

The Relationship between Body Mass Index and Cognitive Function in Healthy Young Adults

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Abstract

Background: Young adulthood is a key developmental stage of life. Malnutrition at this stage can have a detrimental effect on cognitive functioning. Underweight and obesity can both adversely affect neurocognitive development. The association between body mass index (BMI) and cognitive performance is debatable.

Objective: This study investigates the relationship between BMI and cognitive function in young adult age students.

Methodology: This cross-sectional study was done on 200 medical undergraduate students aged between 18-25 years. Different cognitive domains were assessed through Trail making test A (TMT-A), Trail making test B (TMT-B), Animal name test (ANT), Design fluency test (DFT), Digit span forward and Digit span reverse test. The test score of different BMI categories and also the association between BMI and test score were analyzed.

Result: For the total population, with an increase in BMI, better cognitive performance was observed in the TMT-B

($p=0.047$, $r=-0.140$), ANT ($p=0.036$, $r=+0.146$) and novel output score of DFT ($p=0.019$, $r=+0.164$). Among female participants, significant negative correlation was found between TMT-A ($p=0.007$, $r=-0.267$), TMT-B ($p=0.017$, $r=-0.237$) and positive correlation between ANT ($p=0.0008$, $r=+0.328$), novel output score of DFT ($p=0.032$, $r=+0.214$). A statistically significant difference was found in the ANT test performance between the four groups of BMI ($P = 0.009$). Among the female participants significant differences were observed between the four BMI categories for TMT-A ($P= 0.014$), TMT-B ($P=0.001$) and ANT test ($P=0.0002$).

Conclusion: Lower BMI is associated with a higher risk of cognitive impairment in young adults. The negative impact of lower BMI on cognitive performance is more prominent among females.

Keywords: Body mass index, Cognitive function test, executive function, semantic fluency, visual fluency, visuomotor speed, working memory.

Introduction

Malnutrition refers to deficiency, excess or imbalance in the intake of energy or nutrients. The term includes both undernutrition and over nutrition. According to WHO in 2022, approximately 390 million adults worldwide were underweight, 2.5 billion were overweight and 890 million adults had obesity.¹ India is facing the burden of undernutrition and over nutrition both. India contributes a third of the global burden of undernutrition. The risk of underweight is highest in the central and western regions of India.² Prevalence of obesity in India is 40.3%. Obesity is higher amongst females, people living in urban areas and among the more educated population.³

Young adulthood is a key developmental stage transitioning from adolescence to adulthood. It is a critical period of development because intervention strategies at this stage of life may alter the trajectories and decrease threats to health along the adult life course. This stage is associated with physical growth, social development, cognitive and behavioral changes. The brain development, behavioural, and cognitive sequelae of malnutrition may significantly limit the educational and occupational opportunities of the individual.⁴

Cognitive function involves acquisition of knowledge, manipulation of information, reasoning, thinking, learning, and remembering. It also includes visual-spatial skills and aspects such as the motor function of making and controlling movements. Cognitive domains include memory, learning, attention, decision making, and language abilities. Executive function domain which plays a key role in virtually all aspects of cognition involves planning, organization, coordination, implementation, and evaluation of a novel task.⁵

Multiple factors affect cognitive function, while some cannot be changed, evidence suggest that factor like nutrition and physical activity are modifiable factors.

Nutritional and psychosocial interaction are found to have effect on adolescent neurodevelopment.⁶

Malnutrition early in life has been implicated in the subsequent development of problems like inattention, conduct problems, aggression, depression, and academic failure. Many of these adverse outcomes continue into adulthood and can increase the risk of Dementia and Alzheimer's disease.^{6,7}

Considering the above-mentioned fact, it is necessary to conduct study on young adults to find association between malnutrition and cognitive function. In this study we have tried to study the association between BMI and cognitive performance among young adult student population. We evaluated the cognitive function using a battery of neuropsychological test. These tests involve assessment of different cognitive domains.

Our research is important especially in context with developing country like India which has both an increasing burden of obesity and a high prevalence of underweight among the young adults. Better understanding of the impact of malnutrition among late adolescents and young adults is a dire need of the current Indian society. Early detection of the impact of nutritional disorder on cognitive functioning is crucial, since it can have a long impact on the efficiency and quality of life.

