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# EFFECT OF PHYSICAL ACTIVITY, DIET, AND LIFESTYLE MODIFICATIONS ON COGNITIVE HEALTH CHANGES IN OBESE PEOPLE: A SCOPING REVIEW

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## ABSTRACT

The prevalence of childhood overweight and obesity has increased markedly in most countries during the past several decades. Obese individuals often have a reduced life expectancy and increased healthcare needs, mostly due to the increased risk of co-morbidities. Publications were identified through keywords in the databases like PubMed, Trip database, Google Scholar. Predefined eligibility criteria were applied to include only relevant articles. Three stage screening was performed to explore the suitability of the articles. The association between obesity and cognitive function was more consistently found within the domain of executive function which is important for physical health, mental health, and success. The interplay between obesity and brain function relates to executive function (EF), which refers to self-regulatory cognitive processes that are associated with monitoring and controlling both thought and goal-directed behaviors. Intentional weight loss via caloric restriction in elderly obese subjects with mild cognitive impairment could slow the cognitive decline. While it has been suggested that fast food consumption may be linked to weight gain and obesity. Obesity might contribute to impaired executive functioning. In particular reduction in body mass leads to improved executive functioning. Physical activity may affect cognitive function and academic achievement. Lifestyle interventions can improve health and reduce co-morbidities in children, and thus may benefit cognitive and educational outcomes, by reducing sources of metabolic and psychosocial stress, and by improving those neurocognitive abilities associated with weight gain.

**KEYWORDS:** Physical activity, Diet, Lifestyle changes, Cognition, Obesity, and systematic review.

## INTRODUCTION

Obesity is a significant and increasing challenge to public health. Obese individuals often have a reduced life expectancy and increased healthcare needs, mostly due to the increased risk of co-morbidities which are responsible for 2.5 million deaths a year.[1] Obesity is occurring at an increasingly early age, affecting more than 43 million children aged 0–5 years worldwide.[2] Leading the World Health Organization to describe childhood obesity as "one of the most serious public health challenges of the 21st century.[3] With obesity occurring earlier in life, the aggregate exposure and risk of deleterious health consequences also increase.[4]

### Impact of obesity on cognition

Some studies have linked obesity with poorer general cognitive function or intelligence score in children and adolescents.[5,6] In addition, longitudinal studies have shown that being obese in middle life increases the risk of dementia later in life. The association between obesity and cognitive function was more consistently found within the domain of the executive function.[7,9,10] which is important for physical health, mental health, and success.[11] The interplay between obesity and brain function relates to executive function (EF), which refers to self-regulatory cognitive processes that are associated with monitoring and controlling both thought and goal-directed behaviors.[10,11] Cognitive skills such as the ability to suspend pre-potent or default responses (inhibition), to switch between rules and responses (cognitive flexibility), to keep and retrieve information while working on a new task (working memory), and to concentrate (attention) are useful to predict achievements in children and adolescents. Collectively, these cognitive abilities are known as executive functions.[12]

There are several domains of EF, including[1] inhibitory control (suppression of actions that are inappropriate in a given context and that interfere with a goal-driven behavior),[2] attention (the ability to maintain a consistent behavioral response during continuous and repetitive activity) and the closely related concept of mental flexibility (disengagement of an irrelevant task set and subsequent engagement of a relevant task set despite interference and/or priming),[3] reward sensitivity (the relative dominance of the behavioral activation system driving motivated behavior associated with risk-taking behavior), and[4] working

memory (active maintenance and flexible updating of goal/task-relevant information with limited capacity).[7,13]

Children's executive functions in everyday environments have been negatively linked with obesity-related behaviors[14] and the risks of being obese.[15] While it is clear that obesity correlates with negative health outcomes such as poorer adult cognitive functioning.[16-18] Specifically, studies demonstrate an association between adult obesity and decreased cortical gray matter volume with poorer performance on cognitive assessments.[7,8,16,17,19,20] With aging, some cognitive functions such as attention, memory and concentration decline, becoming slower and inefficient, as for some physical functions such as walking and balance.[21]

**The relationship between physical activity and obesity**

Experts have implicated that physical activity (less than necessary with excessive sedentary activity) is the causal path to obesity; researchers have consequently targeted these lifestyle behaviors to prevent obesity.[22] It is unquestionable that physical activity has positive effects on health; indeed, over the last few decades, a large body of evidence has shown that physical activity helps to reduce the risk of obesity.[23] Moreover, it has been demonstrated that an active lifestyle impacts on all causes of mortality. Many studies have shown an inverse relationship between physical activity and the risk of developing cognitive decline[24,25], but the cause of the association has not been clearly established.

