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flexibility tested by the Verbal fluency test. So that, our findings were not consistent with the findings of a previous study carried out by Raine et.al in 2018, who had found that %TBF and subcutaneous abdominal adipose tissue were not related to cognitive abilities.(44)

Finally, our study results agreed with the proposal of that the obesity related adverse associations with cognitive performance in the era of EF may be attributed to excess fat stored viscerally rather than peripherally(66) in the point concerned with the major role of VF in the obesity cognition relationship. However, our findings suggest also possible but lesser roles of each of the TBF and the SAT.

- Aspects of strength in our study included: Assessment of VF and subcutaneous fat using MRI-derived quantification based on a single slice abdominal MRI at the level of L2 vertebra that was safe and radiation free technique, more easily applied than the standard MRI, more time saving as each subject only required about 15 minutes, and with high accuracy compared to the traditional anthropometric measurements; assessment of %TBF using foot- foot (F- F) BIS that has higher accuracy than hand- foot (H- F) BIS; and the large sample size which included 510 participants.
- The limitations of our study included: The observational design that does not allow any inference of causality. So that, Future longitudinal and intervention studies may be required in humans or experimental animal models to decide the possible cause among the discussed 3 possible causal scenarios; some of the applied tests were used in English language which is nonnative language of the subjects, this required to ask each subject if he understand the language of the test and can perform the task in English or not before the start; and due to the number of models included, there was a possibility for Type- I error inflation in this study. Of the assessed 6 EF tests, only one test was expected to show an effect of VF, or a sex- by- VF interaction with the executive function tests by chance alone.

Coclusions:

Our results suggest that the adverse associations found between obesity and EF may vary according to the regional distribution of the excess body fat, and these adverse associations may be attributed to excess VF> %TBF> SAT. Moreover, when correlated across sex, female subjects were found more sensitive to these adverse associations compared to male subjects, this may suggest that these associations were moderated by sex with possible gender related factors in the pathogenesis. Further, our findings suggest that the obesity related cognitive adverse associations are not specific for excess VF, and can be attributed to excess VF> %TBF> SAT.

Declarations:

- Ethics approval and consent to participate: A prior ethical approval was obtained from the Institutional Review Board (IRB) of the Faculty of Postgraduate Childhood Studies, Ain Shams University, Egypt and all methods were performed in accordance with the relevant guidelines and regulations. The study objectives and design were explained thoroughly by a team member to every candidate and his/ her legal guardian then each candidate legal guardian signed an informed consent in representation of minor, in case of acceptance before beginning of the study to insure complete satisfaction.
- Consent for Publication: Not applicable.
- Availability of data and materials: The authors declare that necessary data and materials for conducting the study were available. If someone wants to request, the data from this study he can contact the authors.
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receptors showed a more masculine way of cortical thickness development during adolescence. So, circulating testosterone, mediated by androgen receptor polymorphisms may play a role in regulation of both VF volume and the morphology of the brain areas underlying EF.[45] However, the role of testosterone in the regulation of visceral fat volume and brain morphology was not studied in this Thesis.

Lifestyle factors such as, poor physical activity[48] and excessive intake of calories dense foods[34][55] were included in history taking from the subjects of our study but not included in statistical analysis, and at least one of these lifestyle factors was found positive for each subject.

Previous studies suggested that lifestyle factors may play a role in both of VF accumulation and cognitive performance. Adolescents with better physical activity had been found associated with higher cognitive performance even if these findings were controlled for their cardiorespiratory fitness and BMI.[48] But, another previous adult study found that the physical activity assessed by accelerometers, was negatively associated with the volume of VF.[56]

Thus, poor physical activity may have a role in the observed VF-cognition negative relationships. However, Future studies are required to investigate the impact of interventions using scheduled physical activity on the VF-cognition relationships.

The Stroop color word test used was applied in our study for each subject to assess the ability to prevent cognitive interference that may occur during processing of a specific feature of stimulus while, the processing of another feature of the same stimulus was ongoing, which is known as the Stroop Effect. However, our study did not involve a specific measure of delayed discounting such as "The Kirby Delay- Discounting Task (DDT)" that could be used to measure temporal discounting in future studies to test the tendency of the subjects to prefer a smaller immediate reward over a larger delayed reward. In the Kirby Delay-Discounting Task participants will be asked to complete a series of 27 questions, each question test the ability of the subject to choose between a smaller but immediate reward versus a larger but delayed reward. The variable modeling techniques can be used to fit the function that relates the discounting to time. The steeper (i.e., having sharp inclination) curves of discounting characterizes many of the maladaptive behaviors such as drug abuse and obesity.[21]

Our study found that %TBF estimated by BIS and subcutaneous adipose tissue estimated by MRI- derived quantification of a single MRI abdomen at the level of L2, each of them less adversely related to executive functioning than VF. Our findings were inconsistent with a previous study by Kamijo, et.al. (2012), who found a negative correlation between TBF and cognitive performance,[19] but they did not correlate their findings to each of the volumes of visceral fat or SAT, unlike what we did in our study.

Our study found that excess %TBF was associated with significant negative correlations and/ or lower performance on most of the tested EF domains including the processing speed tested by Ruff 2 and 7 test and coding subtest of WISC III; working memory tested by the Digit span subtest of WISCIII (while, in case of the self- ordered pointing test a significant positive correlation found with error score signifying lower performance, and no significant correlation found with the span score); resistance to interference tested by the Stroop color word test; cognitive flexibility tested by the Verbal fluency test. Our findings were not consistent with the study carried out by Schwartz, et.al., in 2013, who found a few positive correlations between TBF (independent of VF or SAT) and cognitive performance that was present mainly in female subjects and not in male subjects of the participated overweight and obese adolescents.[53]

Our study found that VF volumes (estimated by MRI- derived VF quantification), independent of SAT volumes (estimated by MRI- derived SAT quantification), or %TBF (estimated by BIS), was negatively correlated with EF, and that the female subjects were more sensitive to this correlation compared to male subjects. This finding is consistent with the findings of the same previous study of Schwartz, et.al. (2013), who found also that, VF estimated by MRI- derived VF quantification, independent of total body fat and SAT was negatively correlated with EF, and that female subjects were more sensitive to this correlation compared to male subjects.[53]