Methodology

This observational cross-sectional study was conducted on medical undergraduate students aged 18-25 years. The study was approved by institutional ethical committee (Ref: NIIMS/IEC/May-2022/D-2). By simple random sampling 200 participants (both male and female) were recruited from the medical college. Participants with history of developmental disabilities (e.g. autism, developmental delay), major neurologic or psychotic disorder, substance or drug abuse were excluded.

Diagnosed case of major clinical medical illness like Asthma, hypertension, DM, cancer etc. were also excluded from the study. Apparently healthy students following the inclusion and exclusion criterion were included. Students willing to participate were explained study design and objective of the study and informed written consent was obtained.

Detailed history of study participants was taken. Height and weight were measured using digital weight scale and wall meter. BMI was calculated using Quetelet index. Body weight in kilograms (kg) and height in meters (m) of the subjects were recorded. BMI of subjects was then calculated using the formula $BMI \text{ (in kg/m}^2\text{)} = \text{Weight (in kg)}/\text{height (in m}^2\text{)}$.

The subjects were then grouped into one of the following based on Asian criteria for BMI classification.⁸ The groups being:

1. Underweight (BMI < 18.5 kg/m²)
2. Normal weight (BMI 18.5 – 22.9 kg/m²)
3. Overweight (BMI 23 – 24.9 kg/m²)
4. Obese (BMI > 25 kg/m²)

The subjects were tested in a silent room to provide a distraction free environment. The subjects were explained the procedure, given detailed instructions and trial sessions of each test for better understanding of the cognitive tests. Different domains of cognitive functions (visual attention and task switching, visuomotor speed, semantic fluency, perception, executive functions and working memory) were assessed using the following tests.

A. Tests for Attention

Trail making test^{9,10}

Part A; Assesses visuomotor speed and attention. The circles are numbered 1 – 25. The subject was instructed to draw a line to connect the numbers in ascending order.

The score was the time taken by the subject to complete the task.

Part B; In addition to visuomotor speed and attention, it requires the subject to shift strategy and hence, is a sensitive measure of executive function as well. Subject would draw lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The score was the total time taken by the subject to complete the task.

B. Tests of Fluency

Animal name test¹¹

It is used for category fluency measurement. The subject was asked to generate names of as many animals as possible in one minute. Total number of new words generated formed the score.

Design fluency test¹²

Test to assess visual fluency. Visual fluency is the capacity to generate new visual forms. The subject was asked to invent as many different drawings as they could in 4 minutes using 4 lines. They were explained that a circle would be counted as one line, as would a gentle curve. The drawings could not represent actual object, nor could they be derived from such objects. The number of novel designs drawn formed the novel output score.

C. Test of Working Memory¹⁰

Digit span forward: This test measures immediate auditory recall. It measures attention, short term memory and flexibility in adaptation. A random number sequence arranged in sets was verbally presented to the subject at the rate of one number per second. The subject was asked to verbally repeat the digits in the exact sequences in which they were presented. The number of digits in the sequence were increased until the subject was unable to repeat the sequence correctly. The test stopped when the participant had two consecutive errors at any given digit

set size. The score was maximum number of digits that the subject recalled in the exact order.

Digit span reverse: This test is a sensitive measure of executive function. The subject was instructed to repeat the sequences of number in reverse order to what was said by the examiner. The score was the maximum number of digits that the subject was able to reverse.

Statistical Analysis

Data were collated and analysed using Graph Pad Prism Version 8 software. Descriptive statistics were used to quantitatively describe and summarize the dataset. Intergroup comparison was done using unpaired ‘t’ test for independent variables. Comparison for non-parametric data was done using Mann-Whitney U test. Ordinary one-way ANOVA was applied for comparison of different groups of BMI classification. Post-hoc analysis was done using Tukey’s multiple comparison test to compare all pairs of means to determine any significant difference. Correlations between BMI and neuropsychological tests score were assessed with Pearson correlation co-efficient and Spearman correlation co-efficient as and when applicable. Results were expressed as mean \pm standard deviation (Mean \pm SD). The p-value $<$ 0.05 was considered statistically significant.

Results

Total 200 participants (100 males, 100 females) were recruited and their data was analyzed for this study. The mean BMI of the participants was 22.41 ± 3.36 . The mean value of BMI for the female participants was 21.89 ± 3.44 and for males was 22.92 ± 3.218 . Figure 1 represents the percentage distribution of the participants according to WHO Asian criteria for BMI classification. On applying Chi-square Test Significant difference in the distribution of BMI groups was present between male and female participants (P= 0.0227).