If the anatomical changes like increase in cerebral blood volume and/or perfusion of hippocampus correspond to better cognitive function or not, was not fully understood. [26] It is widely believed that reduced physical activity and/or increasing sedentary behavior, such as television viewing, is implicated in the etiology of childhood obesity[27] Recently, studies examined the effects of physical activity and fitness on cognitive function in children and adolescents.[7] showed that adolescents who regularly participated in a physical activity performed better in executive function.[28]

**The relationship between diet and obesity**

Caloric restriction is one of the mainstays of obesity treatment, and its neuroprotective effect has largely been demonstrated in both animal models.[29] and also in cognitively normal humans.[30,31] In patients with cognitive impairment, however, its effects have not yet been tested. Research on the effects of a hypocaloric diet in the elderly faces major obstacles: late-

life obesity has been associated with decreased dementia risk[32] and many studies show that weight loss is associated with increased mortality and disability, especially in subjects over 70 years of age.[33] Intentional weight loss via caloric restriction in elderly obese subjects with mild cognitive impairment could slow the cognitive decline. While it has been suggested that fast food consumption may be linked to weight gain and obesity, a causal relationship has been difficult to establish because of inconsistent study results.[34]

**Prevalence**

The prevalence of childhood overweight and obesity has increased markedly in most countries during the past several decades.[35] In the past forty-five years, the incidence of obesity in the pediatric population in the United States has more than tripled, with approximately one in three children aged 2–19 classified as overweight (body mass index (BMI) 85–94% for age and sex)or obese (BMI ≥95% for age and sex).[36] Although once considered to be a condition affecting only high-income countries, rates of pediatric overweight and obesity have started to rise dramatically in some low- to middle-income countries too.[37] The condition can also affect psychosocial well-being, with obese young people susceptible to reduced self-esteem and quality of life, as well as stigmatization.[38]

**Search strategy and databases**

The databases searched included PubMed, Trip database, Google Scholar. A two-phase search strategy was employed with an initial search to establish appropriate search terms followed by a second systematic search of all relevant databases using key terms. A broad search included the following keywords: Physical activity, Diet, Lifestyle changes, Cognition, and Obesity.

The search was conducted to identify relevant primary studies. Only primary studies reported from 1995 were searched. This was probably searched due to the fact that the prevalence of obesity had not started to rise significantly before this point in time. A systematic search of the literature was also conducted to identify relevant systematic reviews: as with primary studies, only recent reviews of potential relevance were considered, from 1995 onwards.

**Selection criteria**

**Inclusion criteria**

Type of study: Systematic reviews and meta-analyses including RCTs were considered. Type of interventions: Interventions promoting cognitive health status by correlating with physical

activity, diet and Lifestyle changes. Study populations: Patients with BMI 25-29.9 kg/$m^2$ (overweight), 30-39.9 kg/$m^2$ (obese), BMI >40 kg/$m^2$ (extreme obese) and age groups 12-60 years were included. We also include studies which reported data on the cognitive domain (e.g. attention, executive function, and memory). Included studies implemented cognition in obese people by correlating the relationship between physical activity, diet, and behavior.

