation or surgical treatment of enlarged turbinates (Halbower, McGinley, & Smith, 2008). However, the most common treatment is adenotonsillectomy. Unfortunately, adenotonsillectomies are only effective in reducing symptoms in approximately half of adolescents (Verhulst et al., 2009). There is also evidence that some adolescents experience weight gain following an adenotonsillectomy (Amin et al., 2008). Finally, continuous positive airway pressure or CPAP is another potential treatment (Fitzgerald & Fitzgerald, 2013).

Limitations

This study had several limitations. First, our study utilized cross-sectional data and we cannot make causal statements. Second, the measures of executive function were limited to self – report and parent-report measures without direct assessment of executive function and our findings may underestimate or overestimate executive dysfunction. Thus, it would have been beneficial to have objective measures of executive function to compare to the self and parent-report measures. Third, despite adequate validity and reliability of the PSQ in identifying increased risk of SDB, the participants in this study did not undergo polysomnography which precludes confirmation of SDB using physiological assessment.

Conclusions

Obesity is a risk factor for sleep disordered breathing which has been associated with various health problems and cognitive dysfunction. We found that a substantial proportion of the overweight/obese adolescents in a behavioral weight loss program had symptoms consistent with sleep disordered breathing and that those at risk were rated by their caregivers as having impairment in various aspects of executive function. In contrast, adolescents at risk for sleep disordered breathing were not likely to rate themselves as having executive impairment which may represent poor insight. Given the importance of executive function in achieving weight-loss goals, we recommend that future studies evaluating the efficacy of weight-loss interventions consider screening participants for sleep disordered breathing. Furthermore, when outcome data is available it would be beneficial, and thus we intend to determine the effect that executive dysfunction has on outcome in weight loss interventions. Finally, it may be helpful to consider cognitive demands, particularly related to executive functions, when developing weight-loss programs for obese adolescents.

Table 1

Demographics of participants

	Total Sample (n = 37)	**Low SDB Risk (n = 17)**	**High SDB Risk (n = 20)**
	Mean (SD)	*Mean (SD)*	*Mean (SD)*
Age	14.32 (1.56)	14.35 (1.73)	14.15 (1.35)
BMIz †	2.13 (0.37)	2.14 (0.41)	2.12 (0.34)
	N (%)	*N (%)*	*N (%)*
Sex			
Male	14 (37.8)	5 (29.4)	9 (45.0)
Female	23 (62.2)	12 (70.6)	11 (55.0)
Educational Attainment*			
Junior High School (7-9 total years)	26 (70.2)	12 (70.5)	14 (70)
High School (10-12 total years)	10 (27)	4 (23.6)	6 (30)
Race/Ethnicity*			
White	26 (70.3)	12 (70.6)	14 (70)
Hispanic / Latino	6 (16.2)	5 (29.4)	1 (5)
Black	0 (0)	0 (0)	0 (0)
Asian	0 (0)	0 (0)	0 (0)
Other	1 (2.7)	0 (0)	1 (5)
Mother's Weight*			
Underweight or average weight	6 (16.2)	3 (17.6)	3 (15)
Slightly or very overweight	30 (81.1)	13 (76.4)	17 (85)
Father's Weight*			
Underweight or average weight	0 (0)	0 (0)	0 (0)
Slightly or very overweight	27 (73.0)	15 (88.2)	12 (60)

SDB = sleep disordered breathing. †One participant's BMIz was not included because a valid z-score could not be obtained due to an extremely high BMI. *Some demographic data is missing. This is due to respondents failing to complete the pre-treatment survey.