Furtherly, our study also found that each of excess SAT amounts and %TBF were less adversely associated with the performance on the tested EF domains compared separately to excess VF as, a significant negative correlation and/ or lower performance was found between excess SAT and the (processing speed tested by the Coding subtest of WISCIII; working memory tested by the Digit span subtest of WISCIII while, in case of the self- ordered pointing test a significant negative correlations with the span score with no significant correlation with the error score; the IG score of the Stroop color word test which test resistance to interference with no significant correlation to the performance on the W, C, and CW conditions; and no significant correlation with the verbal fluency test which test cognitive flexibility, with the female subjects were more sensitive to the adverse correlations between SAT and EF compared to male subjects. When the correlations between SAT and EF tested across sex the female subjects showed low performance on the applied six EF test (P from< 0.001 to< 0.002. while, male subjects showed no significant correlation with the IG score of the Stroop color word test and the phonemic condition of verbal fluency test with low performance on the remaining conditions of the six applied EF test (P< 0.001 to 0.009).

Further, our study also found that excess %TBF was associated with significant negative correlations and/ or lower performance on most of the tested EF domains including the processing speed tested by Ruff 2 and 7 test and coding subtest of WISC III; working memory tested by the Digit span subtest of WISCIII (while, in case of the self- ordered pointing test a significant positive correlation found with error score signifying lower performance, and no significant correlation found with the span score); resistance to interference tested by the Stroop color word test; cognitive

factor for developing chronic disease[17] so that, early detection of metabolic syndrome among the overweight and obese children, before being complicated by chronic cardiometabolic comorbidities, is highly important from both the clinical and public health point of view.[5] The cardiometabolic health during adolescence is a significant predictor of the adulthood cardiovascular heath,[32] and the midlife cardiometabolic diseases may carry a significantly higher risk of future dementia.[68][18]

Long term obesity in adulthood were found associated with having lower cognitive scores in the late midlife. So that, public health messages should be announced to promote a healthy weight at all age groups.[49]

Each subject in our study was investigated for metabolic syndrome (MS) using the following;

- Measurement of waist circumference (WC) at the land mark defined by WHO (2.5cm above the umbilicus), precised to the nearest 1 mm and compared to WC percentile curve.
- Measurement of systolic and diastolic blood pressure and the values compared the blood pressure centiles for age sex and height.
- Laboratory estimation of HDL, TAG, Fasting blood glucose level.

Early detection of metabolic syndrome (MS) among the participants was based upon the Cook definition of (MS) by the presence of three or more of the following five conditions:

- Central obesity: (WC)> 90th percentile.
- Fasting triglycerides> 110 mg/dL.
- HDL< 40 mg/dL.
- Blood pressure> 90th percentile for age, sex and height.
- Fasting blood glucose>100 mg/dL.[8]

Insulin resistance (IR) and dyslipidemia are considered common features of metabolic syndrome in children and adolescents.[57] Insulin resistance (IR) can be measured by homeostasis model assessment-estimated insulin resistance or HOMA- IR which can be calculated as the product of (Fasting plasma insulin level (μU/L) × the fasting plasma glucose level (nmol/L) divided by 22.5). The value of HOMA- IR of (3.4) corresponds to the 90th percentile of healthy children, which is considered as the cut- off point to define IR, beyond this value, (IR) becomes a cardiovascular risk factor.[31] However, (HOMA IR) was not calculated for our study subjects and can be investigated in future studies.

Our study is a cross sectional study that utilized the observational research design. So that, the included subjects were explored, the variables were described and the outcomes were measured without any attempt at intervention. Hence, the reported negative effect of (VF) on the executive functioning in the overweight and obese adolescents could reflect one of three causal sequence of events:

- VF accumulation might be the cause of executive functioning (EF) deficits.
- The executive functioning deficits might be the cause of VF accumulation.
- A third factor might be the cause of both VF accumulation and EF deficits.

The first causal scenario i.e., accumulated VF might be the cause of the executive dysfunctioning, could be supported by the ability of excess VF to adversely affect EF through its negative influence on the cardiometabolic health of the subjects that could be mediated by proinflammatory cytokines secreted by the adipose tissue mainly the visceral adipose tissue, then reached the blood stream causing neuroinflammatory response that can alter the cognitive and executive functioning.[65][4]

Finding that may support the first causal possibility in our study includes; we observed that the female subjects were more sensitive to the VF- EF adverse associations compared to male subjects and the finding of the previous studies suggested that C-reactive protein was negatively associated with EF tests (including the backward condition of the Digit-span subtest of WISCIII) in the obese female subjects, but not male subjects.[60] Moreover, each standard deviation increase of VF was found to be associated with increase of CRP in female subjects and not in male subjects. So that, the correlation between VF and cytokines may be also moderated by the sex. However, estimation of CRP was not included in the investigations of the subjects in our study and can be investigated in future studies[42] Previous studies also found that higher levels of interleukin- 6 (another biomarker of inflammation) were associated with decreased performance of female subjects only on the verbal fluency tasks.[14] But, also interleukin 6 was not investigated for the subjects of our study, and can be investigated in future studies.

Findings of previous studies that may support the second causal possibility i.e., EF deficits (EFD) could potentiate excess VF accumulation; this can occur through the negative effect of executive dysfunctioning on the inhibitory control of eating impulses and/ or food preferences, this possibility was supported by one of the previous studies which found that, lower activity in the brain areas controlling the EF, on delay- discounting (i.e., the ability of the child to choose between a small immediate reward and a larger but delayed reward) was associated with higher weight gain during follow- up for (1- 3) years.[22]

Whether, poor executive functioning might be the cause that leads to increased VF accumulation, or the increased VF accumulation might be the cause that leads to EF deficits, understanding this relationship is of equal clinical interest that may help early interventions for the childhood and adolescents' obesity. When poor EF precedes obesity this can indicate that early detection of EFD may help the early interventions through subject tailored improvement of EF that may improve the response of the subject to the lifestyle modification methods including dietetic management and physical exercise.