**Exclusion criteria**

Exclusion criteria include reviews on surgical or pharmaceutical treatments, narrative reviews, opinions or editorials, reports published as meeting abstracts only, reviews of causal relationships between obesity and related factors, and papers focused on physiological, molecular or genetic research and reviews focused on morbidities (such as diabetes, hypertension, arthritis and kidney diseases) in which obesity is a co-morbidity. In order to identify a group of reviews with comparable objectives and methods, systematic reviews that only included individual research studies that examined interventions (e.g. physical activity, diet, lifestyle changes), studies in pregnant women, people with eating disorders, medical conditions where weight loss was used as a treatment such as diabetes and programs that involved surgery or medications or incorporated other lifestyle changes (e.g. smoking cessation) were excluded.

**Data extraction**

Data extraction included Information about 1) Study information (demographic details, year), 2) Intervention (diet, physical activity, lifestyle changes), 2) Participants (characteristics), 3) Search strategy (search terms, inclusion and exclusion criteria), 4) Type (i.e. Systematic review, RCTs, Meta-analysis). The extraction was carried out from the studies that were identified for inclusion.

The composition of the diet may impact cognition and school achievement by altering neuro-trophic and neuroendocrine factors involved in learning and memory. As shown in animal research, these factors are decreased by high-energy diets containing saturated fat and simple sugars and are increased by diets that are rich in omega-3 polyunsaturated fatty acids and micronutrients.[39,40] These findings were also observed in children. Cross-sectional data of school-aged children linked dietary intake of omega-3 fatty acids to increased memory performance[41,42], while consumption of food rich in saturated fatty acids and refined sugar was associated with decreased memory performance.[41] Longitudinal observational data suggest that diets high in fat and sugar in preschool children (N = 3966; aged three to four

years) are associated with decreased intelligence and school performance at primary/elementary school age.[43,44] A controlled healthy school meal intervention over three years in more than 80,000 children led to improved mathematics, English and science achievement.[45] Promotion of healthier school food at lunchtime and changes in the school dining environment over 12 weeks improved classroom on-task behavior in preschool children compared to controls.[46,47] An improvement in dietary quality could, therefore, have beneficial effects on cognition and school achievement even with-out improved weight status.[12]

Six of the seven prospective cohort studies showed very clear associations with increased fast food consumption and associated caloric intake leading to weight gain. The sibling prospective cohort study conducted by Nelson et al. was the one prospective study with discordant results.[34] Dietary interventions targeting the improvement of the school food environment in conjunction with nutrition education resulted in a moderate difference in average achievement across subjects taught at school compared to standard practice in adolescents with obesity, but not in adolescents with overweight. However, the evidence was of low quality. There was no evidence that replacing packed school lunch with a diet rich in berries, root vegetables, whole grains and seafood (New Nordic Diet) improved attention, mathematics or reading achievement in children with obesity or overweight. This finding was also of low quality and further research is very likely to change the effect estimates.[12]

Furthermore, physical activity positively influences cardiovascular risk factors, such as diabetes, hypertension, obesity, and dyslipidemia, and reduces the incidence of cardiovascular and cerebrovascular events, with global hemodynamic benefits. Secondly, another possible protective mechanism is the neurotrophic effect of physical exercise. This may stimulate the release of neurotrophins, increasing synapses and dendritic receptors, and promoting neuronal growth and survival. Finally, it has been reported that an active lifestyle is able to prevent stress by reducing cortisol levels, which can positively influence cognitive function. The effect of physical activity does not appear to be dose dependent, but may be stronger in women than in men.[48,49]

Physical activity may affect cognitive function and academic achievement through physiological mechanisms (elevated blood circulation, increased levels of neurotrophins and neurotransmitters)[50], learning and developmental mechanisms (children's movement experience stimulates the processing of other concepts).[51] A meta-analysis of 44

experimental and cross-sectional studies (in children aged four to 18 years) indicated that increased physical activity caused significant overall improvement in cognitive function and school performance (effect size 0.32; standard deviation (SD) 0.27).[52] A systematic review suggests that school-based physical activity interventions (32 studies; N~ 3762; in children five to 18 years of age) may enhance both cognitive and school performance.[53] Moderate weight loss in conjunction with physical activity improves physical function and health-related quality of life in obese older persons.[54]

Behavior change techniques in overweight and obese children may foster decision making and self-control skills needed to increase energy expenditure and reduce energy intake [55] they also may benefit from studying and thus educational achievement. In summary, lifestyle interventions could act, alone or in combination, through numerous plausible mechanisms of action to benefit cognitive function, school achievement, and future success. Mechanisms explaining how lifestyle interventions could benefit overweight and obese children differently from the general population build on suggestive evidence from observational and experimental studies. These include neurocognitive, psychosocial and pathophysiological mechanisms associated with the development and consequences of obesity.