Table 2

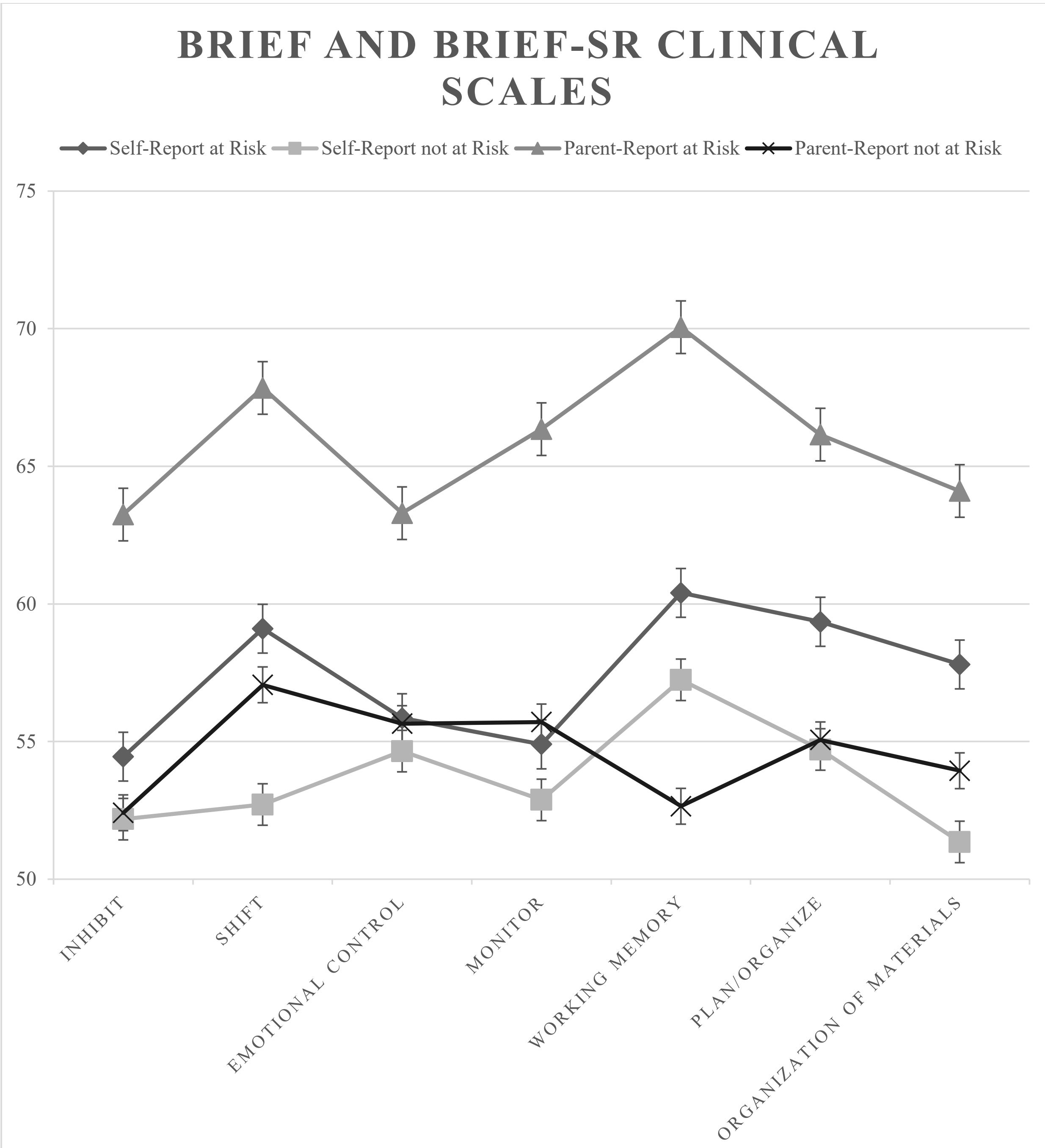
The means (T-scores), standard deviations, F-values, and p-values of the MANOVA for the clinical scales, indices, and GEC for the BRIEF and BRIEF-SR.

	Low SDB Risk	**High SDB Risk**	***F***	***p***
BRIEF-Parent Report				
BRI	55.71 (7.83)	66.65 (10.91)	11.87	.001
Inhibit	52.41 (9.68)	63.25 (13.50)	7.61	.009
Shift	57.06 (7.32)	67.85 (10.85)	12.12	.001
Emotional control	55.65 (7.66)	63.30 (11.59)	5.40	.026
MI	56.18 (8.38)	70.90 (9.36)	25.01	<.000
Initiate	58.24 (7.80)	73.40 (8.77)	30.41	<.000
Working Memory	52.65 (9.47)	70.05 (9.98)	29.30	<.000
Plan / Organize	55.06 (8.92)	66.15 (10.06)	12.38	.001
Organization of Materials	53.94 (7.97)	64.10 (6.50)	18.27	<.000
Monitor	55.71 (8.48)	66.35 (8.22)	14.97	<.000
GEC	56.06 (7.64)	70.65 (9.21)	26.92	<.000
BRIEF-Self Report				
BRI	53.94 (13.32)	57.45 (11.16)	0.76	0.39
Inhibit	52.18 (11.13)	54.45 (9.30)	0.49	0.50
Shift	52.71 (14.04)	59.10 (10.52)	2.50	0.12
Behavioral Shift	51.59 (12.07)	54.15 (9.43)	0.53	0.47
Cognitive Shift	53.06 (15.36)	61.85 (11.47)	3.96	0.054
Emotional control	54.65 (12.04)	55.85 (15.26)	0.07	0.79
Monitor	52.88 (12.67)	54.90 (7.31)	0.37	0.55
MI	56.41 (17.55)	62.15 (12.50)	1.34	0.26
Working Memory	57.24 (17.83)	60.40 (12.51)	0.40	0.53
Plan / Organize	54.71 (14.43)	59.35 (11.82)	1.16	0.29
Organization of Materials	51.35 (17.17)	57.80 (11.78)	1.82	0.19
Task Completion	54.00 (17.26)	63.50 (12.43)	3.77	0.06
GEC	55.65 (16.58)	60.80 (12.24)	1.18	0.29

SDB = sleep disordered breathing, BRIEF = Behavior Rating Inventory of Executive Function, BRI = Behavioral Regulation Index, MI = Metacognition Index, GEC = Global Executive Composite.

Figure 1

A profile of the Clinical Scales of the BRIEF and the BRIEF-SR for those at risk for SDB and those not at risk for SDB.



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