Findings of the previous studies that may support the third causal possibility i.e., the presence of a third factor that simultaneously increased the visceral fat accumulation and decreased executive functioning included; Efficient androgen receptors had been found to be associated with increased VF volumes in male subjects.[38]

Moreover, both male and female subjects with efficient androgen

significant correlation with the % of TBF. While, in the female subjects, no significant negative correlation found between their self- esteem and (VF, SAT, and %TBF). So that, in our study the overweight and obese male subjects when compared to female subjects, they were more sensitive to low self- esteem. While, in our study there were no significant correlations found between academic achievement and (VF, SAT, and %TBF) in both male and female subjects.

Table (7) Correlation Between (VF, SAT and %TBF) With (Socioeconomic Status SES, Sleep Hygiene, Self- Esteem and Academic Achievement ACH) across the total sample and Sex

			VF	SAT	%Tbf
Total Sample	SES	Pearson Correlation	-0.028	0.093	0.078
		P- Value	0.781	0.351	0.433
	Sleep Hygiene	Pearson Correlation	−0.422**	−0.400**	−0.076
		P- Value	<0.001	<0.001	0.450
	Self- Esteem	Pearson Correlation	−0.141	−0.160	0.036
		P- Value	0.156	0.108	0.722
	Academic ACH	Pearson Correlation	−0.168	0.002	0.153
		P- Value	0.091	0. 986	0.125
Males	SES	Pearson Correlation	0. 215	0. 156	−0.090
		P- Value	0. 177	0. 331	0. 576
	Sleep Hygiene	Pearson Correlation	−0.572**	−0.531**	−0.039
		P- Value	<0.001	<0.001	0.809
	Self− Esteem	Pearson Correlation	−0.359*	−0.332*	0.121
		P- Value	0.021	0.034	0.452
	Academic ACH	Pearson Correlation	0.075	0.077	0.080
		P- Value	0. 642	0. 632	0.620
Females	SES	Pearson Correlation	−0.078	−0.028	0.025
		P- Value	0.549	0.833	0. 846
	Sleep Hygiene	Pearson Correlation	−0.374**	−0.291*	−0.242
		P- Value	0.003	0.023	0.060
	Self− Esteem	Pearson Correlation	−0.043	−0.044	0.021
		P- Value	0.740	0.734	0.871
	Academic ACH	Pearson Correlation	−0.119	−0.159	−0.189
		P- Value	0.360	0.221	0.145

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.

Discussion:

Our study proposed the presence of a negative correlation between visceral fat (VF) accumulation and lowering of cognitive functioning particularly in the era of executive functioning in the overweight and obese normally developing adolescents included in the study, independent of subcutaneous fat (SAT), or the % of total body fat (%TBF).

This correlation was investigated using a set of EF tests that were applied for each participant to measure 4 domains of executive functioning including; processing speed (using the Ruff 2 and 7 selective attention test, digit symbol substitution or coding subtests of WISCIII); working memory (using the digit span subtest of WISC III and self-ordered pointing task); resistance to interference (using the Stroop color word test); and the cognitive flexibility (using verbal fluency test).

The relationships between performance of subjects on the EF tests and (VF, SAT) (quantified using single slice MRI abdomen at the level of L2 vertebra), or % TBF (estimated using multifrequency bioempedance BIS) were studied separately either as a main effect or an interaction with sex.

Our study found that the negative correlations and/ or lower performance on the applied EF tests were not specific for excess VF, but could be attributed to the excess VF> %TBF> SAT. Moreover, we found that female subjects were more sensitive to these adverse correlations compared to male subjects suggesting a possible role of gender in the pathogenesis.

The findings of our study are consistent with the findings of many previous studies that found a significant negative correlation between obesity and cognitive functioning in children, mainly on the tasks of (EF). Such as, a previous study that was carried out by Cserjési, et.al. (2007) who found that childhood obesity was associated with deficits in cognitive flexibility and attention.[9]

Also, with another previous case control study that was carried out in 2010 by Verdejo- Garcia, et.al., who found that the overweight adolescents had selective alterations of some components of their EF and performed poorer than the healthy control group on the domains of inhibition, flexibility, and decision- making with no significant effect on the performance on the domains of working memory, planning, and reasoning.[64]

Moreover, with a previous study that was carried out in 2012 by Kamijo, et.al., found that higher BMI and fat mass measured using dual energy x- ray absorptiometry DXA, in the preadolescents of (7- 9) years old were associated with poorer cognitive performance specially in the era of the inhibitory control as suggested by poorer performance of participants on the (NO GO) task.[19]

However, these studies mostly defined obesity depending on the BMI and often did not specify these correlations to regional distribution of body fat,[9][64][19] and did not investigate the interaction of these correlations with sex of subjects, despite the established sex differences in fat deposition, as males tend to have greater amounts of VF and can accumulate VF more than females with any increase of their bodies' total fat mass.[28][51] Further, the findings of our study suggested that female subjects were more sensitive to the adverse associations between the excess (VF, %TBF, SAT, BMI, WC), denoting a possible effect of gender on the mechanisms underlying the body fat- cognition interaction, and clarifying the nature of these mechanisms may need future researches.

Our study observed the cross- sectional relationship between each of (VF, SAT and %TBF) as measures of body fat and the EF in a group of apparently well developing overweight and obese adolescents as the adolescence period is a crucial time of emergence of the cardiometabolic diseases.[61] The prevalence of the metabolic syndrome (MS) between the over- all adolescents of 12 to 19 years old was found (4.2%) affecting about (6.1%) of males and (2.1%) of females, and increased up to (6.8% for overweight and 28.7% for obese) adolescents.[8] The estimated prevalence of (MS) among a sample of obese Egyptian children in 2012 was 25%.[69] The prevalence of the obesity related (MS) is increasing with the increasing prevalence of childhood and adolescence obesity and sedentary lifestyles worldwide. The obesity related (MS) is considered a major risk