Research indicates that overweight and obese people show higher impulsivity and inattention and lower reward sensitivity, self-regulation, and mental flexibility compared with peers of normal weight.[56-58] These neurocognitive factors are associated with increased food intake and uncontrolled eating behavior and thus are assumed to be predictors of weight gain.[57,59]

A randomized controlled trial conducted in 44 overweight and obese children (eight to 14 years of age) suggested that specific training of self-regulatory abilities improved weight loss maintenance after an in-patient weight loss programme in the intervention group compared with the control group.[60] Findings from another randomized controlled overweight treatment programme involving 62 children (mean age 10.3 ± 1.1 years) showed improved problem-solving skills after an intervention duration of six months.[61] Inhibition control skills were improved in 42 obese adolescents from 12 to 17 years of age after 12 weeks of cognitive behavioral therapy.[56]

In comparison with normal weight children and youth, over-weight and obese peers more often experience psychosocial distress through weight-related teasing, discrimination, and social isolation; this can result in impaired self-esteem, self-efficacy and quality of life as

well as depression.[62-65] Overweight related teasing and social rejection are associated with low school performance in overweight or obese children.[66,67] Psychosocial effects of overweight and obesity are suspected to mediate the inverse association between overweight and school performance.[68] Lifestyle interventions for pediatric overweight treatments might benefit school achievement through improvement of self-esteem, depressive symptoms, and quality of life.[69,70] Lifestyle interventions can improve health and reduce co-morbidities in children[69], and thus may benefit cognitive and educational outcomes. Lifestyle interventions for weight management could improve cognitive and school performance by reducing sources of metabolic and psychosocial stress and by improving those neurocognitive abilities associated with weight gain. With increasing adiposity, the severity of neurocognitive, psychosocial and pathophysiological changes might increase, and the benefits of lifestyle interventions for weight management, as seen in school, cognitive and later life outcomes, might depend on the level of adiposity.[54]

Of those studies which did report an association between obesity and impaired executive functioning, the direction of the relationship remains unclear and most studies stress that causality may occur in either direction, with either obesity impacting on executive functioning or impaired executive functioning increasing the risk of obesity.[71] Others have suggested that making good food choices in modern life requires forethought, planning and good self-regulation in order to avoid overeating.[72,73]

These are skills which require good executive functioning abilities and so there is a suggestion that impaired executive functioning leads to obesity via poor food choices. This idea might also fit with the findings from the current review that distinctions between obese and non-obese individuals tend to occur on tasks measuring planning, problem-solving and decision-making, abilities needed to make good food and lifestyle choices. Finally, some studies also report on previous research which showed a reduction in BMI following the administering of methylphenidate, a drug commonly used to treat ADHD.[74]

The implication drawn from these findings is that the drug enhances inhibitory control leading to reduced calorific intake and weight loss as a result. However, for this explanation to be true, we would expect poor executive functioning to be directly related to eating behavior in obese individuals e.g. reporting of over-eating/bingeing and poor choices to be directly related to poor task performance. However, a number of studies in this review failed to include a measure of reported eating behavior and so this comparison could not be

made.[73,75] Thus the relationship between eating pathology and executive functioning was not directly examined. Only two studies made such comparison, neither found a significant correlation between eating pathology (binge frequency, emotional over-eating) and performance on executive functioning tasks, although one reported a tendency for those who showed poorer decision-making to also demonstrate overeating tendencies.[76,77]