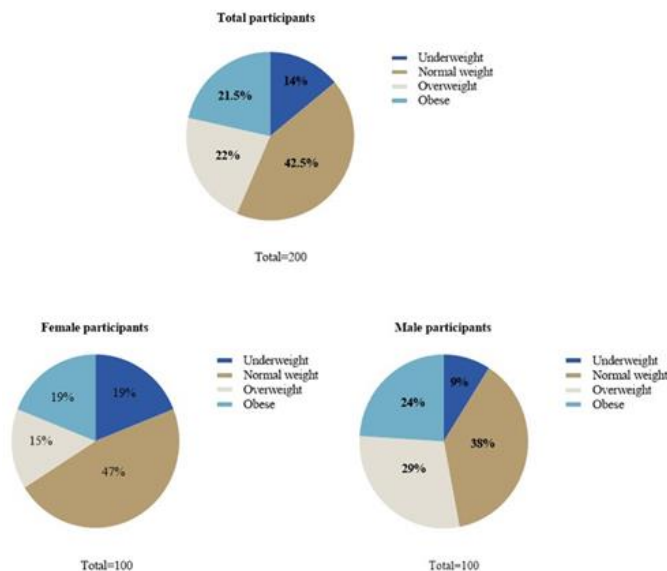


Figure 1: Distribution of different BMI categories among total participants (n=200), male participants (n=100) and female participants (n=100).

Figure 1:

Among the participants the mean score of TMT A test was 24.19 ± 7.127 , TMT B was 51.15 ± 18.62 , DSF was 7.195 ± 1.106 and DSR was 5.30 ± 1.182 . ANT mean score was 17.68 ± 3.985 . In Design fluency test the mean NOS was 20.59 ± 7.960 , PES was 5.160 ± 4.447 and total designs was 25.81 ± 9.88 . When we compared the cognitive function tests score between the male and female participants no statistically significant difference was observed except for TMT B (P= 0.047). Mean value of TMT B test score among males was 53.75 ± 20.49 and among females was 48.54 ± 16.22 .

Further, relationship between BMI and cognitive function test scores was analyzed amongst the participants. A significant correlation was found between BMI and scores of TMT B, ANT and NOS (Figure 2). When this correlation was analyzed separately among the male and female participants statistically significant relation was found only among female participants (Figure 3).

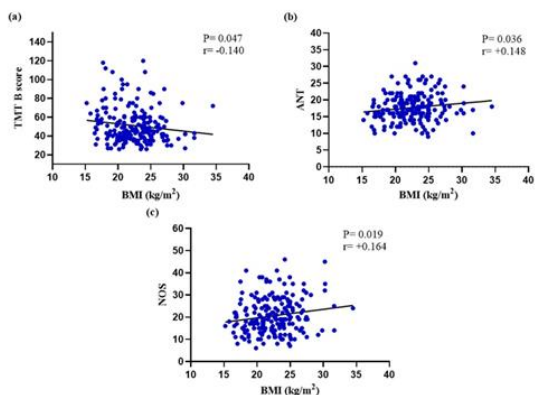


Figure 2: Scatter plot showing the correlation between BMI and (a) Trail making test B (TMT-B), (b) Animal name test (ANT) and (c) Design fluency test novel output score (NOS) among the participants (n=200).

Figure 2:

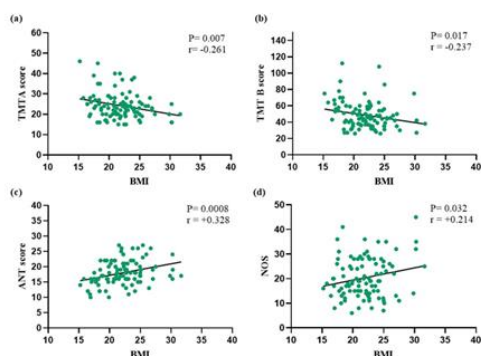


Figure 3: Scatter plot showing the correlation between BMI and (a) Trail making test A (TMT-A), (b) Trail making test B (TMT-B), (c) Animal name test (ANT) and (d) Design fluency test novel output score (NOS) among the female participants (n=100).