			Sat	Males (N= 205)	Females (N= 305)
	Span Sequence	Forward	Spearman Correlation	−0.448**	−0.813**
			P- Value	0.003	<0.001
		Backward	Spearman Correlation	−0.449**	−0.666**
			P- Value	0.003	<0.001
Self- Ordered Pointing Test		Error	Spearman Correlation	0.503**	0.722**
			P- Value	<0.001	<0.001
		Span	Spearman Correlation	−0.811**	−0.822**
			P- Value	<0.001	<0.001
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	−0.498**	−0.782**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	−0.410**	−0.771**
			P- Value	0.008	<0.001
	Controlled Trial	Speed	Pearson Correlation	−0.666**	−0.806**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	−0.634**	−0.791**
			P- Value	<0.001	<0.001
Verbal Fluency Test		Semantic	Pearson Correlation	−0.316*	−0.561**
			P- Value	0.044	<0.001
		Phonemic	Pearson Correlation	−0.272	−0.561**
			P- Value	0.085	<0.001
Stroop Color Word Test		W	Pearson Correlation	−0.939**	−0.794**
			P- Value	<0.001	<0.001
		C	Pearson Correlation	−0.931**	−0.778**
			P- Value	<0.001	<0.001
		CW	Pearson Correlation	−0.925**	−0.746**
			P- Value	<0.001	<0.001
		IG	Pearson Correlation	−0.300	−0.613**
			P- Value	0.057	<0.001

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.
Table (5) Correlation between %TBF with (Coding, digit span, self- ordered pointing, Ruff 2 and 7, verbal fluency& Stroop color word) tests.

				%Tbf
Coding Test			Pearson Correlation	−0.482**
			P- Value	<0.001
Digit Span Test	Span Span	Forward	Spearman Correlation	−0.697**
			P- Value	<0.001
		Backward	Spearman Correlation	−0.700**
			P- Value	<0.001
	Span Sequence	Forward	Spearman Correlation	−0.759**
			P- Value	<0.001
		Backward	Spearman Correlation	−0.708**
			P- Value	<0.001
Self- Ordered Pointing Test		Error	Spearman Correlation	0.800**
			P- Value	<0.001
		Span	Spearman Correlation	0.112
			P- Value	0.261
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	−0.759**
			P- Value	<0.001
		Accuracy	Pearson Correlation	−0.735**
			P- Value	<0.001
	Controlled Trial	Speed	Pearson Correlation	−0.808**
			P- Value	<0.001
		Accuracy	Pearson Correlation	−0.799**
			P- Value	<0.001
Verbal Fluency Test		Semantic	Pearson Correlation	−0.720**
			P- Value	<0.001
		Phonemic	Pearson Correlation	−0.718**
			P- Value	<0.001
Stroop Color Word Test		W	Pearson Correlation	−0.727**
			P- Value	<0.001
		C	Pearson Correlation	−0.726**
			P- Value	<0.001
		CW	Pearson Correlation	−0.719**
			P- Value	<0.001
		IG	Pearson Correlation	−0.647**
			P- Value	<0.001

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.
Table (6) Correlation between %TBF with (coding, digit span, self- ordered pointing, Ruff 2 and 7, verbal fluency, and Stroop color word) tests, across sex

			%Tbf	Males (N= 205)	Females (N= 305)
Coding Test			Pearson Correlation	<0.556**	<0.537**
			P- Value	<0.001	<0.001
Digit Span Test	Span Span	Forward	Spearman Correlation	<0.588**	<.673**
			P- Value	<0.001	<0.001
		Backward	Spearman Correlation	<0.546**	<0.668**
			P- Value	<0.001	<0.001
	Span Sequence	Forward	Spearman Correlation	<0.588**	-0.668**
			P− Value	<0.001	<0.001
		Backward	Spearman Correlation	-0.589**	<0.558**
			P- Value	<0.001	<0.001
Self− Ordered Pointing Test		Error	Spearman Correlation	0.560**	0.692**
			P- Value	<0.001	<0.001
		Span	Spearman Correlation	0.604**	<0.661**
			P- Value	<0.001	<0.001
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	<0.549**	<0.783**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	<0.535**	<0.734**
			P- Value	<0.001	<0.001
	Controlled Trial	Speed	Pearson Correlation	<0.640**	<0.781**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	<0.650**	<0.747**
			P- Value	<0.001	<0.001
Verbal Fluency Test		Semantic	Pearson Correlation	<0.454**	<0.649**
			P- Value	0.003	<0.001
		Phonemic	Pearson Correlation	<0.444**	<0.649**
			P- Value	0.004	<0.001
Stroop Color Word Test		W	Pearson Correlation	<0.392*	<0.760**
			P- Value	0.011	<0.001
		C	Pearson Correlation	-<0.384*	<0.751**
			P- Value	0.013	<0.001
		CW	Pearson Correlation	<0.376*	<0.714**
			P- Value	0.015	<0.001
		IG	Pearson Correlation	<0.102	<0.576**
			P- Value	0.525	<00.001

*Indicates a statistically significant correlation at 0.05 level.
** indicates a statistically significant correlation at 0.01 level.

In both male and female, no significant correlations were found between SES and each of (VF, SAT, % of TBF); significant negative correlations found between sleep hygiene and each of (VF, SAT) (P< 0.001); and no significant correlation between sleep hygiene with% of TBF. So that, the overweight and obese male and female subjects in our study were equally sensitive to alterations of their sleep health. In male subjects, significant negative correlations were found between self- esteem and (VF and SAT) (with the P values ranged from 0.002 to 0.034) and no

				VF
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	−0.546**
			P- Value	<0.001
		Accuracy	Pearson Correlation	−0.466**
			P- Value	<0.001
Controlled Trial		Speed	Pearson Correlation	−0.572**
			P- Value	<0.001
		Accuracy	Pearson Correlation	−0.513**
			P- Value	<0.001
Verbal Fluency Test		Semantic	Pearson Correlation	−0.502**
			P- Value	<0.001
		Phonemic	Pearson Correlation	−0.497**
			P- Value	<0.001
Stroop Color Word Test		W	Pearson Correlation	−0.588**
			P- Value	<0.001
		C	Pearson Correlation	−0.591**
			P- Value	<0.001
		CW	Pearson Correlation	−0.566**
			P- Value	<0.001
		IG	Pearson Correlation	−0.442**
			P- Value	<0.001

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.
Table (2) Correlation between VF with (coding, digit span, self- ordered pointing, Ruff 2 and 7, verbal fluency& Stroop color word) tests across sex.