In order to show that executive functioning might lead to obesity through the mechanism of disordered eating due to poor decision-making/self-control, future research needs to directly compare these factors, preferably using a prospective design allowing pre and post measures to be compared. In contrast to this potential causal relationship, some studies have suggested that being obese may, (even in the absence of other co-morbidities that might impact on cognitive abilities) lead to impaired executive functioning.[20,78] Studies have suggested that individuals with a larger body mass experience reduced blood flow to certain areas of the brain and therefore the metabolic activity of the brain is reduced and cognitive functioning is negatively affected.[79] Other individuals have suggested that the increase in adipocytes seen in obese individuals could also lead to reduced cognitive functioning.[71] A further argument suggesting that obesity might contribute to impaired executive functioning, is the finding that cognitive abilities, in particular, executive functioning improve following weight loss, suggesting that a reduction in body mass leads to improved executive functioning.[80,81]

However some researchers have argued that whilst there is an improvement in executive functioning following weight loss, the level of functioning is still not equivalent to that of a healthy weight individual.[82] This suggests that even when body mass is reduced, individuals still show a cognitive deficit. Either carrying excess weight is not impacting on cognition or perhaps the effect of a high BMI on cognition cannot be easily reversed following weight loss. To examine the validity of this argument, it would be helpful to see if reduced blood flow to particular regions found in obese individuals reverses following weight loss. Impaired executive abilities may lead to poor decision-making, poor inhibition and reduced mental flexibility which could lead to poorer food choices and overeating leading to weight gain. In addition, a number of biological explanations for why obese individuals might demonstrate disrupted brain activation have been suggested which might in turn impact on executive performance.[76,77, 83,84]

Longitudinal results provided additional, innovative insights into the already established cross-sectional association between depression and obesity. Interestingly, the results of this

longitudinal meta-analysis found a larger pooled effect size (OR:1.20-1.58) than the pooled OR of 1.18 reported in the cross-sectional meta-analysis.[85] Possibly time plays a role in the association between depression and obesity. The unfavorable effect of depression on the development of obesity and the effect of obesity on the development of depression may be reinforced by time. The earlier described cross-sectional association was only present in women. However, this longitudinal meta-analysis confirms a reciprocal association between obesity and depression in both men and women. Although evidence of a biological link between overweight, obesity, and depression remains complex and not definitive, it seems relevant to highlight the most current lines of reasoning within the possibility of a biological pathway. Our findings of a longitudinal, bidirectional association between depression and obesity are important for clinical practice. Because weight gain appears to be a late consequence of depression, care providers should be aware that within depressive patients weight should be monitored.[86,87]

**Table 1: Review of studies concerning the effect on cognitive functions.**

| S.No. | Author and publication year | Study type | Sample size | Study selection | Outcomes |
|---|---|---|---|---|---|
| 1. | Floriana et al., 2010 [88] | SR | 7196 | Overweight (body mass index 25-29.99) or obesity (body mass index 30) | Obesity was found to increase the risk of depression and cognitive decline. In addition, depression was found to be predictive of developing obesity. |
| 2. | Tao Huang et al., 2015[89] | RCT | 115 | Children were eligible for participation if they exceeded age- and sex-specific body mass index (BMI) cut-points for overweight based on criteria from IOTF. | The intervention such as PA and diet may benefit emotional control, monitoring, visuospatial construction skills, and cognitive function. |
| 3. | Kaukua et al., 2002 [90] | RCT | 38 | Nineteen men (mean age 45.9 y, mean BMI 39.3 kg=m2) in the treatment group and 19 men (47.2 y, 39.4 kg=m2) in the control group. | Marked weight loss by performing physical activity in obese men leads to improvements in physical functioning, social functioning, psychosocial problems, and perceived health. |