Figure 3:

A one-way ANOVA was conducted to compare the difference in the test score among different BMI groups. A statistically significant difference was found in the ANT test performance between the 4 groups of BMI ($F(3,198) = 3.954, P = 0.009$). Post-hoc analysis indicated a significant difference in the performance between underweight and normal weight, between underweight and overweight and between underweight and obese participants (Table 1). The mean value of ANT score for underweight, normal weight, overweight and obese participants was 15.39, 17.81, 18.34 and 18.23 respectively. Similarly, among the female participant's significant difference was observed between underweight and normal weight, between underweight and overweight and between underweight and obese participants for ANT ($F(3, 96) = 7.412, P=0.0002$) and TMT B ($F(3, 96) = 5.788, P=0.001$) (Table 3,4). Significant difference between underweight and obese female participants was noted for TMT A score ($F(3, 96) = 3.715, P= 0.014$) (Table 2).

Table 1: Tukey post hoc table for ANOVA test of difference between the groups in Animal name test (ANT) score among the study participants (n=200).

Group I	Group J	Mean Diff.(I-J)	95.00% CI of diff.	Adjusted P Value
Underweight	Normal weight	-2.419	-4.620 to -0.2176	0.025
	Overweight	-2.948	-5.390 to -0.5058	0.011
	Obese	-2.840	-5.293 to -0.3865	0.016
Normal weight	Overweight	-0.5291	-2.405 to 1.347	0.885
	Obese	-0.4208	-2.311 to 1.470	0.939
Overweight	Obese	0.1084	-2.058 to 2.275	0.999

*P<0.05-significant **P<0.01- highly significant ***P<0.001-very highly significant

Table 2: Tukey post hoc table for ANOVA test of difference between the groups in TMT A score among the female participants (n=100).

Group I	Group J	Mean Diff.(I-J)	95.00% CI of diff.	Adjusted P Value
Underweight	Normal weight	3.824	-0.6077 to 8.256	0.1158
	Overweight	1.926	-3.704 to 7.557	0.8077

	Obese	6.421	1.132 to 11.71	0.0107
Normal weight	Overweight	-1.898	-6.732 to 2.937	0.7344
	Obese	2.597	-1.835 to 7.029	0.4226
Overweight	Obese	4.495	-1.136 to 10.13	0.1647

*P<0.05-significant **P<0.01- highly significant ***P<0.001-very highly significant

Table 3: Tukey post hoc table for ANOVA test of difference between the groups in TMT B score among the female participants (n=100).

Group I	Group J	Mean Diff.	95.00% CI of diff.	Adjusted P Value
Underweight	Normal weight	15.93	5.155 to 26.71	0.001
	Overweight	15.06	1.370 to 28.75	0.025
	Obese	17.05	4.193 to 29.91	0.004
Normal weight	Overweight	-0.8709	-12.62 to 10.88	0.997
	Obese	1.122	-9.653 to 11.90	0.993
Overweight	Obese	1.993	-11.70 to 15.68	0.981

*P<0.05-significant **P<0.01- highly significant ***P<0.001-very highly significant

Table 4: Tukey post hoc table for ANOVA test of difference between the groups in ANT score among the female participants (n=100).

Group I	Group J	Mean Diff.	95.00% CI of diff.	Adjusted P Value
Underweight	Normal weight	-4.101	-6.651 to -1.550	0.0003
	Overweight	-3.926	-7.167 to -0.6860	0.011
	Obese	-4.842	-7.886 to -1.798	0.0004
Normal weight	Overweight	0.1745	-2.608 to 2.957	0.998
	Obese	-0.7413	-3.292 to 1.809	0.872
Overweight	Obese	-0.9158	-4.156 to 2.325	0.881

*P<0.05-significant **P<0.01- highly significant ***P<0.001-very highly significant

Discussion

We conducted this study to investigate the relationship between BMI and cognitive function among medical undergraduate students. The difference in cognitive performance among underweight, normal weight, overweight and obese young adults was assessed. The results of our study indicate that lower BMI is associated with poor cognitive performance. Gender difference was also found. Underweight female students had statistically significant lower cognitive test scores. Different domains

of cognitive function were assessed. Lower BMI was found to be associated with poor cognitive abilities in domains like semantic fluency, visual fluency, planning, visuomotor speed, attention and executive function. No statistically significant effect of BMI was seen on working memory.