			Vf	Males (N= 205)	Females (N= 305)
Coding Test			Pearson Correlation	−0.414**	−0.530**
			P- Value	0.007	<0.001
Digit Span Test	Span Span	Forward	Spearman Correlation	−0.493**	−0.688**
			P- Value	0.001	<0.001
		Backward	Spearman Correlation	−0.514**	−0.681**
			P- Value	<0.001	<0.001
	Span Sequence	Forward	Spearman Correlation	−0.493**	−0.681**
			P- Value	0.001	<0.001
		Backward	Spearman Correlation	−0.490**	−0.524**
			P- Value	0.001	<0.001
Self- Ordered Pointing Test		Error	Spearman Correlation	0.536**	0.813**
			P- Value	<0.001	<0.001
		Span	Spearman Correlation	−0.852**	−0.682**
			P- Value	<0.001	<0.001
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	−0.546**	−0.853**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	−0.455**	−0.830**
			P- Value	0.003	<0.001
	Controlled Trial	Speed	Pearson Correlation	−0.707**	−0.862**
			P- Value	<0.001	<0.001
		Accuracy	Pearson Correlation	−0.671**	−0.837**
			P- Value	<0.001	<0.001
Verbal Fluency Test		Semantic	Pearson Correlation	−0.363*	−0.718**
			P- Value	0.020	<0.001
		Phonemic	Pearson Correlation	−0.331*	−0.718**
			P- Value	0.035	<0.001

		Vf	Males (N= 205)	Females (N= 305)
Stroop Color Word Test	W	Pearson Correlation	−0.940**	−0.860**
		P- Value	<0.001	<0.001
	C	Pearson Correlation	−0.922**	−0.842**
		P- Value	<0.001	<0.001
	CW	Pearson Correlation	−0.918**	−0.827**
		P- Value	<0.001	<0.001
	IG	Pearson Correlation	−0.289	−0.720**
		P- Value	0.067	<0.001

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.
Table (3) Correlation between SAT with (coding, digit span, self- ordered pointing, Ruff 2 and 7, verbal fluency& Stroop color word) tests.

				SAT
Coding Test			Pearson Correlation	−0.199*
			P- Value	0.045
Digit Span Test	Span Span	Forward	Spearman Correlation	−0.328**
			P- Value	<0.001
		Backward	Spearman Correlation	−0.349**
			P- Value	<0.001
	Span Sequence	Forward	Spearman Correlation	−0.285**
			P- Value	0.004
		Backward	Spearman Correlation	−0.264**
			P- Value	0.007
Self- Ordered Pointing Test		Error	Spearman Correlation	−0.043
			P- Value	0.666
		Span	Spearman Correlation	−0.826**
			P- Value	<0.001
Ruff 2& 7 Test	Automatic Trial	Speed	Pearson Correlation	0.012
			P- Value	0.906
		Accuracy	Pearson Correlation	0.072
			P- Value	0.474
	Controlled Trial	Speed	Pearson Correlation	0.071
			P- Value	0.479
		Accuracy	Pearson Correlation	0.137
			P- Value	0.169
Verbal Fluency Test		Semantic	Pearson Correlation	0.160
			P- Value	0.108
		Phonemic	Pearson Correlation	0.163
			P- Value	0.101
Stroop Color Word Test		W	Pearson Correlation	0.091
			P- Value	0.365
		C	Pearson Correlation	0.082
			P- Value	0.412
		CW	Pearson Correlation	0.120
			P- Value	0.229
		IG	Pearson Correlation	0.237**
			P- Value	0.017

*Indicates a statistically significant correlation at 0.05 level.
** Indicates a statistically significant correlation at 0.01 level.
Table (4) Correlation between SAT with (coding, digit span, self- ordered pointing, Ruff 2 and 7, verbal fluency& Stroop color word) tests across sex.

			Sat	Males (N= 205)	Females (N= 305)
Coding Test			Pearson Correlation	−0.404**	−0.384**
			P- Value	0.009	0.002
Digit Span Test	Span Span	Forward	Spearman Correlation	−0.448**	−0.688**
			P- Value	0.003	<0.001
		Backward	Spearman Correlation	−0.486**	−0.813**
			P- Value	0.001	<0.001

quantified using multifrequency bioimpedance (BIS), and the (EF) in a sample of (510) healthy overweight and obese adolescents (305 females and 205 males, whose ages ranged from 12 to 18 years). For each subject, each of (VF), (SAT) and (%TBF) was measured separately and independently, then the executive functioning was assessed using a group of six tests that measured a set of four EF domains included in our study which are (processing speed, working memory, resistance to interference and cognitive flexibility). Our study also examined separately the relation between each of (VF, SAT, %TBF) and each of the following potential confounding factors including, (The socioeconomic status SES assessed using the "Scoring scale for family socioeconomic status; the sleep hygiene assessed using the "Adolescent Sleep Hygiene Scale"; the academic performance assessed using the "Academic Self- Concept Scale"; and self- esteem assessed using the "Rosenberg Self- esteem Scale"), for each subject with each of the same set of EF tests.

Statistical Analysis:

Descriptive statistics were presented in the form of frequencies and percentages for categorical variables, while the mean and standard deviation were used to present the numeric variables. Correlation between different scales was tested using Pearson's correlation coefficient. IBM SPSS 28 software for windows (IBM SPSS Inc.; Chicago, IL, USA) was used for the statistical analysis. P- Value< 0.05 is considered statistically significant.