| | | | | | |
|---|---|---|---|---|---|
| 4. | Nidia et al., 2015 [91] | PCS | 80 | Subjects aged 60 or older (68.14.9 years, body mass index (BMI) 35.54.4kg/m2, 83.7% women, 26.3% APOE4 carriers). | Intentional weight loss by physical activity and controlled diet was associated with cognitive improvement in patients with obesity. |
| 5. | Celia et al., 2008 [92] | RCT | 9891 | Eligible studies were randomized trials enrolling adolescents assessing the impact of interventions on both lifestyle behaviors and body mass index (BMI). | Physical activity and dietary interventions found small beneficial changes in the target behaviors and cognitive improvement. |
| 6. | Al-Khudairy et al. 2017 [37] | RCT | 4781 | Selected randomized controlled trials (RCTs) of diet, physical activity and behavioral interventions for treating overweight or obesity in adolescents aged 12 to 17 years. | Behavior changing interventions and improvement in physical activity improved cognition and quality of life. |
| 7. | Brown et al., 2018 [93] | RCT | 644 | A study was included if the design was a randomized controlled trial or controlled clinical trial, of a lifestyle intervention in children, 5–18 years old, were included. Study designs that compared lifestyle interventions with usual care or with other active interventions were included. | The findings suggest that combined diet and PA interventions may help to improve cognitive decline and preventing obesity. |
| 8. | Nicola et al., 2016 [94] | RCT | 551 | Considered studies that included overweight and obese people before any weight loss intervention, defined through a body mass index (BMI) between | Intentional weight loss among obese and overweight individuals is associated with improvements in cognitive performance across different cognitive domains |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 25 and 29.9 and a BMI >= 30 kg/m2 (WHO consultation, 2000). | |
| 9. | Angevaren et al., 2008 [95] | RCT | 765 | All published randomized controlled trials comparing aerobic physical activity programmes with any other intervention or no intervention with participants older than 55 years of age were included. | Improvements in cognitive function which can be attributed to physical exercise are due to improvements in cardiovascular fitness, some cognitive functions seem to improve with (aerobic) physical exercise. |
| 10. | Anne Martin et al., 2014 [96] | RCT | 2584 | Included randomized and quasi-randomized controlled trials (RCTs) of behavioral interventions for weight management in children and adolescents with obesity or overweight. | Physical activity interventions can lead to small improvements in problem-solving skills. Changing behavioral patterns about nutrition can lead to moderate improvements in general obesity. |
| 11. | Steven et al., 1999 [97] | RCT | 1295 | A group of 1295 ethnically diverse grade 6 and 7 students from public schools in 4 Massachusetts Communities. | Intervention sessions focused on diet and behavior by decreasing television viewing, decreasing consumption of high-fat foods, increasing fruit and vegetable intake, and increasing moderate and vigorous physical activity improved cognitive status. |
| 12. | Nicola Napoli et al., 2014 [98] | RCT | 107 | Eligible participants had to be older (aged 65 y), obese [BMI (in kg/m2)30], sedentary (regular exercise, 1 h/wk), and with stable body weight (62 kg in the preceding year) and on stable medications ($6 mo) before enrollment. | Results showed that a combination of weight loss and exercise provides greater improvement in executive functioning and cognition. |

Abbreviations: RCT: Randomized clinical trials, PCS: Prospective cohort study, BMI: Body mass index, IOTF: International obesity task force, PA: Physical activity, WHO: World health organization.

Physical activity may affect cognitive function through physiological mechanisms, learning, and developmental mechanisms. It may help cognitive performance during aging, by preventing disability rather than a specific disease. Low-to-moderate levels of physical activity similarly resulted in a significantly reduced risk of deterioration of cognitive performance. Behavior change techniques in obese people may foster decision making and self-control skills needed to increase energy expenditure and reduce energy intake; they also may benefit studying and thus educational achievement. Individuals with a larger body mass experience reduced blood flow to certain areas of the brain and therefore the metabolic activity of the brain is reduced. Thus, obesity might contribute to impaired executive functioning. Lifestyle interventions can improve health and reduce co-morbidities in children, and thus may benefit cognitive and educational outcomes, by reducing sources of metabolic and psychosocial stress, and by improving those neuro-cognitive abilities associated with weight gain. Dietary intake of omega-3 fatty acids increases memory performance, while a decrease was observed with consumption of food rich in saturated fatty acids and refined sugar. Even without improved weight status, an improvement in dietary quality could, therefore, have beneficial effects on cognition.

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