We found significant positive correlation between BMI and TMT-B, ANT, novel output score of DFT (Figure 2). Trail making test B is a reliable and popular test for assessing visuomotor speed, set-switching ability,

attention and executive function and involves prefrontal and parietal neuronal network.¹⁴ ANT is a verbal category fluency test and DST assesses nonverbal fluency. Though these assessments involve large neuronal network but fluency tests are considered sensitive to the frontal lobe function.¹³ When we analyzed male and female data separately, among female participants higher BMI was found associated with better performance in the cognitive tests TMT-A, TMT-B, ANT and the novel output score of DFT (Figure 3). No significant correlation was found among the male participants. No statistically significant association with BMI was found for the Digit span forward and Digit span reverse test, suggesting working memory is being unaffected.

On further analysis of different BMI groups, we found statistically significant differences in the ANT score, with Underweight having the lowest score in comparison to the other three groups (Table 1). Among the female participants, along with ANT scores, statistically significant differences were also found in TMT-A and TMT-B (Table 2-4). The mean score was highest for the obese group and lowest for the underweight group.

Studies in the past have also found similar results, but largely in the older population. Dong W et. al. concluded in their study that being underweight is a risk factor for development of cognitive impairment among older adults, particularly among old female population.¹⁵ Similarly, in a survey data collected from 'the Korean Longitudinal Study of Aging', it was found that obesity is associated with lower risk of cognitive decline among mid- and old-age population. They also found that obese individuals, as compared to those with normal weight, experienced a slower decline in cognitive function in the follow-up period. In addition, the protective association

of high BMI with cognitive performance was more prominent among women.¹⁶

Studies have also shown that being underweight or having a decrease in BMI in late-life are associated with increased risk of Dementia and Alzheimer's disease.^{17,18}

In a population-based prospective cohort study of 1,836 Japanese Americans, it was found that higher baseline body mass index and slower declining BMI in late life are associated with a reduced risk of dementia, especially for those who were initially overweight or obese.¹⁹

The reason for this protective association of higher BMI on cognition is unclear at present. The probable reason for better cognitive function among individuals with higher BMI could be the presence of high leptin and urate levels in them. The circulating leptin are found to be directly proportional to body adiposity. Leptin receptors are widely expressed in the CNS and influences neuronal excitability via activation of specific potassium channel in several brain regions.²⁰ Higher level of leptin has cognitive enhancing and neuroprotective action and is seen associated with a lower risk of cognitive decline and Alzheimer's disease.^{21,22} Urate serve as one of our major endogenous defences against oxidative and nitrosative damage. Due to this antioxidant action, they play a significant neuroprotective role.²³ Study findings have identified serum urate as the molecular factor directly linked to the progression of typical Parkinson's disease.²⁴ Underweight is found to have a negative impact on cognitive capabilities. Anorexia nervosa (AN) which is characterized by extremely low body weight is found to be associated with structural and functional brain abnormalities, effecting their cognitive abilities.²⁵ In comparison to underweight state weight-restored Anorexia nervosa patients were found to have widespread and sizable reduction in cortical thickness and subcortical volume.²⁶ The reason for statistically

significant results observed mainly in the female participants could be due to difference in the percentage distribution of BMI categories. Female participants had a significantly higher number of participants with lower BMI than males (figure 1).

Contrary to our findings, many studies done in the past have shown that overweight and obese people are at higher risk of cognitive impairment. These findings are especially noticeable in the younger adult age groups. Khade Y et. al. in their study concluded that higher BMI increases the risk of cognitive impairment in young students.²⁷ Meo SA et. al. in their study found a significant decline in different areas of cognitive skills among obese school adolescents.²⁸

There are certain limitations in our study. It was a cross-sectional study. Long-term follow-up studies on the younger adult population could better establish the causal relationship between BMI and cognitive performance. We also should have included other indicators like waist-to-hip ratio, abdominal circumference and waist circumference for obesity assessment. Although our study found a positive association between BMI and cognitive function, but random effects cannot be ruled out. Studying a larger population prospectively can provide a better understanding.

Conclusion

Our study results suggest that lower BMI has a detrimental effect on cognitive function among young adults. Lower BMI can cause a decline in the executive function, semantic fluency, visual fluency and visuomotor speed. Gender difference is also present, with the positive association of BMI and cognitive function more prominent among females.

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