Our study found that excess amounts of VF were associated significant negative correlations and/ or low performance on the six applied EF tests (all correlations were negative except with the error score of Self ordered pointing test which also signified low performance and all P values were< 0.001) and when these associations were correlated across sex, the female subjects were found more sensitive all correlations were negative (P values for the significant negative correlations ranged from< 0.001 to 0.035), except a significant positive correlation with the error score of Self ordered pointing test which also signified low performance and all (P values were< 0.001) compared to male subjects (not all correlations were negative, with a significant positive correlation was found with the error score of Self ordered pointing test (P< 0.001) which also signified low performance and no significant correlation was found with the IG score of the Stroop color word test. While, excess (SAT) volumes were associated with significant negative correlations with the performance on the coding subtest of WISCIII that was applied to test processing speed (P= 0.045), and the Digit span subtest of WISCIII that was applied to test working memory (P< 0.001 to 0.007); a significant negative correlation with the span score of self- ordered pointing test that was applied to test working memory (P< 0.001) with no significant correlation with its error score; a significant negative correlation with the IG score of the Stroop color word test which was applied to test resistance to interference (P <0.017), with no significant correlations with the performance on its (W, C, and CW) conditions. Further, no significant correlations were found with the Ruff 2 and 7 selective attention test in both the automatic and controlled conditions that were applied to test processing speed and the verbal fluency test in both semantic and phonemic conditions which were used to test verbal fluency. Moreover, the observed adverse associations became more evident when correlated across sex, with the female subjects showed negative correlations and/ or low performance on the applied six EF test (P ranged from< 0.001 to< 0.002). while, the male subjects showed no significant correlation with the IG score of the Stroop color word test and the phonemic condition of verbal fluency test with low performance on the remaining conditions of the six applied EF test (P< 0.001 to 0.009). These findings may suggest gender related role in the pathogenesis. But, the excess amounts of %TBF were associated with significant negative correlations and/or low performance on five out of the six applied EF tests, significant negative correlations were found with the performance on the (Coding subtest of WISC III; Ruff 2 and 7 test; Digit span subtest of WISC III on both the forward and backward conditions; Stroop color word test on its (W, C, CW) conditions and with the IG score; and with the verbal fluency test (all the P values were< 0.001). While, in case of the Self- ordered pointing test there was no significant correlation found with the span score with a significant positive correlation with the error score (P< 0.001) which also signified low performance. When these associations were correlated across sex, the female subjects were more sensitive to the adverse associations between %TBF and cognition compared to male subjects. Female subjects had significant negative correlations and/ or low performance on the applied six EF test, and all significant correlations were negative (P values< 0.001), except a significant positive correlation with the error score of Self ordered pointing test (P< 0.001), which also signified low performance. While for male subjects all significant correlations were negative (P< 0.001 to 0.015) except a significant positive correlation with the error score of Self ordered pointing test (P< 0.001), which also signified low performance, and no significant correlation found with the IG score of the Stroop color word test.

Table (1) Correlation between VF with (coding, digit span, self- ordered pointing, ruff 2 and 7, verbal fluency& Stroop color word) tests.

				VF
Coding Test			Pearson Correlation	−0.491**
			P- Value	<0.001
Digit Span Test	Span Span	Forward	Spearman Correlation	−0.646**
			P- Value	<0.001
		Backward	Spearman Correlation	−0.647**
			P- Value	<0.001
	Span Sequence	Forward	Spearman Correlation	−0.638**
			P- Value	<0.001
		Backward	Spearman Correlation	−0.574**
			P- Value	<0.001
Self- Ordered Pointing Test		Error	Spearman Correlation	0.554**
			P- Value	<0.001
		Span	Spearman Correlation	−0.422**
			P- Value	<0.001

- Assessment of Pubertal Development: Estimation the stage of puberty of each subject was based upon self- report of 8- items based on Tanner stages,[40] which is also known as the Sexual Maturity Rating (SMR) and has (85- 95)% accuracy within one Tanner stage according to physician ratings and is considered to be correlated with the circulating sex hormones levels such as, testosterone and dehydroepiandrosterone in both male and female subjects and estradiol in female subjects only,[54] yielding five categories of puberty:
  1. Prepubertal.
  2. Beginning pubertal.
  3. Midpubertal.
  4. Advanced pubertal.
  5. Postpubertal, and Both prepubertal and postpubertal were excluded.[52][7]
- Body Composition Measurement: Height (estimated to 0.1 cm precision), weight (estimated to 0.1 kg precision), BMI (Kg/ m^2) and WC (estimated to 0.1 cm precision) were assessed for each subject. BMI for each subject was compared the Egyptian growth curves,[13] and the underweight and normal weight adolescents were excluded.
  % TBF was measured using a multifrequency bioimpedance, a bipolar foot- foot BIS was applied for each subject to measure the %BF using the TANITA® BF-689 floor scale (Arlington Heights, IL 60005, USA). Participants were instructed to come after overnight fasting and to avoid caffeine and vigorous physical activity for 24hr before the study. The volume of VF and SAT were assessed separately using MRI using the 3.0T system Philips Achieva 3.0TX (Philips Medical Systems Netderlands, Best, Netherlands). Each subject was assured to be free from any MRI contraindications including (Metallic implants, claustrophobia, pacemakers, MRI- incompatible prosthetic heart valves) and each subject's weight was suitable for the MRI table weight limitations, then applying the standard protocol, a standard TSE T2- weighted sequence in the transverse plane was used to take a single slice at the level of the second lumbar vertebra then that slice was utilized for (VF) and (SAT) quantification based on a semi-automatic body composition analysis using the parametric Magnetic Resonance Imaging v1.2.31- b (pMRI) software, which is free and available at the following website (www. parametricmri.com).[30]
- Testing of Executive Functioning: Four domains of executive functioning were assessed; processing speed, assessed using Ruff 2 and 7 selective attention test,[47] and Coding subtest of WISCIII;[67] working Memory, assessed using Self- ordered pointing test (SOPT) and Digit span subset of WISCIII;[41] resistance to Interference, assessed using the Stroop color word test;[15] Cognitive Flexibility, assessed using verbal fluency test.[24]
- The Ruff 2 and 7 Selective Attention Test: Each subject completed both the Automatic and Controlled Detection Trials, in which each subject was asked to identify the target digits (2 and 7) which are intermixed with letters in case of the Automatic Detection or with other digits in case of the Controlled Detection. In both trials, each participant was asked to cross out the digits (2 and 7) within a time limit of 15 seconds per block (and each condition consisted of 10 blocks). The speed is the total number of target digits identified that was calculated for both Automatic and Controlled Detection and have very high test-retest reliability.[59]
- The Coding subtest of WISC- III: Subjects were asked to transcribe a digit- symbol code and the final score was equal to the number of correctly transcribed digit- symbol items in 120 seconds. Test- retest reliability of Coding is moderate.[67]
- The Digit- span subtest: Subjects were asked to repeat a string of digits whose length ranged from 2 to 9 digits, read aloud and clear by the examiner at a rate 1 digit per second and each subject was asked to repeat the string in the same heard order (Digits Forwards) or in reverse order (Digits Backwards), with two strings were read per length. Participants took one point for every correctly repeated string. The test- retest reliability of Digit- span is moderate.[67]
- The Self- Ordered Pointing: 12 abstract pictures, presented on 12 pages and each abstract picture has different location within each page, were shown to each subjects, and the subject was asked to point to a different abstract picture on each page. Each subject completed the task three times, and the total errors for the three trials was calculated. The test- retest reliability of Self- Ordered Pointing is moderate.[2]
- The Stroop color word test: The stroop test consists of three trials:
  1. Reading color names, printed in black ink on white background.
  2. Naming colors of Xs printed in Green, Red or Blue.
  3. Naming the color of ink in which color names were printed in an incongruent color.

  Each subject was given 45 second for each trial, and the score for each trial was calculated as the number of items correctly named. Stroop Interference (IG score) was calculated as the difference between the true and predicted score on trial three, with the predicted score is the product of scores on trials one (color names in black ink) (x) the score on trial two (Xs in colored ink) divided by the sum of (scores on trials one+ two). This test has moderate to high test-retest reliability.[15]
- The Verbal Fluency Test: Consists of two conditions; the Semantic and Phonemic Fluency. In the Semantic condition, each subject was asked to say as many (animals, or foods and drinks) as possible. In the phonemic condition, each subject was asked to name as many words starting with the letters (F, A, or S) as possible within a 1- min time limit for each of the five trials, and the total score was the sum of the trials for the semantic and phonemic conditions. The test- retest reliability of verbal fluency test is moderate.[59]

Operational Design:

- Type of study: A cross- sectional study method. Our study examined separately and independently the cross- sectional relationship between visceral fat (VF) quantified using MRI, subcutaneous adipose tissue (SAT) quantified also using MRI and the % of total body fat (%TBF)

Introduction:

Obesity is the excessive accumulation of body fat which is considered a major health issue for both children and adults[35] and has been found associated with poorer cognitive functioning especially on the tasks of EF such as, inhibitory control and working memory, which are required for a better academic performance and school achievement.[19] However, the causal scenarios of these findings remain controversial.[33]

The regional distribution of fat seems to be an important indicator for the obesity associated cardiometabolic comorbidities that can include glucose intolerance despite hyperinsulinemia that may suggest an insulin resistance,[6][43][37][29] dyslipidemias[16][25] and cardiovascular alterations as, hypertension, atherosclerosis of coronary, cerebral and peripheral vessels,[20][26] whose burden increase with obesity than in those with normal body weight, especially in case of the central i.e., android, or abdominal obesity that has an important link to excess accumulation of VF, more than in case of the peripheral i.e., gynecoid, or gluteofemoral obesity.[10][63][39]

Excess VF compared to other body fat was suggested in previous studies to carry a higher risk for the obesity associated cardiometabolic comorbidities,[27][66][12] which in turn may increase the risk of cognitive decline.[36][23] However, the relation between excess VF and the obesity related cognitive dysfunctioning need further studies to be clarified.[53]

Aims:

The study aims at raising awareness level in the field of child health and nutrition about the relation between overweight and obesity of adolescents and cognitive functioning in the era of executive functioning.

Objectives:

To assess the cross sectional relationship between VF independent of SAT or TBF and cognitive functioning in the era of EF, in healthy, overweight and obese adolescents.

Participants& Methods

Participants:

Healthy overweight and obese, male and female adolescents (total number 510, with 305 females and 205 males), who were 12 to 18 years old.

1. Inclusion Criteria:
   a. Overweight (i.e., BMI= or above the 85th centile) and obese adolescents (i.e., BMI= or above the 95th centile).
   b. Age 12- 18 years.
   c. Both males and females sex.
   d. Primary obesity: The included subjects were free from any cause of secondary obesity as (hypothyroidism, polycystic ovarian syndrome (PCOS), Cushing's disease, hypothalamic injury or disorders as craniopharyngeoma, and genetic mutations).
   e. Average IQ (90- 109), assessed according to the Stanford revision and extension of the (Binet- Simon scale) for measuring intelligence[62]
2. Exclusion Criteria:
   a. Adolescents with underweight (BMI <5th centile) or normal weight (BMI= 5th centile to < 85th centile) of both sexes.
   b. Mental retardation and known severe mental illness such as, attention deficit hyperactivity disorder, autism or schizophrenia.
   c. Secondary obesity (i.e., secondary to other disorder such as hypothyroidism, polycystic ovarian syndrome (PCOS), Cushing's disease, hypothalamic injury or disorders as craniopharyngeoma, and genetic mutations).
   d. Pre- pubertal and post- pubertal participants.
3. Technical Design: Descriptive research design (observational study).
4. Site of Study: Mansura city, Egypt.
5. Sample Size: (N= 510, with 305 females and 205 males) of healthy overweight and obese male and female adolescents of (12- 18) years old. The sample was calculated using open Epi-I program at confidence interval 95% and power of test 80%.[50]

Tools:

- Full history taking: included the age, sex; the age of onset and duration of obesity; and history of symptoms suggesting obesity associated comorbid conditions or causes of secondary obesity.[3]
- Questionnaires: All subjects completed four questionnaires about their (socioeconomic status using the Assessed using the "Scoring scale for family socioeconomic status (SES) for health research in Egypt", the total score= 84, and the socioeconomic level was classified to very low, low, middle and high levels depending on the quartiles of total score;[11] sleep hygiene assessed using the "Adolescent Sleep Hygiene Scale", which is a self- report questionnaire that can be applied to youth 12 years old or more to assess the sleep hygiene domains that can influence the sleep quality and quantity and includes 8 subscale scores: Physiological Factors (mean of 5 items); Behavioral Arousal Factors (mean of 3 items); Cognitive/ Emotional Factors (mean of 6 items); Sleep Environment Factors (mean of 5 items); Sleep Stability Factors (mean of 3 items); Daytime Sleep Factors (mean of 2 items); Substances Factors (mean of 2 items); Bedtime Routine Factor (value for 1 item) and the overall sleep hygiene score of each subject was calculated as (sum of means of the first to seventh subscales+ the score on 8th subscale);[58] academic performance assessed using the "Academic Self- Concept Scale" which is a is self- report scale included 40 items. The responses of each subject to each item of the scale ranged from 1 (strongly disagree) to 4 (strongly agree), and the higher scores reflected more positive academic self- concept;[46] and their self-esteem assessed using the "Rosenberg Self- esteem Scale" which included 10 items measuring the global self- worth by measuring both the positive and the negative feelings about the self, and all items are answered using a 4 point Likert scale format ranging from strongly agree to strongly disagree. The items[19][43][37][16][25] were reverse scored. Total score was= The of sum the scores for all ten items, and higher scores indicate higher self- esteem.[1]

Visceral Fat In Relation To Lowering the Executive Functions In Overweight and Obese Adolescents

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Summary

Background: Obesity is a major risk factor for cardiometabolic disorders, and cognitive dysfunctioning that starts at childhood and continues cumulatively throughout later life. Visceral fat (VF) compared to other body fat may carry a higher risk of obesity related cardiometabolic disorders. It is still unclear whether (VF) carries a same risk of obesity related cognition dysfunction.

Methods: Our study is A cross- sectional study of the relationship between (VF) and (EF), independently of the subcutaneous adipose tissue (SAT) and the % of total body fat (%TBF) in a sample of otherwise healthy 510 adolescents (12- 18 years old, 305 females and 205 males), (VF) and (SAT) were quantified separately using magnetic resonance imaging. While, the % of (TBF) was measured using multifrequency bioimpedance study (BIS), and the EF were assessed using a set of EF tests measuring (processing speed, working memory, resistance to interference, and cognitive flexibility).

Results: Our study found that excess amounts of VF has significant negative correlations and/ or low performance on the six applied EF tests and when correlated across sex, the female subjects were found more sensitive to these correlations compared to male subjects. While, these adverse correlations were less evident between (SAT) and (%TBF) and (EF) compared to VF. Also, the observed adverse associations between (SAT) or (%TBF) and cognition when correlated across sex, the female subjects were more sensitive compared to male subjects. This may suggest a gender related role in the pathogenesis.

Conclusions: Our results suggest that The adverse effects of overweight and obesity on cognition in the era of EF could be attributed to excess amounts of VF> %TBF> SAT and these associations were suggested to be moderated by sex as the female subjects were more sensitive to these adverse associations when compared to male subjects.

Keywords: Visceral fat; Subcutaneous fat; Total body fat; Executive functioning; Adolescence.

العلاقة بين الدهون الحشوية وانخفاض الوظائف التنفيذية في المراهقين زائدي الوزن والبدناء

الخلفية: السمنة هي عامل خطر رئيسي لاضطرابات القلب والأوعية الدموية، والخلل الإدراكي الذي يبدأ في الطفولة ويستمر بعدها بشكل تراكمي. قد تحمل الدهون الحشوية مقارنة بدهون الجسم الأخرى مخاطر أعلى للإصابة باضطرابات القلب المرتبطة بالسمنة. لكن لا يزال من غير الواضح إذا كانت زيادة الدهون الحشوية تحمل نفس القدر من المخاطر للإصابة بضعف الإدراك المرتبط بالسمنة.

الطريقة: دراستنا عبارة عن دراسة مقطعية للعلاقة بين الدهون الحشوية والوظائف التنفيذية، بشكل منفصل عن الأنسجة الدهنية تحت الجلد أوالنسبة المئوية لدهون الجسم الكلية في عينة بحث تتكون من خمسمائة وعشرة مراهقا تراوحت أعمارهم بين اثنتي عشرة الي ثمانية عشرة سنة، (ثلاثمائه وخمسة منهم إناث ومئتين وخمسة منهم ذكور)، تم قياس كمية الدهون الحشوية والأنسجة الدهنية تحت الجلد بشكل منفصل باستخدام الرنين المغناطيسي. بينما تم قياس النسبة المئوية للدهون الكلية للجسم باستخدام دراسة المعاوقة الحيوية متعددة الترددات، وتم تقييم الوظائف التنفيذية باستخدام مجموعة اختبارات لقياس (سرعة المعالجة، والذاكرة العاملة، ومقاومة التداخل، والمرونة المعرفية).

النتائج: وجدت دراستنا أن زيادة الدهون الحشوية لها ارتباطات سلبية بارزه أو أداء منخفض في اختبارات الوظائف التنفيذية الستة المطبقة، وعند دراسة الارتباط عبر الجنس، وجدنا أن الإناث أكثر حساسية لهذه الارتباطات مقارنة بالذكور. بينما، كانت هذه الارتباطات السلبية أو انخفاض الأداء أقل وضوحا بين الأنسجة الدهنية تحت الجلد أو النسبة المئوية للدهون الكلية للجسم والوظائف التنفيذية، مقارنة بالدهون الحشوية. وأيضا، عند دراسة الارتباط عبر الجنس، كانت الاناث أكثر حساسية لهذة النتائج مقارنة بالذكور.

الاستنتاجات: تشير نتائجنا إلى أن الآثار السلبية لزيادة الوزن والسمنة على الإدراك خاصة فيما يتعلق بالوظائف التنفيذية يمكن أن تعزى إلي زيادة الدهون الحشوية أكثر من النسبة المئوية للدهون الكلية للجسم أو الانسجة الدهنية تحت الجلد وكانت الإناث أكثر حساسية. لهذه الارتباطات السلبية عند مقارنتها بالذكور مما قد يشير إلى دور متعلق بالجنس في السببية.

الكلمات المفتاحية: الدهون الحشوية، دهون تحت الجلد، إجمالي الدهون في الجسم، خدمات خاصة، مرحلة المراهقة.

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